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Estimation of Pedestrian Temporal and Spatial Gap Acceptance at Signalized Intersections

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Abstract - *An Intersection could be defined as a road junction where two or more roads meet or cross and include areas required for movement of all modes of travel e.g., pedestrian, bicycle, motor vehicle and transit. They are the critical points of road network, where delay normally occurs due to sharing of space and time from the conflicting streams due to movement of vehicles and pedestrians. Several studies have been done for evaluating performance of intersections considering vehicular traffic and also different techniques are available for designing intersections considering vehicular flows, but pedestrians who share the same space and time at the intersection are often neglected, which often leads to a non-compliance pedestrian movements on the intersections. This study attempts to understand different types of pedestrian movements that occur on an at-grade signalized intersection and how it influences the performance of an intersection. For this purpose, three signalized intersections were identified in Vijayawada considering traffic flows, pedestrian flows and road network density. The overall performance of intersection was then analyzed considering network speed. Further, the pedestrian behavior is categorized in compliance and non-compliance category. The non-compliance behavior was further sub-categorized into Priority Taking, Priority Surrendering behaviors. In this study, spatial and temporal critical gap were estimated using a deterministic model namely Raff's Approach. Based on the analysis we found there is decrease in performance of the intersection which is 30.9% reduction in the network speed due to pedestrian vehicular interactions.*

Key Words: Compliance Behaviour, Non-Compliance Behaviour, Priority Taking, Priority Surrendering, Critical Speed, Network speed.

1. INTRODUCTION

The efficiency of the road network mainly depends on two terms viz. Level of Service and Network Speed being provided. Basically the overall traffic flow of the complete transport network system in an urban area depends on the performance of the individual intersections, arterial and collector roads. In this regard intersections are the most critical point where different hierarchy of roads will meet.

- Intersections are a critical aspect of street design as the point where motorist, bicycle and pedestrian movements coverage (Adapted from Urban Street Design Guide)
- Intersections are planned points of conflict in any roadway system. (Adapted from US Department of Transportation, Federal Highway Administration)
- Intersections are critical points of road network, where delay normally occurs due to sharing of space and tie from the conflicting streams/ movements of vehicles (Indo-HCM, 2017)

Unlike the other at grade intersections (roundabout, un-signalized intersections) signalized intersections are different, signalized intersection is one where the space is shared alternatively by a fixed number of approaches for a pre-defined time interval or vehicle actuated time interval as per the phasing scheme used at the intersection. Even for the pedestrians sometimes a separate time is allotted to cross the road and sometimes red time for the approach is used as green time for the pedestrians. Because of the longer waiting for pedestrians at signalized intersections due to higher traffic density and greater urgency to reach various land use facilities, here non-compliance behavior pedestrians tend to cross the road by accepting certain gaps even though red phase for them, which reduces the network speed of the intersection. In their gap acceptance mechanism, pedestrian may reject several inadequate gaps, but some of these rejected gaps may be accepted by some other pedestrians because of differing behavioral characteristics such as increase in speed and path change conditions while crossing the road. Pedestrian quantification of gaps is an important factor in pedestrian facility design as well as intersection performance. Furthermore, driver yield behavior also affects the pedestrian gap acceptance size and it should be noted that the driver yielding behavior in developing countries can be quite different when compared with developed countries because of higher pedestrian density leading to higher pedestrian-vehicular interactions. In mixed traffic conditions, different vehicles have different speeds and vehicle drivers do not drive always in the same lane, and may exhibit path change to avoid vehicular-pedestrian interactions, which influences pedestrian's critical gap estimation (Raghuram Bhadradri Kadali & Vedagiri Perumal, 2016) . A critical gap can be defined as Minimum gap in traffic stream that all entering pedestrians will accept. The critical gap as minimum time gap in seconds for a pedestrian to attempt crossing the road (HCM, October 2000).

In this research we have considered both in terms if spatial critical gap and temporal critical gap. Thus three vehicles (Two Wheeler, Three Wheeler and Four Wheeler) are considered to estimate critical gaps. The critical gaps may vary for vehicle to vehicle for non-compliant behavior of pedestrians. Significant variation of critical gaps related to pedestrian behavior with different modes is our motivation to study pedestrian critical gaps (spatial and temporal) at signalized intersections.

This paper is organized into five sections, including this section. Section 2 reviews about past literature related to pedestrian behavior, pedestrian gap acceptance methods. Section 3 explains methodology of data collection and data extraction procedure. Section 4 details about non-complaint behavior pedestrians and discusses the estimated critical gaps and results accepted by pedestrians. Section 5 summarizes conclusions and limitations of the study.

2. LITERATURE REVIEW

A driver / passenger entering the intersection must determine whether or not a gap of opposing traffic stream is sufficiently wide enough to perform the desired step safely. In general, a driver/passenger embraces all the distance that is more than his / her vital distance and refuses the rest. Thus critical gap determines the least amount of gap that a driver can tolerate.

One of the first attempts towards defining critical gap can be credited to Green shields (1947), when they introduced the concept of average minimum acceptable gap, which is the lag accepted by more than 50 per cent of the drivers (Gattis & Sonny, 1999). Later (Raff & Hart, 1950) introduced the definition of a critical lag which refers to the size of the lag which has the property that the number of lags accepted is shorter than that of the number of lags rejected longer than that. And some many authors estimated critical gaps with different methods such as MLE (Tian, et al., 1999), logit and probit models (Hamed, et al., 1997),(Brilon, et al., 1999), and advanced techniques using artificial neural networks (Lyons, et al., 2001). On the other hand, researchers have explored the effect of age and gender in gap acceptance, with simulated road-crossing techniques (Oxely, et al., 2005), (Lobjois & Cavallo, 2007). In order to explore pedestrian vehicle interactions researchers also developed simulation models (Schroder, et al., 2007).

(Mithun Mohan & Satish Chandra, 2016) This study introduces different techniques to estimate critical gaps. This study using VISSIM software found that estimates of many of these methods are dependent in the volume of conflicting traffic. It is found that the Maximum Likelihood Method provides the nearest and reliable estimation of critical distance followed by the Probability Equilibrium Method and Raff method.

(Nathan P. Blez, et al., 2014) Addressing existing roundabout modelling and analysis approaches by concentrating on driver behavior styles that is not gap-based acceptance, does not comply with offside priority regulations, is collaborative between traffic flows and has real performance-related effects. A Paradigm is introduced to clarify Priority Abstaining, Priority Taking and Priority Surrendering. Priority abstaining, in which an entering vehicle stops when it should not. Priority taking, in which an which an entering vehicle enters the stream when it should not. Priority surrendering, in which a circulating vehicle stops when it should not. Results indicate that roundabout efficiency is significantly influenced by these non-compliant driver activities in emerging modelling methods, and remain uncounted.

However, studies have rarely explored the effect of pedestrian behavioral characteristics such as rolling behaviour, speed change with different techniques such as , speed change) with different techniques such as HCM, Raff's method, MLE, and logit models and comparison of the estimated critical gap using these methods under mixed traffic conditions.There, the present study explored the critical gap acceptance by the pedestrians interms of spacial and temporal gaps by using Raff's Method.

Gap: Time span between two consecutive vehicles that create conflict with an entering pedestrian.

Critical Gap: Minimum gap in traffic stream that all entering pedestrians will accept.

Accepted Gap: Gap which pedestrian perceives as safe gap to cross road. (Usually>Critical Gap).

Rejected Gap: Insufficient gap between vehicles that are rejected by pedestrians. (Usually<Critical Gap).

$$Fr = 1 – Fa$$

Fa = Cumulative probability of accepted gaps

Fr = Cumulative probability of Rejected gaps

Critical gap is not a constant but varies from drivers to driver and from time to time. Critical gap was found to also vary with subject vehicle type, intersection geometry, approach gradient, delay, weather conditions etc.

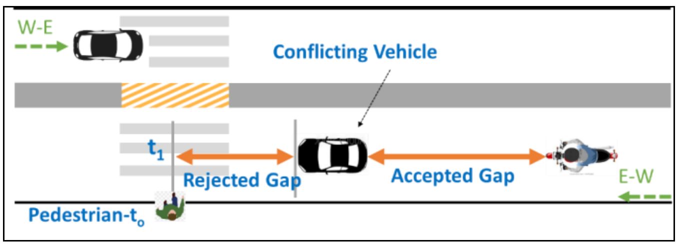

Figure 1 Definitions associated with temporal and spatial gap and lag

Temporal lag is the time passed after a pedestrian is ready to cross the road until the first approaching vehicle reaches the conflicting point.

Spatial lag is the distance of first conflicting vehicle from conflict point when a pedestrian starts looking for a suitable gap.

3. METHODOLOGY

3.1 Characterization of Behavior

Pedestrian behavior is of two types: Compliance and Non-Compliance Behavior

Compliance Behavior, People who comply with the traffic law, and do not take an illegal action (People who follow signal and cross the road only on pedestrian green time).

Non-Compliance Behavior, People who look for appropriate gaps between vehicles to cross during red signal (People who do not follow signal and cross the road in by obstructing vehicular flow). In the similar manner (Nathan P. Blez, et al., 2014) approach of characterizing behavior used in this study but for the behavior of the pedestrians and it is characterized into three.

Priority Taking, Pedestrian is entering on carriage way when he/ she should not, (Non-Compliance Behavior).

Priority Surrendering, He/ She will hesitates to cross even there is vehicle stopped at intersection (Non-Compliance Behavior).

Free flow, Pedestrian is obeying the traffic rules and waiting for his phase.

3.2 Site Selection

Three locations were considered in Vijayawada for the critical gap estimation and these are protected (signalized) intersections. The details are summarized in Table 1

Table 1 Summary of selected intersections

Location No.	Location Name	Type of Intersection	Vehicle traffic in peak hour in Veh/hr.
1	Vijaya Talkies Junction	3 legged intersection	3864
2	Kotha Vanthena Centre	4 legged intersection	5318
3	BSNL Bhavan Centre	4 legged intersection	5551

3.3 Data Collection and Extraction

A video recording survey was conducted for a total of 3 hours during morning and evening on working days in each selected location. The camera were positioned to capture pedestrian's gap acceptance behavior, pedestrian characteristics and vehicular characteristics. Vehicular speed is also captured from the video and prior to the video survey; a known length was marked for the vehicle speed data extraction.

The data extracted includes decision of pedestrian (accepted or rejected), spatial gap in meter (M), temporal gap in second (S), approach speed (KMPH) of the conflicting vehicles, type of conflicting vehicle (two wheeler, four wheeler (car) and three wheeler), and geometry of the sites.

Figure 2 Pedestrian is waiting suitable gap to cross the road

In the fig 1 pedestrian (non-compliance behavior) is waiting to cross the road in between the traffic they are rejected the gap in between the vehicles i.e. they are not willing to cross the road as they feels it is not safe to cross and it is known as rejected gap (R).

In the fig-2 and fig-3 pedestrians (non-compliance behavior) had felt that the gap between the two 4 Wheeler is safe for them and they just crossed the road. The distance between the two 4 Wheeler is noted as spatial accepted gap (A). The distance is noted in between rear end of preceding vehicle and front of the succeeding vehicle.

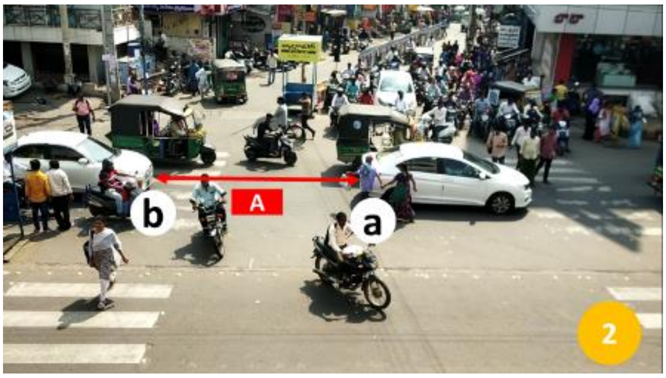

Figure 3 Pedestrian Just Crossed the Road

Rear end of preceding vehicle is 'a' and front of the succeeding vehicle is noted as 'b'. Time taken for succeeding vehicle to reach point 'a' to point 'b' is noted as temporal accepted gap in S, space between them is noted as spatial accepted gap in M. The pedestrian gap acceptance data is collected in between three modes (Two Wheeler, Three Wheeler and Four Wheeler).

The accepted vehicular gap data were extracted with respect to each individuals crossing path. Actual vehicle speeds were extracted by the known marked length (10 m) from the videos. The collected variable descriptions are given in Table 2. Figure 4 shows sample graph of estimation of critical gap acceptance by Raff's Method.

Table 2 Actual vehicular speed (KMPH)

Mode	No.of Observations	Length	Average Time	Speed
2 Wheeler	23	15	3.2	16.9
3 Wheeler	28	15	3.4	15.9
4 Wheeler	16	15	3.8	14.2
Average	67 (Total)	15.0	3.5	**15.7**

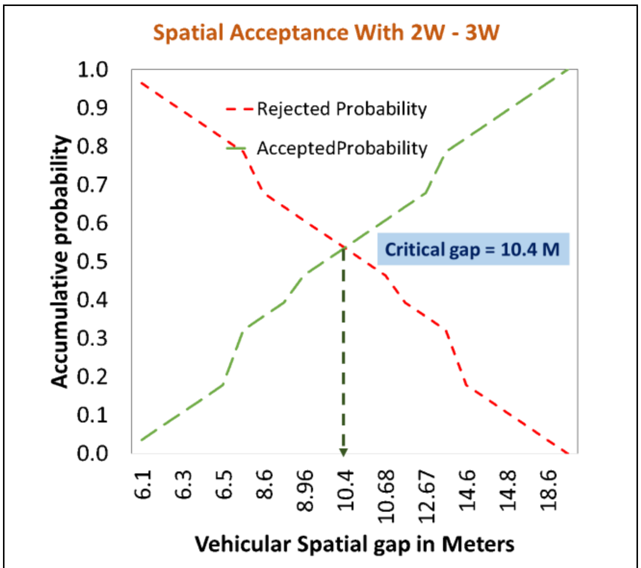

Figure 4 Raff's Method of Critical gap estimation

Critical gaps were calculated based in pedestrians accepted and rejected gap data observed in field at three locations by using Raff's method. In Raff's method cumulative proportions of accepted and rejected gaps were considered in the critical gap estimation.

Critical gap is not a constant but varies from drivers to driver and from time to time. Critical gap was found to also vary with subject vehicle type, intersection geometry, approach gradient, delay, weather conditions etc.

4. RESULTS

4.1 Critical gap estimation and Non-complaint behavior pedestrians

A total of 514 pedestrians, observations were made, out of which 37.7 % (194) pedestrians are found noncompliant to rules and taking risk in the traffic and causing for vehicular conflicts. Out of 194 pedestrians 89.4% of people with priority surrendering, 10.6 % of people with priority taking, risking themselves to cross the road and causing severe pedestrian vehicular conflicts.

Spatial critical gap

The spatial critical gap accepted by the pedestrians to cross the road at the intersection between, 2 Wheeler, 3 Wheeler, 4 Wheeler and other modes respectively are

Table 3 Spatial Critical Gap

Spatial Critical Gap (M)				
Mode	**2 Wheeler**	**3 Wheeler**	**4 Wheeler**	**ALL MODES**
2 Wheeler	9.3	10.4	10.65	10.6
3 Wheeler	10.53	11.02	11.5	11.45
4 Wheeler	14.4	13	9.5	13
ALL MODES	10.1	11.2	10.63	10.9

The spatial critical gap is found max as 14.4 M with 4 Wheeler with preceding vehicle and 2 Wheeler as succeeding Vehicle and Minimum in between 2 Wheelers as 9.3 M. Spatial critical gap irrespective of the mode is found as 10.9 M.

Temporal critical gap

The temporal critical gap (S) accepted by the pedestrians to cross the road at the intersection between different modes respectively are given on the table below.

Table 4 Temporal Critical Gap

Temporal Critical Gap (M)				
Mode	**2 Wheeler**	**3 Wheeler**	**4 Wheeler**	**ALL MODES**
2 Wheeler	2.39	3.43	3.2	3.35
3 Wheeler	2.86	4.06	3.6	3.65
4 Wheeler	4.2	4.53	3.8	4.12
ALL MODES	3.15	4.1	3.7	3.6

The Temporal critical gap is found max as 4.53 S with 4 Wheeler with preceding vehicle and 3 Wheeler as succeeding Vehicle and Minimum in between 2 Wheelers as 2.39 S. Spatial critical gap irrespective of the mode is found as 10.9 M.

Critical Speed

Based on the speed, distance and time relationship the approximate critical speed of the vehicles accepted by the Non-Compliance Behavior pedestrians so that they can cross the road with that speed. This calculation is done to know what is the speed of the when pedestrians interrupts vehicle flow by violating the signal.

Table 5 Critical Speed

Critical Vehicular Speed (KMPH)				
Mode	**2 Wheeler**	**3 Wheeler**	**4 Wheeler**	**ALL MODES**
2 Wheeler	14.0	10.9	12.0	11.4
3 Wheeler	13.3	9.8	11.5	11.3
4 Wheeler	12.3	10.3	9.0	11.4
ALL MODES	11.5	9.8	10.3	10.9

The Maximum critical speed is observed in between 2 Wheeler as 14 KMPH and Minimum in between 4 Wheeler as 9 KMPH. The critical speed of vehicles with pedestrian interaction is observed as 10.9 KMPH.

Without pedestrian interference at the intersection with the vehicles the speed is observed as 15.7 KMPH (Table 2) which is average speed of the intersection. But with pedestrian vehicular interaction is causing more delays for the vehicles. The speed is reduced to 10.9 KMPH (**30.9 % decreased**) from average intersection speed. This reduces overall performance of the intersection.

5. CONCLUSIONS

The maximum spatial gap was (accepted by pedestrians) observed between two wheeler (preceding vehicle) and four wheeler (succeeding vehicle) as 14.4 M. and the maximum spatial gap was (accepted by pedestrians) observed between two wheelers (preceding vehicle and also succeeding vehicle) as 9.3 M. The average spatial gap between all the modes is observed as 10.9 M. The maximum temporal gap was (accepted by pedestrians) observed between four wheeler (preceding vehicle) and three wheeler (succeeding vehicle) as 4.53 S. and the maximum spatial gap was (accepted by pedestrians) observed between two wheelers (preceding vehicle and also succeeding vehicle) as 2.39. The average temporal gap between all the modes is observed as 3.6 S. From this the critical speed is calculated accepted by the pedestrians to cross the road as 10.9 KMPH. The actual vehicular speed without pedestrian interaction is observed as 15.7 KMPH. The results also indicated that the non-compliance behavior of the pedestrians decreased the performance of the network speed by 30.9%. Thus, it is concluded that in designing of the intersections the pedestrian crossing behavior should be considered in designing of the intersections to optimize the overall efficiency of the intersections. This study explored the accepted critical gap pedestrians by categorizing pedestrian behaviors on an at-grade signalized intersection for only three intersections. The outputs of this study could be improvised further considering more similar category of intersections.

Limitations

This study also does not categorize the pedestrian behaviors based on age groups and gender profile which could be explored further to understand pedestrian's behavior at microscopic manner.

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