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Analyzing Driver's Response to Yellow Indication Subjected to Dilemma Incursion: An Econometric Approach

Ramesh Chandra Majhi[a], Velmurugan Senathipathi[b]

[a]*Traffic Engineering and Safety Division, CSIR-Central Road Research Institute, Mathura Road, New Delhi, India, 110025*

[b]*Traffic Engineering and Safety Division, CSIR-Central Road Research Institute, Mathura Road, New Delhi, India, 110025*

Abstract

Under mixed traffic conditions, the behavioral pattern of the drivers changes erratically while facing yellow signal at intersections. Hence it becomes quite complex to predict response of the drivers which is influenced by several factors. The present study analyzes the effect of surrounding vehicles on response of the drivers while facing dilemma at intersections. Due to the above phenomenon of traffic heterogeneity, different vehicle types tend to occupy different lanes arbitrarily resorting to non-lane based traffic movement and thus affecting the decision making process of drivers who face indecision whether to cross or stop at a given intersection. Further, this study identifies the behaviour of the drivers by characterizing into various groups based on critical time analysis. Although dilemma zone definitions holds true in case of homogeneous traffic, a statistical analysis is performed to check the consistency across the definitions under mixed traffic condition. For carrying out the research, study locations are chosen in such a way to reflect diversity in road geometry, traffic composition and signal characteristics. The results deduced in this study indicate a strong correlation between driver's response and presence of front vehicle in decision making process under mixed traffic conditions.

Keywords: Mixed Traffic Condition; Dilemma Zone; Critical Time

1. Introduction

Yellow interval always leads to risky behavior of vehicles following crashes resulting from DZ (Dilemma Zone) incursions. In case of drivers who are relatively close to the stop line make a decision to stop abruptly instead of proceeding ahead, whereby rear end collision from the following vehicle is likely to occur. On the contrary, vehicles that are far behind stop line choosing to cross the intersection would invariably find themselves in the middle of the intersection leading to right-angled collision (Gazis et al., 1960).

A fixed relationship between signal timing and safety is the clearance interval or yellow duration which is used as a transition period between two signal phases. Improper design of clearance time can ultimately lead to potential vehicle conflicts and further crashes. Two types of dilemma zone situation arise for drivers when they face with a yellow indication termed as Dilemma Zone I or Risk Zone and Dilemma Zone II or option zone. Type I dilemma zone is defined as the zone from where 10 percent of vehicles choose to stop and ends where 90 percent of vehicles choose to stop (Zegeer, 1977). An alternative definition exists which describes type I dilemma zone exists from 2.5 to 5.5 seconds from stop line. Type II dilemma Zone otherwise called "Option Zone" exist at a distance from stop line where vehicle has a option to cross or stop and in both the cases the decision made by the driver is safe. Several studies (Olson and Rothery, 1961; Sheffi and Mahamassani, 1981; Parsonson, 1992; El Shawarby, 2006) have been carried out by various researchers to identify the variability in driver decision making process. Based on driver behavior, drivers have been categorized into various categories in different studies (Liu et al., 2007; Papaioannou P., 2007; Gates T. and Noyce D., 2010) in order to quantify the DZ. Based on the driver feedback to yellow signal, it was found that a series of factors contribute to the deviation in behavior which includes driver attitude, emotional state and knowledge about the intersection (Van Der Horst and Wilmink, 1986; Milazzo et al., 2002; Shultz and Babinchak, 1998).

As drivers face conflict towards the yellow dilemma, several factors come into play such as PRT (Perception Reaction Time) of the drivers coupled with the associated acceleration and deceleration maneuvers performed by them. These studies carried out for homogeneous traffic conditions exhibit a definite trend in these parameters with the driver decision making process (El Shawarby et al., 2007; Rakha et al., 2007; Zhixia et al., 2010; Burnet N. and Sharma A, 2011). With respect to driver conflict modelling at yellow onset, there are several studies (Sharma et al., 2007; Sharma et al, 2011; Li Pengfei and Abbas M, 2010) has been carried out focusing on vehicle parameters as contributing factors. Although a lot of research has gone into the DZ analysis, in most of the studies, data were gathered in a controlled environment or using Driver Simulator. Driver behavior extracted from such environments could be biased due to the lack of consideration of its interaction with surrounding traffic environments.

This paper proposes a guideline to decide the dynamic DZ range for various vehicles types under mixed traffic conditions by analyzing the influencing parameters that affects DZ distance through Vehicle Trajectory analysis. Moreover, it presents an economic approach to the DZ study by implementing breakeven analysis to the driver's safety.

2. Research Methodology

Overall research framework is outlined as calibration of influencing parameters that affects DZ range followed by a cost-benefit approach to the safety and delay cost to the drivers. As indicated earlier, the study methodology is divided into two phases (refer Figure 1) to achieve the research objectives.

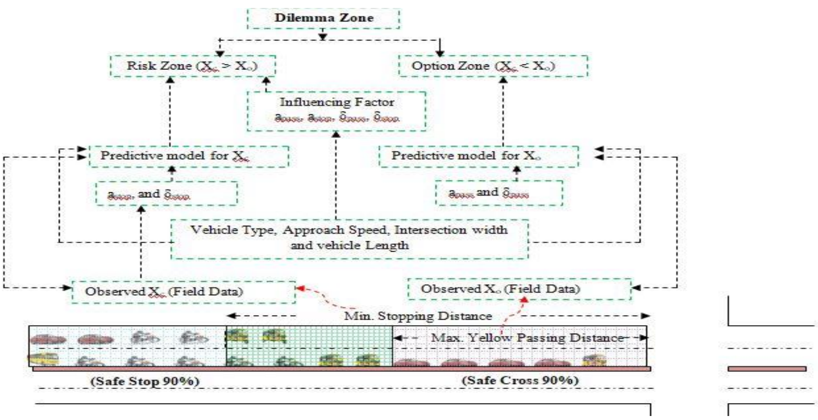

Fig. 1. Framework for calibration of Influencing Factors

As mentioned earlier, cost-benefit approach for sensitization of driver safety at signalized intersection has been attempted in this paper which is detailed in Figure 2.

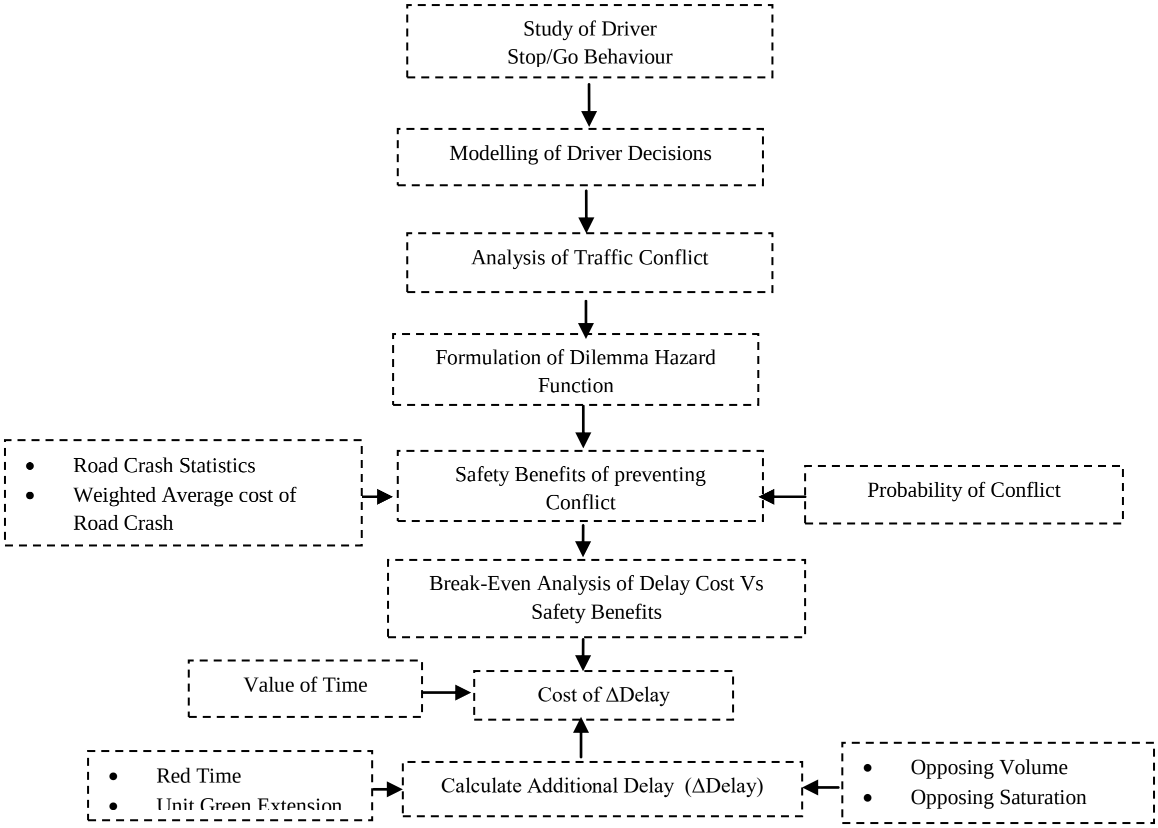

Fig. 2. Economic Analysis Framework for Driver Safety

3. Data Collection and Extraction

3.1. Data Collection Procedure

Five intersections were chosen in the city of Delhi exhibiting varying intersection characteristics and traffic composition. All selected intersection were four armed except location 4 which is a T-intersection but for the analysis purpose, only major approaches were chosen and wherein videography data was collected during morning peak hour in the month of April 2017. Due to paucity of funds, seasonal variation could not be captured in the study by confining the data collection period to summer season. To cover one approach, two HD cameras was used and the data was synchronized later on during the frame by frame analysis using ACG player (Media Player) to achieve an accuracy of 0.001 seconds. The data collection methodology is presented in Figure 3.

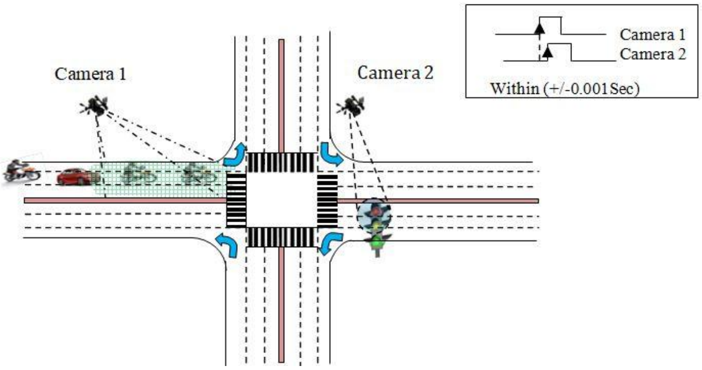

Fig. 3. Data Collection Technique adopted at Signalized Intersection

A site inventory was prepared to gather all information for the study intersections including approach details, signal timing, etc. The typical information collected at the candidate intersections is presented in Table 1.

Table 1. Intersection Characteristics

Characteristics	Location 1			Location 2		Location 3		Location 4		Location 5	
Subject Approach	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11
Number of Approach lanes	2	2	2	2	4	3	3	3	3	3	3
Lane Width(m)	9.2	9.2	9.5	8	13.5	10.5	11	10.8	12.8	10.5	10.5
Intersection Width(m)	25.8	20.1	25.8	21	21	20	20	22.7	13.4	20	20
Green Time(s)	15	20	20	63	88	45	20	38	85	56	45
Amber Time(s)	5	5	5	6	6	5	5	6	6	5	5
Red time(s)	60	76	76	73	70	93	118	141	95	143	153
Development (Area type)	Urban			Urban		Urban		Urban		Urban	

For optimum selection of sample size, there are various factors involved which are listed below.

1. Confidence Level
2. Video graphic data duration
3. Cycle Length

For sample size calculation, the following formula (Panagiotis Papaioannou, 2007) is used.

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

Where, ‘p’ and ‘q’ are proportion of vehicles facing the signals that has stopped and the number of vehicles facing the signals that has crossed. K is a constant at desired confidence level and E is the acceptable error.

Considering a probability of 0.5 for stopping and crossing and acceptable error as 5 percent with confidence level 95 percentile, the sample size was found out to be 386. Moreover, as only first to stop and last to go vehicles were considered in the study, in one cycle there were only two vehicles captured in the analysis. Eventually, based on the duration and cycle length of videography, minimum sample size was satisfied from the analysis point of view.

3.2. Data Reduction

Four hours of continuous data was gathered at selected locations covering the city of Delhi. For extracting the data, we have used a semi-automated traffic data extraction software developed as part of Indo-HCM (2017). The software needs four points on the ground with measured distance length and width in vertical and horizontal direction so as to calibrate the camera parameters so as to convert 3-D to 2-D coordinates which is then used to track the vehicles on the ground. For that purpose, four distinct corners (by placement of traffic cones on the raised kerb) were earmarked at the study approach, two near the stop line across the carriageway and other two corners at a known vertical distance across the carriageway from the first two cones.

At the onset of yellow, vehicle trajectory were extracted using the software. Vehicles were tracked till the stop line for first to stop vehicles and for last to go vehicle when they cross the stop line during yellow interval. For analyzing the dilemma zone under mixed traffic condition, vehicle data (based on vehicles types) were extracted at yellow onset. During the analysis of data, it was found that three vehicle types together constituted almost 95 percent of vehicle population. Eventually for the subsequent phase of the analysis and development of statistical models, the following three types of vehicles were considered namely, Car, Motorized Two Wheelers and Auto-Rickshaws. The other parameters that were extracted from the videography data such as approach speed distance to stop line, actual time to reach stop line or cross the stop line, acceleration and deceleration characteristics.

4. Data Analysis

4.1. Study of Dilemma Zone Influencing Factors

Based on the previous studies (Gates et al., 2007), it is evident that factors influencing dilemma zone are not constant and vary based on the different approach speeds. Deceleration rate for stopping increases with increase in approach speed and acceleration rate decreases with increase in approach speed (Gazis et al., 1960); the driver perception time also decreases with increase in approach speed. The modified GHM (Gazis Herman Maraduin) model is shown below.

$$X_c = V_o\delta_{stop} + \frac{V_0^2}{2*a_{stop}} \quad (2)$$

$$X_o = V_o y + \frac{1}{2}a_{pass}\ [y - \delta_{pass}]^2 - W - Z \quad (3)$$

Where X_c = Minimum stopping distance from the stop line at speed V_o(m); X_o = Maximum yellow passing distance from the stop line at speed V_o (m); δ_{stop} = Minimum perception reaction time of the drivers to stop safely at speed V_o (s); δ_{pass} = Minimum perception reaction time of the drivers to cross safely at speed V_o (s); a_{stop}= Maximum deceleration rate of the drivers for safe stopping at speed V_o (m/s^2); a_{pass}= Maximum acceleration rate of the vehicles for safe stopping at speed V_o (m/s^2); y = Yellow Duration (s); W =Width of Intersection (m); Z = Length of vehicle (m).

The model calibration is done by using field data with the actual value of X_c and X_o using classical GHM Model. Considering the trend observed by researchers in their earlier studies as mentioned above, priority has been taken in the process of calibrating the contributing factors. The calibration process is done in three steps which are described in the succeeding sections.

Step I: Selection of model to fit into the trajectory profile of vehicles

To select appropriate model, calibration of the field observations of X_c and X_o been done. In this context, correlation coefficient and root mean square error were found out for different regression model and the most appropriate model is presented in Table 3 and Table 4. The RMSE statistics of various model regimes is shown in Table 2.

Table 2. RMSE Statistics for Various Models

Vehicle Type		Root Mean Square Error Value					
		Linear	Exponential	Logarithmic	Power	2nd Deg.	3rd Deg.
Car	X_c	2.42	2.54	1.93	2.1	0.62	0.81
	X_o	6.1	8.24	3.57	5.65	2.4	2.41
Motorized Two Wheeler	X_c	2.87	2.91	2.68	15.45	0.67	1.98
	X_o	2.44	3.49	0.87	1.77	0.57	0.65
Auto Rickshaw	X_c	1.87	2.13	1.16	1.47	0.23	1.9
	X_o	0.712	0.86	1.04	0.780	0.71	4.45

Step II: Fitting Model to the Trajectory of First-to-Stop vehicles

Firstly the trajectory profile of First to stop vehicles at onset of yellow is plotted in the graph with approach speed (Kmph) in X-axis and Distance to stop line in Y-axis. The plot is presented in Figure 4.

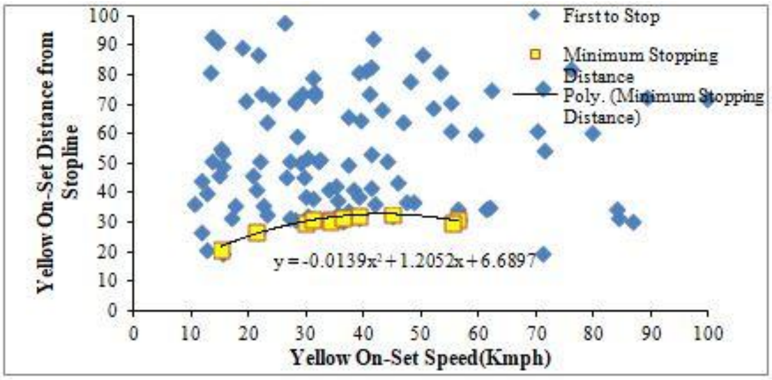

Fig. 4. Ground profile of Minimum Stopping Distance (Car)

The above analysis is done by combining four approaches which includes Location 3 and Location 5. The purpose of combining of two intersections is due to their same amber time and intersection width. As the sample size depends on the number of vehicles samples to be extracted from the video rather than number of intersections, the data obtained from various candidate intersections considered in this study for different types of analysis. The ground truth profile of X_c (obs) for different vehicle types is shown in Table 3.

Table 3. Model Statistics of X_c (obs)

Vehicle Type	**Fitted Model (Min. Safe Stopping Distance)**
Car	$X_c(obs) = -0.0139V_o^2 + 1.2052V_o + 6.6897$ Adjusted $R^2 = 0.96$
Motorized Two Wheeler	$X_c(obs) = -0.0312 V_o^2 + 2.5089 V_o - 12.363$ Adjusted $R^2 = 0.9566$
Auto-Rickshaw	$X_c(obs) = -0.0135 V_o^2 + 1.2242 V_o + 4.9624$ Adjusted $R^2 = 0.9964$

Step III: Fitting Model to the Trajectory of Last-to-go vehicles

Similar trajectory profiles are plotted for last to go vehicles to get the ground profile which are shown in Figure 5.

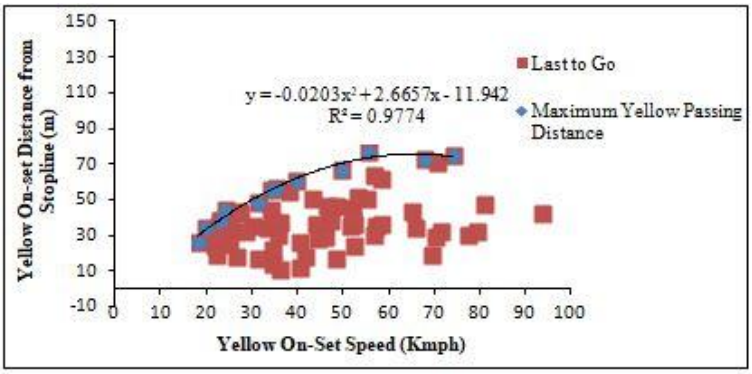

Fig. 5. Ground profile of Maximum Yellow Passing Distance (Car)

Table 4. Model Statistics of Xo (obs)

Vehicle Type	Fitted Model (Max. Yellow Passing Distance)
Car	$X_o(obs) = -0.0203V_o^2 + 2.6657V_o - 11.942$ Adjusted $R^2 = 0.9774$
Motorized Two Wheeler	$X_o(obs) = -0.0153\ V_o^2 + 2.0679\ V_o + 4.0423$ Adjusted $R^2 = 0.9976$
Auto-Rickshaw	$X_o(obs) = -0.0003V_o^2 + 0.7388\ V_o + 22.938$ Adjusted $R^2 = 0.99$

Step IV: Calibration of influencing factors

The ground profile of X_c (obs) and X_o (obs) is then matched with the traditional GHM model by fitting suitable contributing factors keeping in mind the variability in their trend with increase in approach speed. Hit and trial method is used for the fitting of model. Observed yellow duration of 5 seconds was used for developing theoretical X_c and X_o model. It is assumed that the vehicle consume whole yellow duration for crossing the intersection. The RMS error has been optimized in the process of calibration of model for both X_c and X_o.

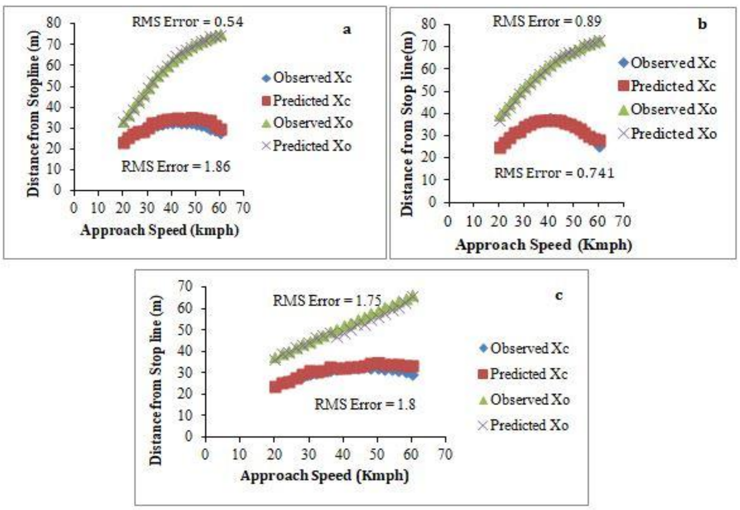

Fig. 6. Calibration of Contributing Factors (a) Car (b) Motorized Two-Wheeler (c) Auto-Rickshaw

Based on the observed X_c and X_o, GHM model parameters are calibrated to match the field data. The trend for different parameters in the calibration process is shown in Table 5.

Table 5. Calibration of Contributing Parameters (Car)

δ_{stop} (s)	a_{stop} (m/s^2)	a_{pass} (m/s^2)	δ_{go} (s)	V (Kmph)	X_c(obs) (m)	X_c(pred) (m)	X_o(obs) (m)	X_o(pred) (m)
2.5	1.64	4.15	1.2	20	24.93	23.3	33.26	33.25
2.45	1.79	3.95	1.1	22	26.33	25.41	36.88	36.1
2.4	1.94	3.9	1.05	24	27.59	27.46	40.35	39.26
2.35	2.21	3.87	1	26	28.73	28.78	43.65	42.58
2.3	2.78	3.84	0.98	28	29.73	28.77	46.79	45.42
2.25	2.93	3.7	0.8	30	30.61	30.61	49.76	49.81
2.2	2.99	3.6	0.75	32	31.36	32.77	52.58	52.46
1.95	3.11	3.5	0.7	34	31.97	32.76	55.23	55.08
1.84	3.27	3.4	0.65	36	32.46	33.7	57.72	57.67
1.73	3.48	3.3	0.6	38	32.82	34.27	60.05	60.23
1.65	3.78	3.2	0.55	40	33.05	34.67	62.21	62.74
1.61	4.17	3.1	0.53	42	33.14	35.11	64.21	64.81
1.45	4.45	2.95	0.5	44	33.11	34.51	66.05	66.48
1.39	4.9	2.77	0.48	46	32.95	34.43	67.73	67.69
1.34	5.1	2.6	0.45	48	32.66	35.3	69.25	69.08
1.29	5.61	2.43	0.42	50	32.24	35.11	70.6	70.44
1.21	6.13	2.26	0.4	52	31.69	34.5	71.79	71.64
1.06	6.23	2.04	0.38	54	31.01	33.96	72.82	72.28
0.98	6.48	1.9	0.35	56	30.21	33.92	73.68	73.82
0.72	6.59	1.66	0.31	58	29.27	31.3	74.38	74.32
0.54	6.71	1.4	0.28	60	28.2	29.7	74.92	74.43

4.2. Development of Dilemma Zone Grid Chart

Based on the study carried out for different vehicle types, dilemma zone grid chart is prepared to look up for deciding the existence of risk zone otherwise called as "Dilemma Zone I" and option zone also called as "Dilemma Zone II" in case of variability in yellow interval. Both X_c and X_o have been plotted in the same graph with variation in clearance interval as shown in Figure 7 keeping the assumption as change in yellow time does not affect the variability in drivers reaction time for acceleration or deceleration and the change in acceleration or deceleration (Saito et al., 1990; Olson and Rothery, 1961).

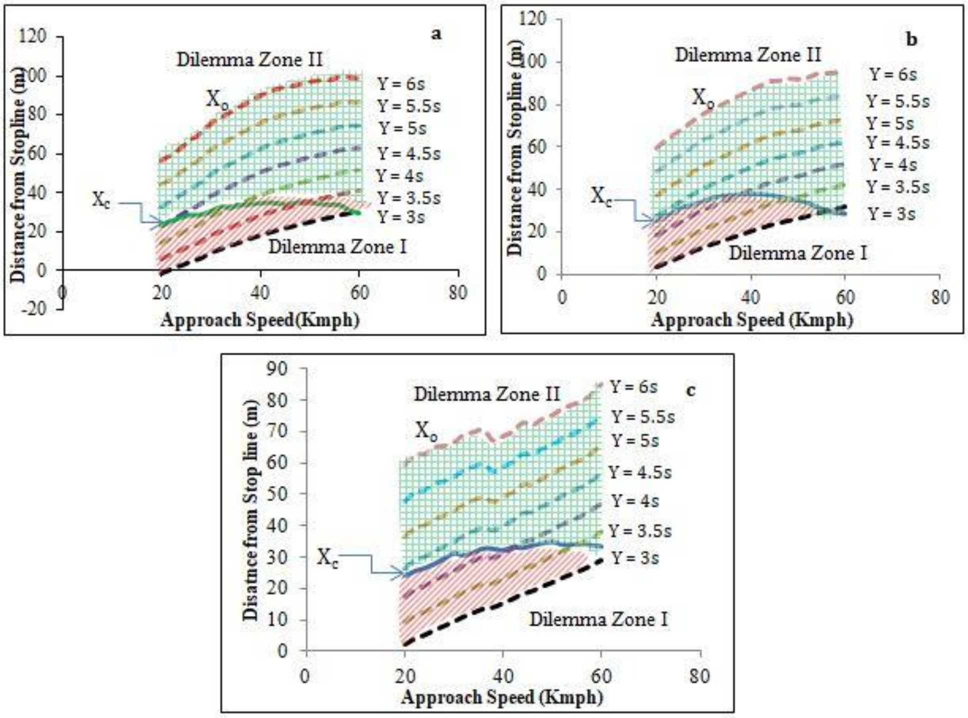

Fig. 7. Dilemma Zone Grid chart for (a) Car (b) Motorized Two Wheeler (c) Auto-Rickshaw

4.3. Analyzing Dilemma Zone as a Cost-Benefit Approach

Although numerous studies have been done in the context of optimum clearance interval by minimizing the number vehicles facing dilemma in the zone but very limited literature is available focusing on the safety aspects of dilemma faced vehicle in coordination with its effect on additional delay caused to vehicles in high speed approach existing on the intersection. In the present study an attempt has been to provide a methodology on the cost-benefit approach for dilemma faced vehicles under mixed flow conditions.

Surrogate Measure for Crash Analysis

Though road crash analysis leads to most accurate prediction of traffic safety measures at intersection but it is quite tedious and difficult to get ready access road crash data in the context of developing economies. So alternatively, traffic conflict is used as a surrogate measure for crash analysis. In this study also we consider traffic conflict as a measurable parameter to decide safety of dilemma zone faced vehicles. For modeling traffic conflict during dilemma period, perceived time (T_p) to reach the intersection is considered as the random variable for analyzing driver decision as it is more realistic from driver perspective while analyzing the situation.

Time based Approach for analyzing Driver's Perspective

Driver's choice to stop or cross the intersection at yellow onset is a binary choice as already discussed. Let T_p is the perceived time to reach the stop line from a randomly chosen driver from the population. Since T_p varies with several factors such as experience of the drivers, safe acceleration, perception of distance to stop etc. can be modeled as a normally distributed random variable.

$$T_p = T_{req} + \xi \tag{4}$$

Where, T_{req} is the required time to safely enter the intersection at the end of yellow. The term ξ is a random variable is assumed to be normally distributed. We assume that $\xi \sim N\,(0, \sigma_{\xi}^{2})$. The probability of stopping can then be calculated as

$$P_{Stop} = \Pr\,(T_p > T_t) \tag{5}$$

$$P_{Stop} = \Pr\,(z < (T_{req} - T_t) = \Phi\,(T_{req} - T_t) = \Phi(a \times T_{req} + b) \tag{6}$$

Where Φ ( ) denotes the standard CDF (Cumulative Distribution Function) and the functional form $\Phi\,(a \times T_{req} + b)$ is a probit construct. Also, $a = 1/\sigma_{\xi}$ and $b = T_t\,/\sigma_{\xi}$. The analysis is done at approach A7 and chosen vehicle type is car. Similar analysis can be done for remaining two vehicle types. The probit analysis results are shown in Table 6.

Table 6. Probit results of perceived Time (Car)

	Value	Std. Error	P-Value
Intercept	5.513201	1.379405	0.00006421
Coefficient	-1.62075	0.395621	0.000041
Chi-Square		42.47402	
p-value		7.16E-11	
Alpha		0.05	
Significance		Yes	
Overall Accuracy of Model		0.83	

Driver's decision to stop or cross changes dynamically depending on surrounding conditions. Based on probit results, a graph has been developed for predicting stopping and crossing behavior which is shown in Figure 8.

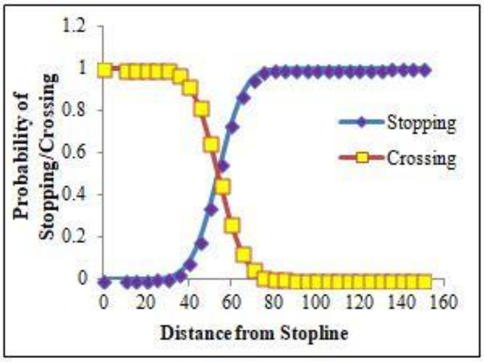

Fig. 8. Decision Prediction of Driver

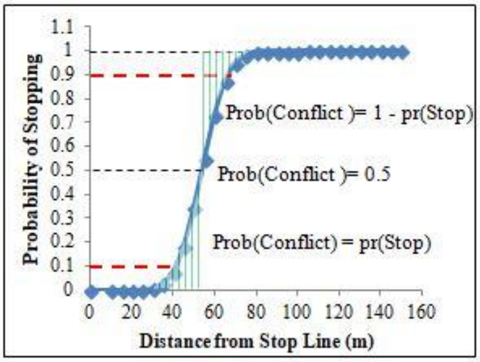

Fig. 9. Stopping Probability

Figure 9 shows the probability of stopping at a given distance from stop line when the vehicle approach speed is 30 Kmph. Considering a vehicle stands at a distance of 40 m and 70 m from stop line, the stopping probability is 0.1 and 0.9 respectively with approach speed of 30 Kmph. At a distance of 40 m from stop line, a car moving at 30 Kmph would easily cross the stop line without any acceleration considering a yellow interval of 5 sec. So the vehicle stopping at this point (a) will face the traffic conflict. Similarly at a distance of about 65 m, the vehicle attempting to cross will face a conflict because the crossing probability at point (b) is 0.1. Hence to summarize the results, the traffic conflict at both points is 0.1. The dilemma hazard function for the car approaching at 30 Kmph with safe acceleration is presented in Figure 10.

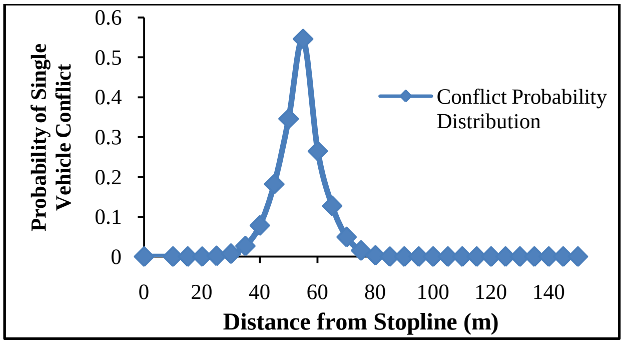

Fig. 10. Single Vehicle Conflict

Implementation of Vehicle Conflict to Cost-Benefit analysis

As shown in Figure 10, similar analysis can be done to develop different hazard function for various approach speed. After establishing the function, the next step is to compute the benefits of preventing the traffic conflict. For the simplicity of analysis only single vehicle conflict is considered in this study but multiple vehicles can also be undertaken which would lead to much more complex vehicle interaction. For calculating safety benefits aimed at preventing vehicle conflict, the comprehensive cost of each road crash is used from the literature (Davis et al., 2015). For simplicity a single value of crash probability is used instead of using hazard function. In Table 7, a sample calculation is shown representing safety benefits of single vehicle conflict.

Table 7. Safety Benefits of Single Vehicle Conflict

Accident Cost in New Delhi (Delhi Traffic Police, 2015)				
	Events	Cost per Crash ($)	Crash Ratio	Weighted Cost ($)
Fatal	1548	26829.87	0.2098983	5631.54
Major	5698	4786.68	0.7726102	3698.24
Minor	129	628.88	0.0174915	11.00
Total	7375			9340.78
Total Weighted Average Cost				9340.78
Probability of Getting involved in a crash subject to a conflict (Gettman et al. 2008)				0.00005
Estimated Benefit of Preventing Traffic Conflict				0.47
Probability of Single Vehicle Conflict				0.2
Benefit of Preventing One Vehicle Decision Conflict				0.1

The weighted average cost is calculated from the cost per crash and crash ratio. After combining all the crash incidents, the total weighted average cost is calculated. The probability of a getting involved in a crash subjected to the conflict is 0.00005 (Gettman et al., 2008). After multiplying the weighted average cost to the Pr (Crash|Conflict), the benefit of preventing a traffic conflict is calculated. Finally benefits of preventing a single vehicle from its decision conflict is zone is calculated by multiplying the probability of occurrence of traffic conflict and the benefits of preventing it. In the above example, it is evident that the benefit is found out to be $ 0.1 for saving single vehicle conflict which would change depending on the road crash data at individual intersection approach. The cost of clearing a vehicle through its dilemma conflict zone can be calculated by using the amount of delay incurred by the queue formed on the red phase. Figure 11 shows the increase in delay due to extension of green.

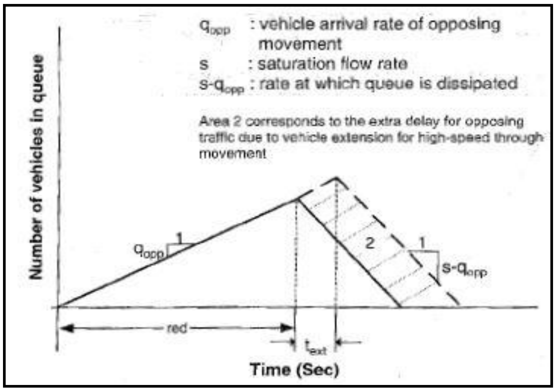

Fig. 11. Increase in delay due to Green Extension

The triangular un-shaded area is the existing delay without green extension and the shaded area is the increase in delay with single vehicle extension. The total shaded area is calculated as follows (Sharma et al, 2007).

$$\Delta \text{Delay} = \frac{q_{opp}}{1 - \frac{q_{opp}}{S_{opp}}} * r * t_{ext} + \frac{q_{opp}}{2 * (1 - \frac{q_{opp}}{S_{opp}})} * t_{ext}^{2} \quad (7)$$

Where, ΔDelay is the increase in delay because of extending through green by a unit vehicle; q_{opp} is the opposing volume (PCU/hr); S_{opp} is the opposing saturation flow (PCU/hr); r is the red time provided in the opposing approach; t_{ext} is the Unit Vehicle extension Time. For calculating volume and Saturation flow in the opposing traffic, PCU values are taken from CSIR-CRRI (2017) study on Indian Highway Capacity Manual. The total cost of delay is calculated by multiplying the ΔDelay with the time value of delay cost of vehicles. The value of time for different vehicle types and PCU factors adopted in this study is shown in Table 8.

Table 8. Mode Wise Adopted VOT values in Delhi City

Mode	VOT / person Trip ($/hr)	Occupancy	VOT ($/Veh-hr)	PCU factor (Indo-HCM, 2018)
Motorized Two-Wheeler	1.64	1.4	2.31	0.4
Car	3.67	1.25	4.60	1
Auto	1.64	1.2	1.97	0.5
LCV	0.98	-	-	1.1
HCV/BUS	0.98	-	-	1.6

Break-Even Analysis:

The breakeven point can be calculated from the intersection of safety benefits and delay cost line. The constraint to be satisfied at breakeven point is as follows

$$\Delta \text{Delay x VOT (\$-Veh-hr)} = \text{Pr}(TC_{n,m}) \text{ x Safety Benefits (\$/ } TC_{n,m}) \quad (8)$$

Where $TC_{n,m}$ is the probability of conflict that “n” vehicles on “m” approaches have traffic conflict if green is not extended in terms of flashing green. Figure 12 shows the theory of economic evaluation of cost and benefits associated with the extra green time provided for safe passage of dilemma zoned vehicle. The time associated with the additional green is given in X-axis and the corresponding delay cost for every unit extension of green is plotted in Y-axis along with the fixed Benefit line determined for escaping single from traffic conflict in dilemma zone. A sample analysis is done for approach A7 as subject approach and A6 as opposing approach. Peak hour volume and saturation flow for the A6 was found out to be 710 PCU/hr and 5500PCU/hr respectively.

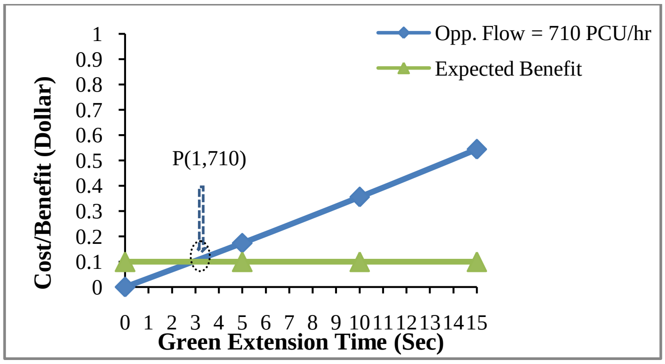

Fig. 12. Marginal Cost-Benefit Curve for Dilemma Zone

The breakeven point P (1,710) stands for clearing single vehicle facing dilemma from the dilemma zone when opposing volume is 710 PCU/hr and signifies the maximum green that can be provided beyond existing green duration at which the delay cost and safety benefits remains equal. From the plot, at breakeven the optimum green extension was found out to be 2.9 seconds with safety benefits of $0.1 for saving single vehicle conflict. Similar such analysis can be carried out to prevent two or multiple vehicles from facing conflict in the dilemma zone. Current study is limited to single vehicle scenario because of time constraint and resource limitation.

5. Conclusion

Present study focused in analyzing complex behavior of drivers in mixed traffic condition at yellow onset. From the statistical analysis of field observations, it was found that driver's decision making process is a conjunction of various parametric effects which govern the behavior invariably. Further analysis showed that development of Dilemma zone grid chart based on various approach speed and vehicle types would be a helpful tool for the decision makers in designing optimal signal strategy to address safety of the drivers. Further econometric analysis of DZ safety was found out to be an effective tool for sensitizing the users as well as planners while prioritizing the signal timings. The conclusions of this research have led to some recommendations which are described as follows.

- The field evaluation and data collection strategy undertaken could be formalized and developed as a routine evaluation technique for evaluating the nature and extent of dilemma zone issues. Consideration should be given to the creation of formal dilemma zone identification in the field.
- Dilemma zone Grid chart can be revised by gathering more samples at various intersections to represent it as a guideline to design the signal length based on the existence of dilemma zone.

Additional areas of future research related to the present research detailed herein have been identified. Future research recommendations include but are not limited to the following:

- This study generated a wealth of field data. Though the results of this study were determined to be significant, future study is required to expand upon the sample size of dilemma zone incursions in the field.
- The cost benefit analysis can be extended further for the multiple vehicle scenario as the vehicle entrapped in the dilemma always face mutual interaction with the surrounding vehicle and always affect the follower vehicle depending on its decision to stop or go.

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