European Transport \ Trasporti Europei (2017) Issue 63, Paper n° 8, ISSN 1825-3997

Impacts Of Dilemma Zone Situations And Red Light Running On The Safety At Signalised Junctions

Faisal Mushtaq Awan[1], Malik Muneeb Abid[1*], Anwar Khitab[1], Junaid Tariq[1]

[1]*Department of Civil Engineering, Mirpur University of Science and Technology, Mirpur, AJK, Pakistan.*

Abstract

When drivers are approaching to a signalized intersection at the onset of yellow signal, they may hesitate to decide whether to stop or cross the intersection due to the dilemma zone. This paper focuses on analyzing the impacts of approaching speeds and distance from stop line at the onset of amber on the safety of a signalized intersections, particularly the drivers behavior after amber and their decisions of stop or go. As the drivers behavior at signalized intersections is one of the main factors contributing to the safety level. This behavior, with respect to amber signal obedience or violation, is examined at a signalized intersection in Salford, Manchester. The data, collected for the study purposes, include vehicles' speeds and distance from stop line when exposed to amber light, as well as reaction of platoon leaders. Behaviors have been grouped into five criteria's, based upon different scenarios of a dilemma or option zone and their initial approaching speed. All five criteria are categorized according to driver's decision of stopping or violating. The findings of this research indicate that a large percentage of drivers facing the amber signal are in a dilemma zone due to high approaching speeds and less distance from stop line, exercise an aggressive behavior. The research concludes that a high percentage of all drivers either violate red light or apply sudden braking causing danger for themselves and others. However, by modifying survey methodology for high speed junctions it can be helpful to improve option zones for drivers and to control red light running thus providing better safety at signalized intersections.

Keywords:Signalized intersections, Red light running, violating red light, Dilemma-zone.

1. Introduction

Traffic lights or signals are used very effectively worldwide as a method of junction control. Signals are usually installed to improve the capacity of the junction and to balance the flows on different arms. Other supporting reasons are to reduce the conflicts among the vehicles and to provide safer crossings for pedestrians and cyclists. In short, traffic signals are becoming most important tool in traffic management.But "accidents are still happening on junctions".

The most complex form of junctions within any highway network are at grades intersections. At a typical of two way streets there are 12 legal vehicular movements, including left turn, straight ahead, and right turn from four approaches, and four legal

* Corresponding author: Malik Muneeb Abid (muneeb.ce@must.edu.pk)

pedestrian crossing movements. These movements indeed cause many potential conflicts where vehicles and/or pedestrians try to occupy the same physical space.
As Figure 1 shows, at a level crossing intersection, there are a total of 16 conflicts caused by vehicular movements, four between straight-ahead movements, and four between turning movements. In addition there are eight vehicular conflicts between turning movements and straight-ahead movements. Similarly for T junctions there are three potential conflicts caused by vehicular movements from approaches. This concludes that number of conflicts depends upon number of approaches to the intersection.

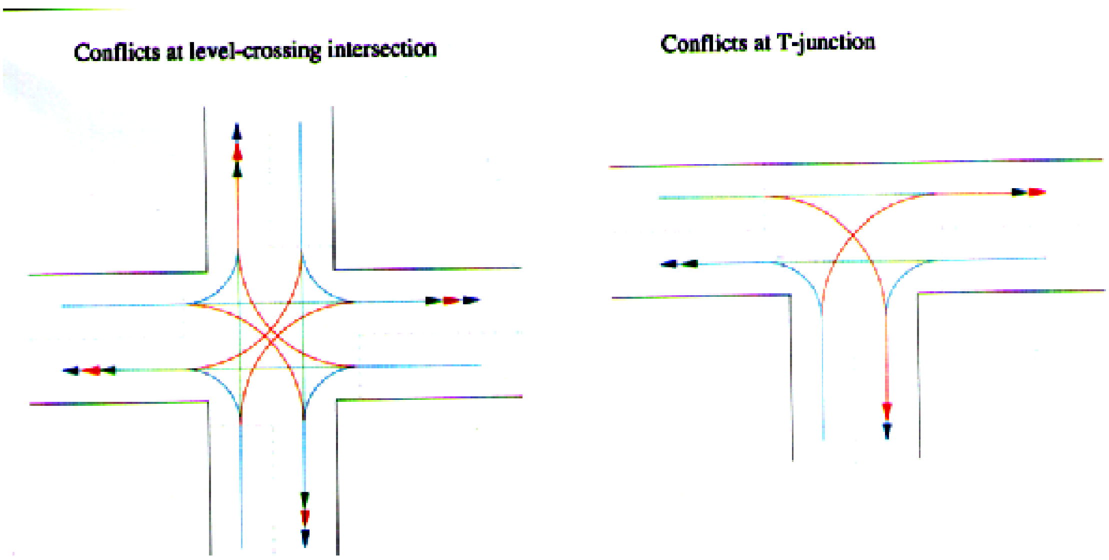

Figure 1: Potential conflicts at intersections

There are some important decisions to be taken by the drivers while approaching a signalized junction.

- How to modify the speed while approaching a junction and how this speed selection will affect their driving decisions?
- Selection of proper lane
- Maneuvering to get into proper lane and proper position
- When to decelerate, stop, and accelerate?
- How to manage a safe gap?

This study will consider the effect of red light running on signalized junctions and will try to cover the different safety issues arising due to different situations drivers have to face in dilemma zone. As proved by recent researches, accidents happened at signalized junctions are mostly due to noncompliance of signals. Red light running has become the most common reason of fatal accidents worldwide. This study will try to find out reasons behind noncompliance and how red light running can be effected by dilemma zone situations.
Dilemma zone problem is a major safety problem especially at high speed junctions. As part of this study, an overview of this problem is conducted in the light of recent researches. The study also looks into different scenarios of dilemma zone, by conducting sight surveys. In short, following objectives have been considered:

- Determination of possible dilemma zone scenarios.

- Driver behavior in terms of compliance.
- Observation of general trends.

The paper is organized as follows. Next section presesnts the literature review of the proposed topic. Section 3 describes the methodology adopted to achieve the desired objectives. Results are presented in Section 4 and last section concludes the paper.

2. Literature Review

2.1 Dilemma-zone

When clearance intervals are not properly timed, drivers may be forced to choose between abruptly stopping and running the red light. This situation, in which neither decision is satisfactory, occurs at a location on the intersection approach known as the dilemma zone (Figure 2).

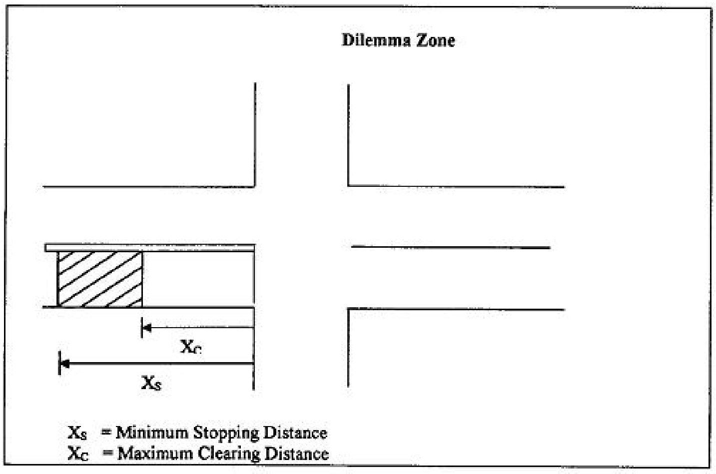

Figure 2: Dilemma Zone

A vehicle should be able to safely come to a stop during the signal change interval, and it should also be able to safely clear the intersection during the same interval. In Figure 2, the stopping distance is referred to as X_s and the clearing distance is referred to as X_c. If the vehicle is farther than X_s or closer than X_c, it does not experience any dilemma zone. However, if X_s is greater than X_c and the vehicle is placed between them, a dilemma zone is formed and neither the distance to the intersection is adequate for stopping nor is the yellow interval adequate for clearing the intersection.

A dilemma zone is a stretch of the approach to intersection within which the decision as to whether to go or to stop is not clear cut. (Zhang. et al., 2014).

When green light ends, the drivers approaching traffic signals are faced with a decision of whether they should apply brakes or they should carry on. These decisions some time becomes quite marginal depending upon speed of the vehicle and its distance from the junction. Under these conditions different drivers take different decisions. This situation becomes more complicated at high speed intersections, where, either driver has to apply sudden braking or he has to take the risk of entering the junction during the red. The distance from the intersection over which there can be some uncertainty of the appropriate action at the end of green is called “dilemma zone”. . (Zhang. et al., 2014). This situation has high safety implications as there e is always chance of potential conflict between the driver who runs the red and apposing traffic and pedestrians , and can be a risk of rear end collision if driver chooses to stop the car.

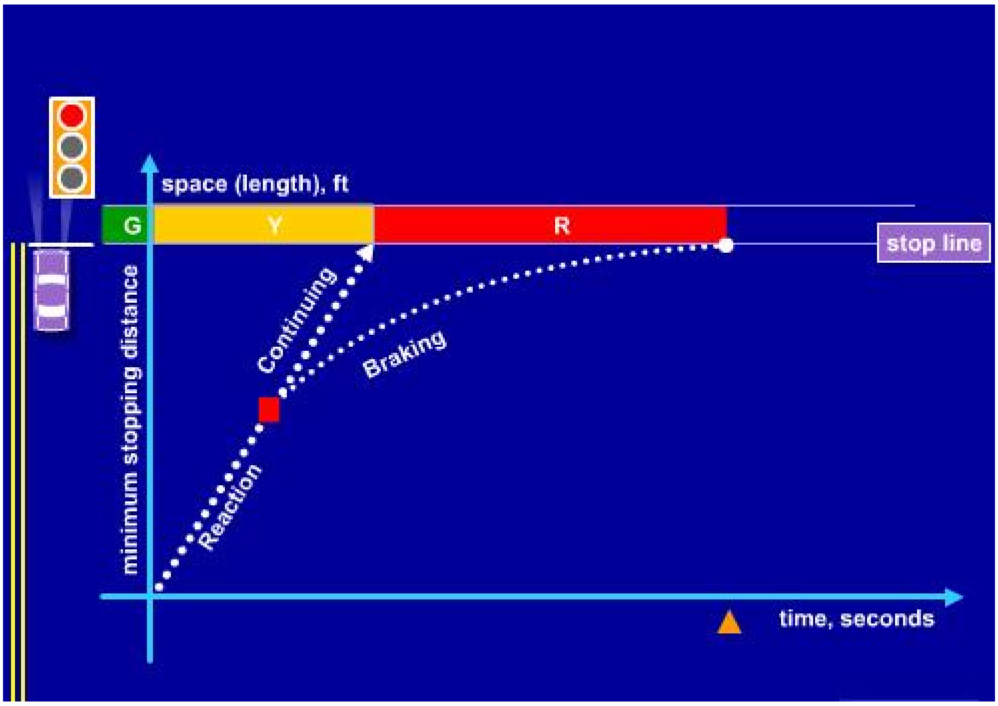

Figure3 : "Stop-Or-Go" Decision, The Driver Faces When Approaching an Intersection With a Yellow Light.

Two curves are depicted:

- The first curve, denoted by bigger dots, shows the driver's decision of continuing through the intersection. The car will cross the intersection violating the red light.
- The second curve, denoted by smaller dots, shows the decision of braking and stopping comfortably before the stop line.

Both curves share the driver's reaction to the yellow light before the intersection.

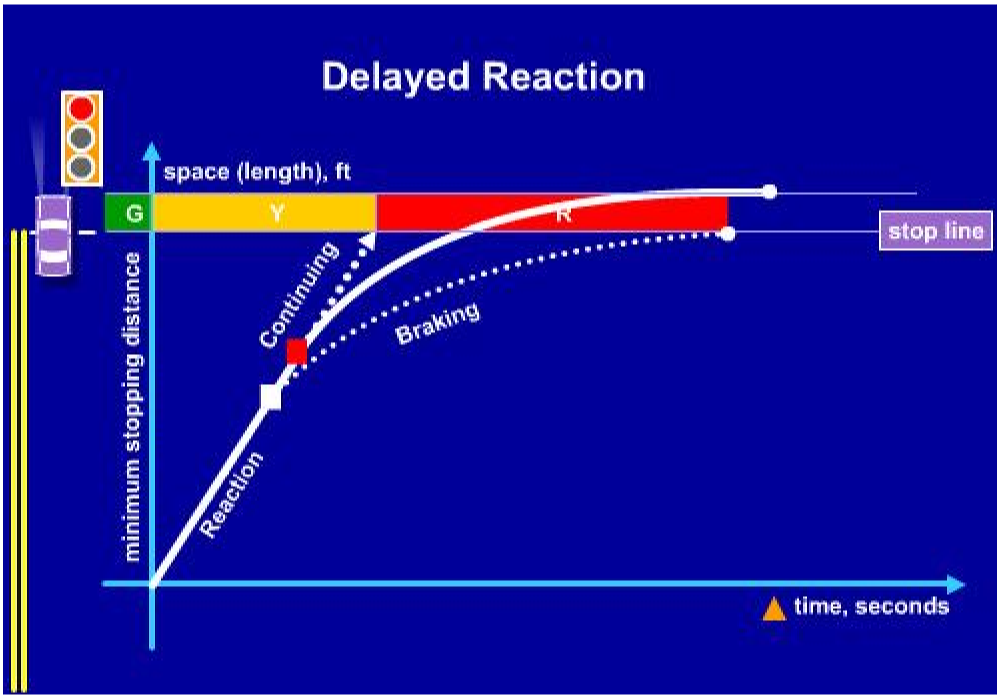

Figure 4: Delayed Driver's Reaction When Approaching the Intersection With a Yellow Light.

Three curves are depicted:

- The curve denoted by the continuous line shows the delayed reaction of the driver. As a consequence of this delay the car will not able to stop comfortably before the stop line.
- The curve denoted by bigger dots shows the driver's decision of continuing through the intersection. The car will cross the intersection violating the red light.
- The curve denoted by smaller dots shows the decision of braking and stopping comfortably before the stop line.

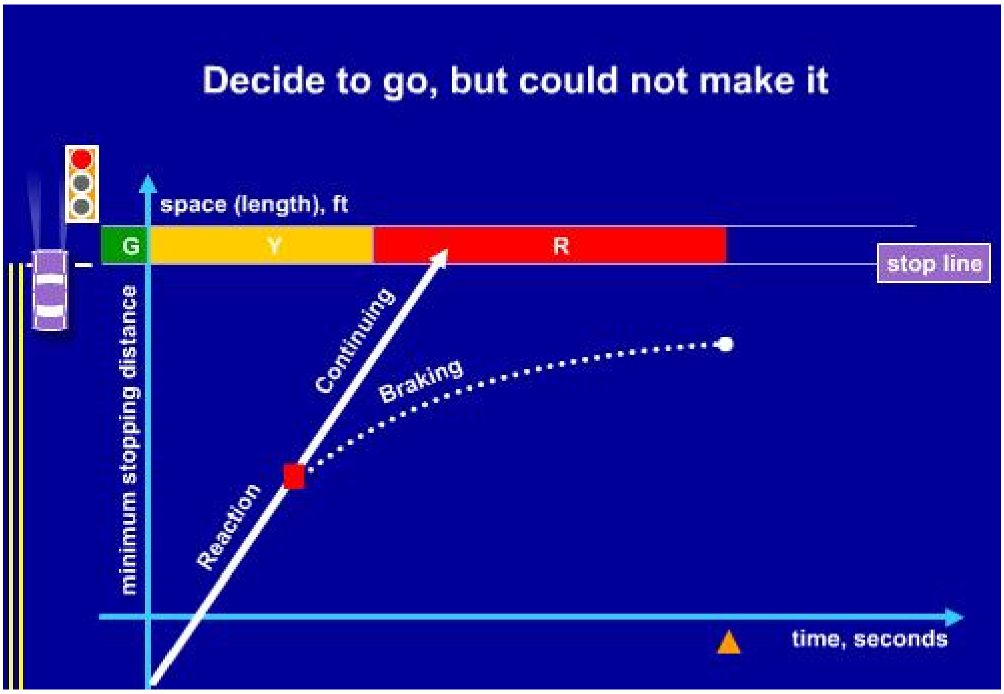

Figure 5: The Driver's Decision To Go, But The Decision Is Done Too Late So The Car Will Not Be Able To Go Through The Intersection Safely.

Two curves are depicted:

- The curve denoted by the continuous line shows the decision to go that results in violating the red light when the stop line is crossed.
- The curve denoted by smaller dots shows the decision of braking and stopping comfortably before the stop line.

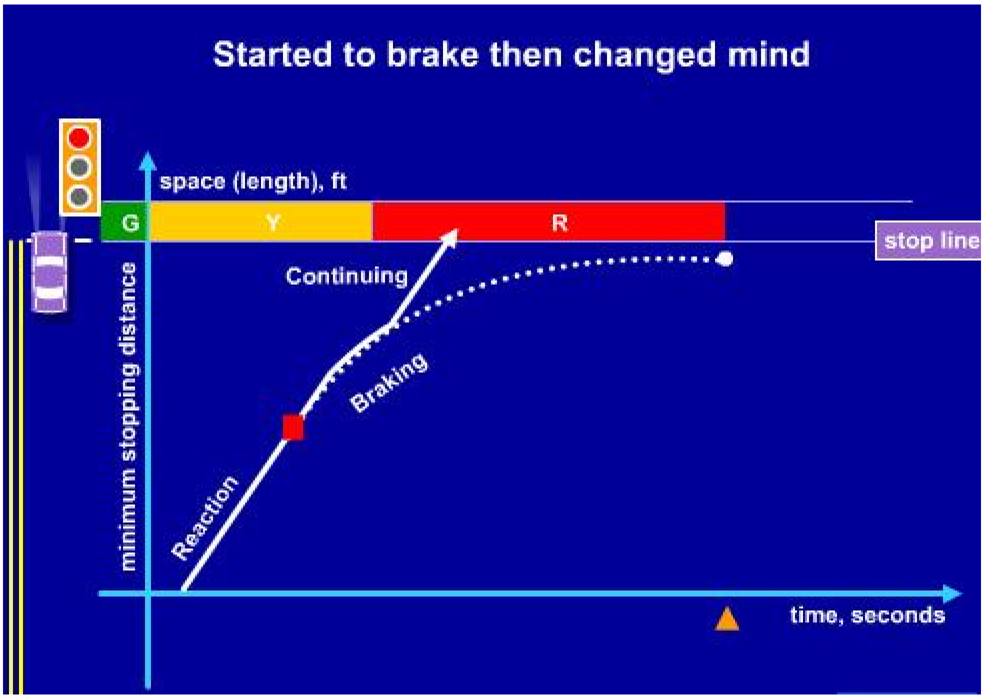

Figure 6: Driver Started To Brake But Then Change His/hers Mind And Tries To Go Through The Intersection.

Two curves are depicted

- The curve denoted by the continuous line shows the initial decision to brake and then the decision to accelerate and continue. This decision will result in a violation of the red light when the stop line is crossed.
- The curve denoted by smaller dots shows the decision of braking and stopping comfortably before the stop line.

2.2 Dilemma zone analysis

Most of the researches done on dilemma zone focused on definition and determination of boundaries of dilemma zone based on the data obtained from different surveys. According to Zhang et al. (2014) the definition of dilemma zone found in literature can be divided into two categories. First one is the definition based on probability of stopping (Zegeer et. al., 1977). Second one is the definition based on deterministic kinematical equations for safe stopping and clearance (ITE, 2001).

In the first case, drivers' probability for stopping defines the dilemma zone boundaries. The assumption that 90% of drivers will stop if amber were displayed defines the beginning of the zone, and, the distance within which 10% of driver will stop is defined as end of the zone. In case of varying decisions by the drivers this zone covers majority of the area. In the second case, the driver is said to be in dilemma zone if, at amber, he/she can neither stop safely nor clear the approach within the amber duration.

According to Papaioannou (2007), if the driver decides to pass through signal, a critical crossing distance (*CCD*) is always associated with the driver approaching traffic signal. This critical crossing distance(*CCD*) depends upon, approaching speed(*V*) , perception reaction time (*p*), performance in accelerating and road gradient. If driver chose to stop instead, then a minimum safe stopping distance (*SSD*) is required for the vehicle to stop

safely. The factors on which SSD depends are same as for CCD, but deceleration instead of acceleration and pavement condition as an additional factor is also important. SSD is also strongly depends upon friction coefficient *(m)*. if the driver is within critical crossing distance, that corresponds to his/her speed, then driver should keep on going to cross the stop line. Similarly if the driver is outside safe stopping distance that corresponds to vehicles speed it is wise to brake and stop.
Designing signalized junctions must be aimed in a way to avoid dilemma zone situation for drivers who are driving within speed limits. Dilemma zone elimination is not possible for the drivers driving over speed limits unless a long yellow time or possibly all red interval is set. At high speed signalized intersections, advance warning signs should be installed to ensure secure driver actions. Studies in US and Europe show that these signs had a significant effect on drivers (Head et al., 1992). There are several mathematical equations available for calculation of SSD and CCD.

$$d_s = \frac{1/2{v_0}^2}{x - V_0 P} \quad (1)$$

Where
d_s Smooth deceleration rate
x Distance of vehicle from stop line at the onset of amber
V_0 The approaching speed of vehicle
P The perception/reaction time

$$SSD_c = v_o p + {v_o}^2 / 2d_m \quad (2)$$

Where
V_0 The approaching speed of vehicle
P The perception/reaction time
d_m The maximum deceleration

$$CCD_o = v_o t - (w + l) \quad (3)$$

$$CCDa = v_o t - (w + l) + 1/2[a_m (t - p)^2] \quad (4)$$

Where
CCD_o Critical crossing distance without acceleration
$CCDa$ Critical crossing distance with maximum acceleration
a_m The maximum acceleration rate
w The width of the crossing road
t The yellow time interval
l The vehicle length

These four equations showed the mathematical forms for SSD and acceleration rate in case of force and smooth braking, as well as CCD in case of crossing with and without acceleration. Also, these equations include some of the driver factors, like, perception/reaction time, deceleration/acceleration rate, and decision making time. Whereas some characteristics are not taken into account, like, age and gender, experience, concentration level etc. so the choice of driver to stop or go depends upon the combination of these factors and both objective and subjective data are interrelated to each other. In short, following are the factors which can influence the decision of drivers while approaching to a signalized junction.

- Driver characteristics

- Distance from stop line
- Gradient
- Pavement conditioner
- Vehicle characteristics
- Signal cycle length
- Phasing sequence
- Position in platoon
- Vehicle speed
- Overall intersection layout
- Yellow signal duration

Literature reviews has been studied to gain a greater understanding on dilemma zone situations and driver behaviors at signalized intersections. Different scenarios of dilemma zone and different aspects of driver behavior at signalized junctions have been reviewed in relation to safety at signalized junctions. Key points of impact of these situations on safety at signalized junctions have been obtained and main findings are discussed here.

The real dilemma exists at high speed intersections. The situation become more complex as approaching speeds becomes high. There is always a problem for drivers in stopping safely during amber or crossing stop line before red. Drivers usually exposed to two kinds of risks in such conditions.

- Rear end collisions in case of abrupt stopping.
- Angle accidents if attempts are made to cross at the onset of red interval.

As compared to other conflicts, more accidents happen due to red light conflicts in a road network. Design speed along with excessive approach speed is one of the major factors for such accidents.

To avoid these kinds of conflicts and to minimize red light conflicts many studies were conducted in recent past, some with really good effects on controlling or minimizing red light running. Red light cameras are found to be affective in some cases with additional benefits of helping to determine the cause of crashes which is the biggest advantage for researchers.

It was found in literature review that there are several sources of marginal violations which are:

- Intentional red light violations
- Misjudgment
- Temporary inattentiveness
- Incorrect stop/go decisions
- Excessive reaction time
- Insufficient yellow time

The factors which are responsible for these situations are:

- Traffic conditions
- Approach speed
- Directional uncertainty
- Proximity to the intersection

Another important finding from literature review is that duration of amber time is not universal; it varies with speed limits and local authorities policies.Appropriate amber timing along with all red intervals can be an important safety measure but these countermeasures are not intended to reduce red light running; rather it is a safety measure.

At high speed junctions with approach speed over 40MPH warning signs or advance amber flashing lights are advantageous, especially at junctions with limited site distances. Warning signs are beneficial with steep grade or curved approaches. Adjusting the approach speed based on observations and studies can effectively help to control red light running problems.

Recently countdown timers are introduced in different countries to review the impacts on red light running. According to Amer (2016), these methods have significant effects on other factors like discharge rate but no significant effect on red light running violations.

For good signal operation and safety, understanding the all possible scenarios of dilemma zone is essential. Addressing those scenarios is a key to safety and performance of that junction.

Some scenarios can be addressed by selection of appropriate amber change and red clearance intervals; some can be addressed by proper design of detection system and appropriate selection of controlling timing parameters (Koll et al., 2004).

In last thirty years, automated traffic enforcement has mainly been applied to speed and red light violations; however, these technologies are now being used for other violations, e.g., headways, lane management, and toll payment violations. Use of technologies, like vehicle detection systems can be employed to hold the green time to its maximum and allow the vehicle to legally enter the intersection and safely clear it.Some other countermeasures like removal of unwanted traffic lights and minimizing on street parking may be beneficial some times.

3. Methodology

In order to get a greater of dilemma zone scenarios and right violations a survey has been designed and conducted. The survey was conducted at a signalized T-junction. Objective was to see how drivers behave at signalized intersections which usually reflect by their compliance to red lights. The aim was also to observe the different situations drivers have to face at the onset of amber, how they react to these situations and what are the effects of approaching speeds, distance from stop line or other conditions like, time of day, day of week etc. on their decisions.

3.1 Survey site

The survey was carried out at a signalized T-junction, located near University of Salford campus. The major arm is A6 (the crescent) minor arm is called Irwell place.

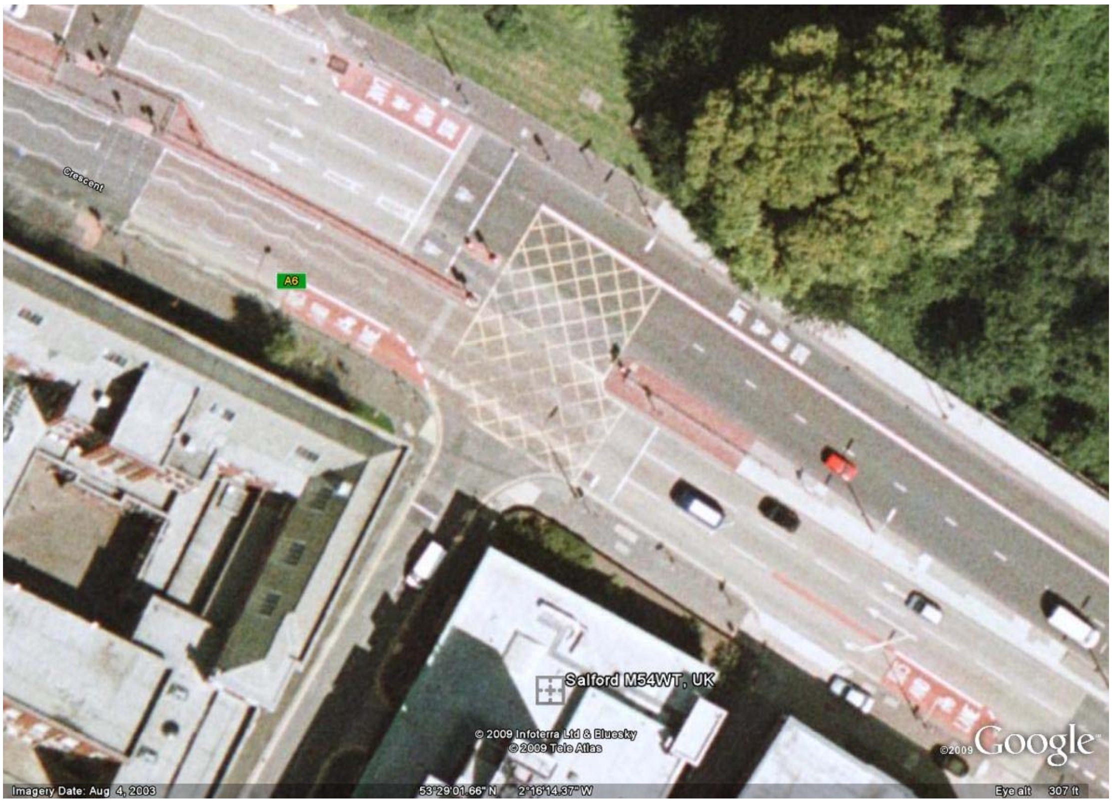

Figure 7: Site View Taken From Google Earth.

This signalized intersection is located near university of Salford campus connecting the ire well place to main A6. Volume of traffic is very high at A6 but for the minor arm it’s very low, and almost no traffic on minor arm at weekends. As shown in the figure, a pedestrian crossing exists just before the main signal, which also affects the behavior of the drivers and performance of the junction.

The Crescent (A6) is a 40mph road. It consists of three lanes, prior to the junction. First lane is a bus lane; other two will be shared by the rest of the traffic. Cycle time is 120seconds for weekdays, it is different for weekends because of low traffic volumes on A6 and traffic at minor arm is negligible.

3.2 Survey methodology

The method adopted for this particular survey is of videotaping. A digital camera was used. Survey is carried out in free flowing condition and clear weather. The filming was done for the traffic at A6 for the traffic moving towards Manchester town centre as shown in figure.

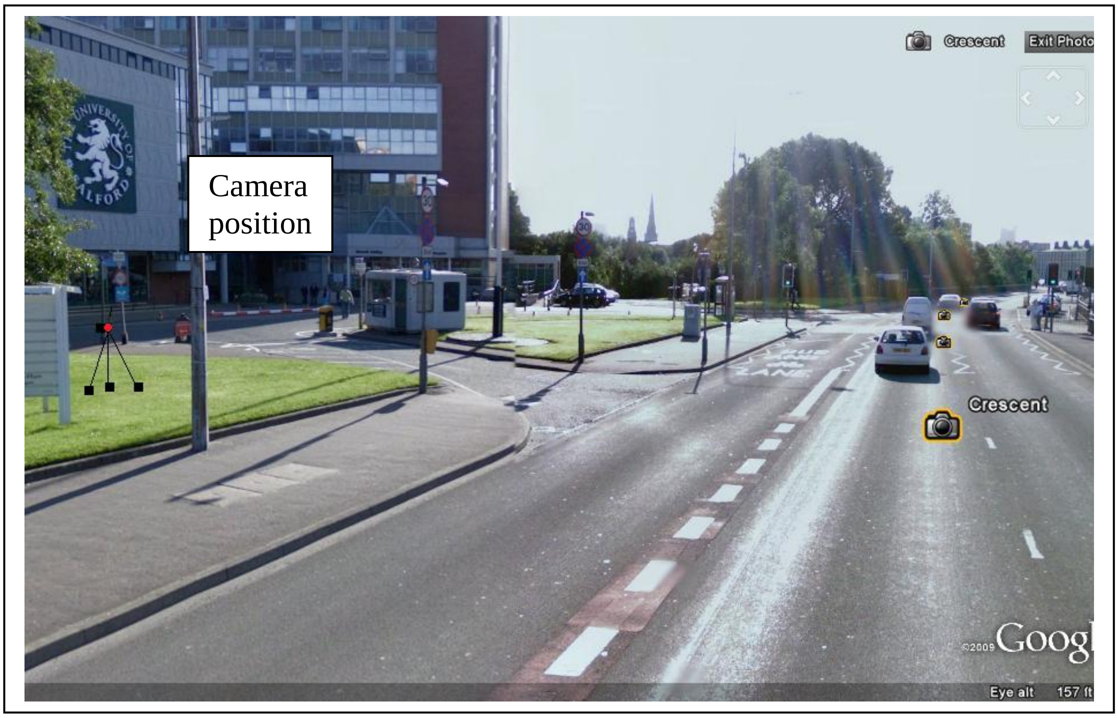

Figure 8: Site View And Camera Position(Derived From Google Earth)

Same survey is repeated three times to compare different time of day, and different days of week.First survey was done on Wednesday morning from 11 am to 12 pm as morning off-peak time in weekdays. Second was done from 2:45pm to 3:45pm on Wednesday evening for evening off-peak. Final survey was for weekends, and was carried out on Saturday morning from 11am to 12pm. A continuous one hour filming was done for each survey.

Analysis process subsequently was done at home using desktop computer. Microsoft movie maker software was used to watch and analyses the videos for all three surveys.

3.3 Extraction of data from videos

The traffic data were manually extracted from the videos, which was time consuming and fairly complicated. Data extracted from videos was on the basis of five different criteria of dilemma zone which were observed onsite. These criteria's are;

Criteria 1: *Vehicle slowing down initially and then speed up to try to cross stop line but violating red signal*.

Criteria 2: *Speeding up initially and then applying sudden brake*.

Criteria 3: *Carrying in same speed violate red light*.

Criteria 4: *accelerating after amber and violate red light*.

Criteria 5: *Carrying in same speed and apply sudden brakes*.

Data extracted and its description is given below.

Table 1 Description of Extracted Data

Type of data	**Description**
Vehicle number	Number of vehicles in frame at the onset of amber.
Criteria	Criteria's mentioned above , that which vehicle falls under which criteria
Probability	Probability of violation, if vehicle is under criteria 1,3 or 4 its 100 and zero otherwise
Cycle number	There are 40 cycles recorded for weekdays mornings and evening off-peak and 17 cycles for weekends
lane	Whether the vehicle is in middle lane or far side lane.
Approaching speed	Speed of vehicle as it enters the frame
Speed after amber Distance from stop line	Speed after signal turns to amber
Distance from stop line	Distance of vehicle from stop line at the time of amber

4. Results

This part of paper includes:

- Road user behavior analysis
- Dilemma zone analysis
- Speed analysis
- Distance (from stop line) analysis
- Combine effect of approaching speeds and distance from stop line at the onset of amber

Focus of this exercise will be on key safety issues which will be determine by site surveys and to come up with some sustainable solutions in the light of results obtained by these exercises.

Table below showed the analysis table from the data extracted from the video of weekday's morning.

Table 2: weekdays morning analysis

Criteria	Total number of vehicles	Vehicles in far side lane	%age	Vehicle in middle lane	%age
1	6	2	33%	4	67%
2	0	0	0	0	0
3	14	5	36%	9	64%
4	15	7	43%	8	53%
5	13	4	31%	9	69%

As it can be seen from table 2, most of the vehicles falls under criteria 1, 3 and 4, which means most of the vehicles from the data are violating red lights. The number of vehicles which slowed down initially and then speed up to violate red light is 6 in total of 40 cycles observed. Amongst six, two were in far side lane and four in middle lane. So, %age of violating vehicles in middle lane is much higher than in far side lane. Number of vehicles, which carry same speed after amber and violating red light after amber, is 14. Amongst those 14, five were caught violating using far side lane, and nine using middle lane. So again %age of vehicles using middle lane and violating red lights is much higher for this criteria. Total number of which accelerated after amber and end up violating the red light is 15. Amongst 15, seven were caught in far side and eight in middle lane. So for these criteria there is not a significant difference in terms of %age of vehicles using different lanes. It’s 43% and 53% respectively for far side and middle lane. The number of vehicles observed for this criterion for 40 cycles is highest. So most vehicles tends to accelerate after amber and violate red light.
As far as sudden braking is concerned, for criteria 2 which is speeding up initially after amber and applying sudden brakes at stop line, no vehicle is found. There are about 13 vehicles, which carry on same speed then applying sudden brakes. Amongst them four were found in far side and nine in near side lane. So there is huge difference in number of vehicles using different lane. %age is quite high for vehicles using middle lane.

4.1 Weekdays evening

Table below showed the analysis table from the data extracted from the video of weekday’s evening.

Table 3: weekdays evening analysis

Criteria	Total number of vehicles	Vehicles in far side lane	%age	Vehicle in middle lane	%age
1	0	0	0	0	0
2	0	0	0	0	0
3	1	0	0	1	100%
4	25	7	28%	18	72%
5	10	3	30%	7	70%

As it can be seen from table 3, most of the vehicles falls under criteria 4, which means most of the vehicles from the data are violating red lights. The number of vehicles which slowed down initially and then speed up to violate red light is 0 in total of 40 cycles observed. Number of vehicles, which carry same speed after amber and violating red light after amber, is just 1 which is caught in middle lane. Total number of vehicles which accelerated after amber and end up violating the red light is 25. Amongst 25, seven were caught in far side and eighteen in middle lane. So for these criteria there is

significant difference in terms of %age of vehicles using different lanes. It's 28% and 72% respectively for far side and middle lane, which is a huge contrast for these criteria from weekday's mornings. The number of vehicles observed for this criterion for 40 cycles is highest. So most vehicles tends to accelerate after amber and violate red light.
As far as sudden braking is concerned, for criteria 2 which is speeding up initially after amber and applying sudden brakes at stop line, no vehicle is found. There are about 10 vehicles, which carry on same speed then applying sudden brakes. Amongst them three were found in far side and seven in middle lane. So there is huge difference in number of vehicles using different lane. %age is quite high for vehicles using middle lane.

4.2 Weekends

Table below showed the analysis table from the data extracted from the video of weekends.

Table 4: weekend analysis

Criteria	Total number of vehicles	Vehicles in far side lane	%age	Vehicle in middle lane	%age
1	0	0	0	0	0
2	0	0	0	0	0
3	9	3	33%	6	67%
4	5	1	20%	4	80%
5	0	0	0	0	0

Traffic flow on A6 is usually very low on weekends. So the sample size from the weekend survey is very low, in fact consists of only 14 vehicles. There are no vehicles caught under criteria 1, 2 and 5. All the vehicles were violating red lights.
Number of vehicles, which carry same speed after amber and violating red light after amber, is 9. Amongst those 9, three were caught violating using far side lane, and 6 using middle lane. So again %age of vehicles using middle lane and violating red lights is much higher for this criteria.
Total number of vehicles which accelerated after amber and end up violating the red light is 5. Amongst 5, one was caught in far side and four in middle lane. So for these criteria there is again significant difference in terms of %age of vehicles using different lanes. It's 20% and 80% respectively for far side and middle lane, which is a huge contrast for this criteria from weekdays mornings but more or like same to weekends evening despite low traffic volume. So most vehicles carry same speed after amber and violate red light on weekends.

4.3 Overall analysis

Table below showed the analysis table from the data extracted from all the videos. Combining results of all three surveys together following results are obtained to analyze the general trend of behavior on site.

Table 5: Overall Analyses

Criteria	Total number of vehicles	Vehicles in far side lane	%age	Vehicle in middle lane	%age
1	6	2	33%	4	67%
2	0	0	0	0	0
3	24	8	33%	16	67%
4	45	15	33%	30	67%
5	23	7	30%	16	70%

As it can be seen from table 5, most of the vehicles falls under criteria 3, 4 and 5, which means most of the vehicles from the data are violating red lights or applying sudden brakes. The number of vehicles which slowed down initially and then speed up to violate red light is 6. Amongst six, two were in far side lane and four in middle lane. So, %age of violating vehicles in middle lane is much higher than in far side lane. All 6 vehicles are caught violating on weekdays morning, no vehicle under this category is found on weekdays evenings or weekends.

Number of vehicles, which carry same speed after amber and violating red light after amber, is 24. Amongst those 24, eight were caught violating using far side lane, and sixteen using middle lane. So the overall %age of vehicles using middle lane and violating red lights is much higher.

Total number of which accelerated after amber and end up violating the red light is 45 in total. Amongst 45, fifteen were caught in far side and thirty in middle lane. So for this criteria there again a significant difference in terms of %age of vehicles using different lanes. It's 33% and 67% respectively for far side and middle lane. So the total %age of vehicles for this criteria is 44% amongst all the vehicles as compared to 23%for criteria 3 and just 5.8% for criteria1.The number of vehicles observed for this criterion for 40 cycles is highest amongst all criteria. So most vehicles tends to accelerate after amber and violate red light.

As far as sudden braking is concerned, for criteria 2 which is speeding up initially after amber and applying sudden brakes at stop line, no vehicle is found. There are about 23 vehicles, which carry on same speed then applying sudden brakes. Amongst them seven were found in far side and 16 in middle lane. So there is huge difference in number of vehicles using different lane. %age is quite high for vehicles using middle lane.

So it has been observed for vehicles violating red light, %age of vehicles travelling in middle lane is 62.5%, and for vehicles applying sudden braking its 70% for vehicles using middle lane. It also showed amongst all data total %age of vehicles which ends up violating red light is 73.5%.

4.4 Speed analysis

Number of vehicles for all criteria in relation with their speeds is shown in table below.

Table 6: Distribution of Data amongst Different Speed Groups.

Speed limit	Criteria	Number of vehicles with approaching speeds.	Total vehicles	Number of vehicles with speeds after amber	Total vehicles
10-15	1	0	0	1	1
	3	0		0	
	4	0		0	
	5	0		0	
15-20	1	0	0	0	0
	3	0		0	
	4	0		0	
	5	0		0	
20-25	1	0	0	0	0
	3	0		0	
	4	0		0	
	5	0		0	
25-30	1	0	5	2	27
	3	3		4	
	4	2		0	
	5	0		21	
30-35	1	3	76	1	16
	3	17		13	
	4	35		1	
	5	21		1	
35-40	1	1	10	1	24
	3	2		4	
	4	6		18	
	5	1		1	
40-45	1	0	1	1	28
	3	0		3	
	4	0		24	
	5	1		0	
45-50	1	1	1	0	2
	3	0		0	
	4	0		2	
	5	0		0	

Table 6 shows the speed groups for all criteria. As it can be seen from the table for speed group 10-15MPH, there is only one vehicle found after amber in this range. There is no vehicle with approaching speed in this limit. For speed limits 15-25MPH and 20-25MPH there is no vehicle before or after amber.

For speed group 25-30MPH, there are 5 vehicles in total with approaching speed and all of them ends up violating red light. Twenty seven vehicles found in this range after amber. Amongst them 21 stopped at stop line and 6 ended up violating red light. So

vehicles with approaching speeds in this speed group more likely to violate, vehicles in this group found after amber are likely to stop.
For speed group 30-35MPH, there are 76 vehicles with approach speed in this limit. Amongst 76, 55 end up violating red light and 21 apply sudden brakes. Vehicles for approaching speeds between 35-40MPH are more likely to run red light. Sixteen vehicles after amber are found in this group, 15 ends up violating red light.
For speed group 35-40MPH, there are 10 vehicles with approach speed in this limit, 9 end up violating red light and just 1 apply sudden brakes. Vehicles for approaching speeds between 40-45MPH are more likely to run red light. Twenty four vehicles after amber are found in this group, 23 ends up violating red light.
For speed group 40-45MPH, there is just 1 vehicle with approaching speed. Surprisingly, it stopped at stop line. Twenty eight vehicles are found after amber and they all end up violating red light.
For speed group 45-50MPH, one vehicle is found with approaching speed and 2 with speeds after amber; all three of them end up violating red.

4.5 Distance (from stop line) analysis

Table 7: Distribution of Data Based On Different Groups for Distances from Stop Line.

Distance from stop line(meters)	Criteria	No of vehicles	Percentage for criteria	Total	Percentage
18-20	1	4	4.08	31	31.63
	3	9	9.18		
	4	17	17.35		
	5	1	1.02		
20-22	1	2	2.04	41	41.84
	3	14	14.29		
	4	20	20.41		
	5	5	5.10		
22-24	1	0	0.00	15	15.31
	3	1	1.02		
	4	8	8.16		
	5	6	6.12		
24-26	1	0	0.00	11	11.22
	3	0	0.00		
	4	0	0.00		
	5	11	11.22		

Table 7 shows the distance groups for all criteria. As it can be seen from the table, for distance group 18-20 meters, total of 31 vehicles found at the onset of amber. Amongst them, 1 vehicle ends up applying sudden brake. All other 30 vehicles violate the red light. So percentage of vehicles violating for distances of 18-20meters from stop line is 97.
For vehicles within the range of 20-22 meters from the stop line, there are a total of 41 vehicles found. Amongst them 5 end up applying sudden brake while 36 ends up violating. So the percentage of violation for this distance group is about 88% approximately.

For distance group 22-24 meters there is a total of 15 vehicles found. Amongst 15, 9 end up violating red light and 5 applying sudden brake. So percentage of violators for this group is 60%.
Finally for vehicles in range of 24-26 meters, total of 11 vehicles are found and all end up stopping before stop line. So for this group no vehicle is found violating red light. So it is quite obvious that as the distance from stop line increases percentage of red light violation reduces.

4.6 Distance vs. speed (violating red light)

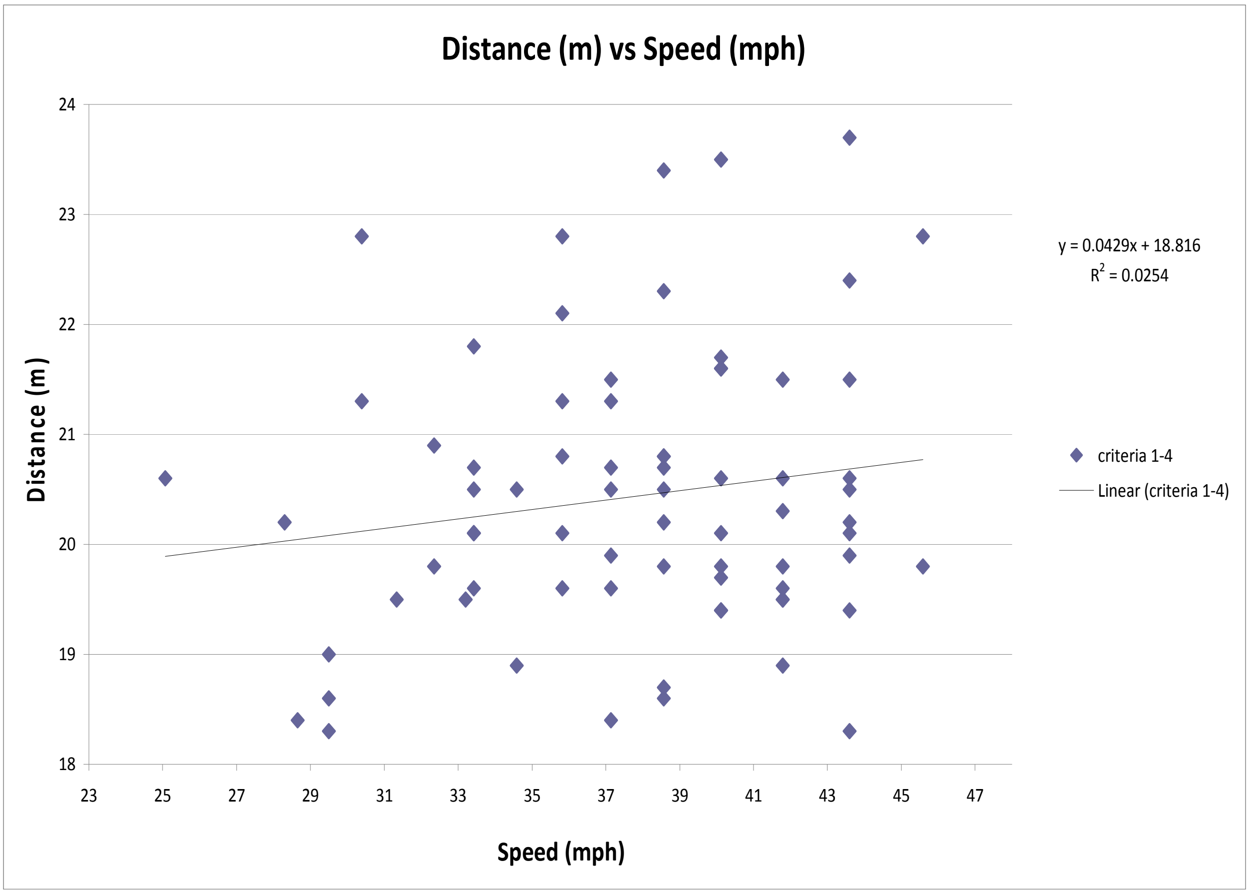

Figure 9: Data Distribution between Distance and Speed Groups for Vehicles Violating Red Lights
As can be seen in the figure above most vehicles caught violating with the speed limit of 30-45MPH and distance of 18-22 meters from stop line. So for this particular junction these speed and distance values are critical.

4.7 Distance vs. speed (applying sudden brake)

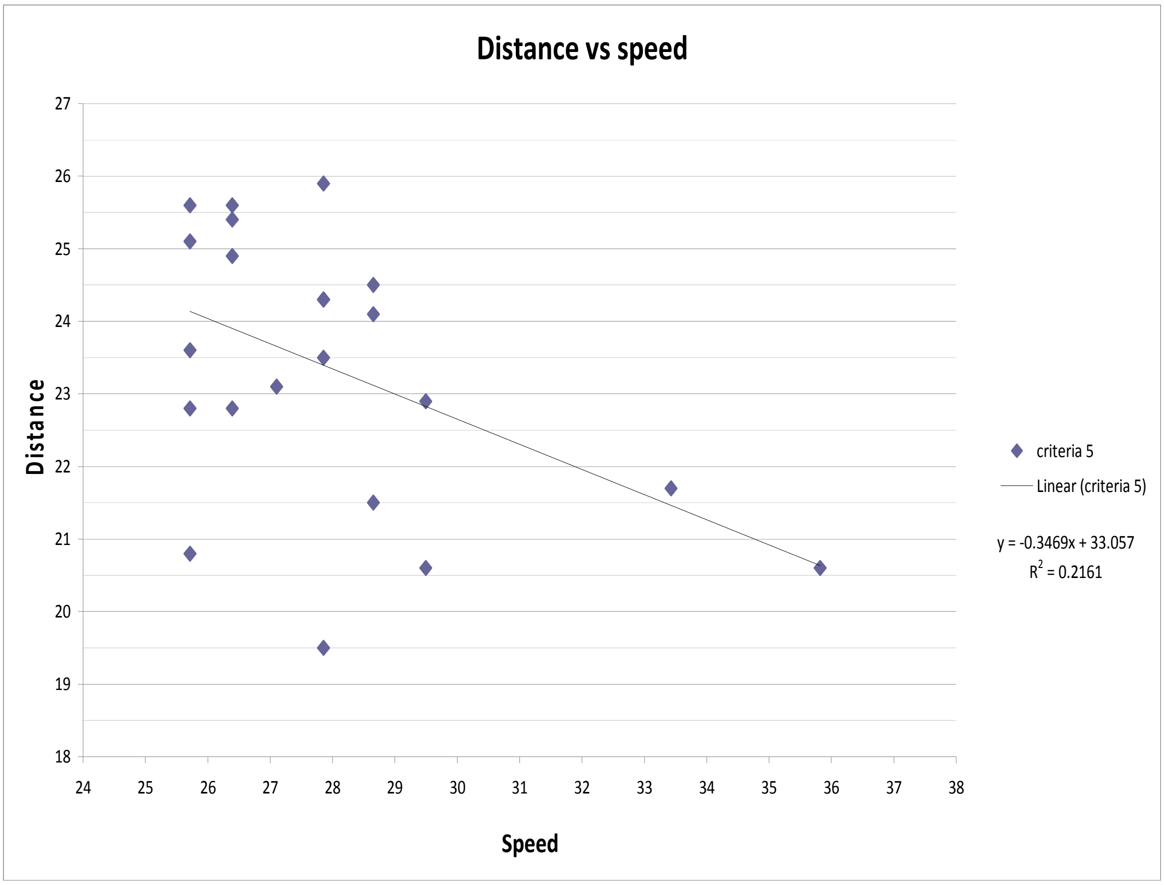

Figure 10: Data Distribution Between Distance And Speed Groups For Vehicles Applying Sudden Brake.

As can be seen in the figure above, certain number of vehicles found to be applying sudden brake. But in contrast, most of the vehicles in this criteria are found to be in speed range of 25-30MPH and distance of 22-26 meters from stop line.

5. Conclusion and Recommendations

This paper focuses on safety at signalized junctions taking into account different aspects of red light running and situations of dilemma zone related to it. All drivers have their own perceptions to deal with different situations while driving, but at signalized junctions there are several factors which affect their decisions. Sometime there are situations where drivers have different choices but sometimes they have to deal with situations where they have only one choice.

Several factors affect the decision of driver to stop or go in dilemma zone. Most important factor which influences the driver's decision is their approaching speeds. Higher the approaching speed driver is more likely to violate. Second important factor is distance of vehicle from stop line at the onset of amber. Vehicles which are closer to stop line are more likely to violate or sudden stop. Combination of both approaching speeds and distance from stop line has significant effect on drivers. Some vehicles being very close to stop line at onset of amber can stop comfortably due to low approaching speed. Similarly vehicles with high approaching speeds find it comfortable to stop due to longer distance from stop line.

The percentage of aggressive drivers seems to be quite high for all three surveys.A central value for overall noncompliance is 70%.This bears safety issues for studied signalized junction, since a large number of drivers may be caught in the middle of the intersection lacking adequate clearing time. Prolonging amber signal time will not improve the situation, since it will create longer option zones and subsequently uncertainty that may be the cause of rear end accidents(Koll et al., 2004)

In this paper survey has been conducted at a specified site with specified time which provides audience a certain level of understanding how drivers behave at traffic signals, thus observing just few scenarios of dilemma zone and red light running, therefore observations on all possible scenarios are not fully studied.

With respect to the appropriate measures aiming at improving the current situation, if approaching speeds are high, advance warning flashing lights and advance detection systems will have to be installed. In addition, stricter enforcement should be introduced at such locations. Adjustments of the speed limits may be necessary to reflect the real traffic conditions. Finally, educating drivers must be the preferred long-term measure that will improve the existing situation and that will secure in conjunction with the other measures a better behavior.

Acknowledgement

The authors thank the anonymous reviewers for their valuable comments.

References

- Amer, M. M. A. 2016. Statistical and behavioral modeling of driver behavior on signalized intersection approaches. PhD thesis, Virginia Polytechnic Institute and State University.
- Head, L.K., P.B. Mirchandani, and D. Sheppard. 1992. Hierarchical Real-Time Traffic Control. Transportation Research Record, 1992. 1360: p. 82-88.
- Institute of Transportation Engineers (ITE), Traffic Control Devices Handbook, ed. J.L. Pline. 2001, Washington, DC: Institute of Transportation Engineers.
- Koll, H., Bader, M., Axhausen, K.W. 2004. Driver's behavior during flashing green before amber: a comparative study. Accident Analysis and Prevention, 36 (2), 273–280.
- Papaioannou, P. 2007. Driver Behaviour, Dilemma Zone and Safety Effects at Urban Signalised Intersections in Greece. Journal of Accident Analysis and Prevention. 39(1): p. 147-158.
- Zegeer, C. V. 1977. Effectiveness of green-extension systems at high-speed intersections . Research Report 472 , Kentucky Department of TransportationFrankfort.
- Zhang, Y., Fu, C., Hu, L. 2014 .Yellow light dilemma zone researches: a review. Journal of Traffic and Transportation Engineering (English Edition), (5): 338-352.