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Effect of Gap Acceptance Behavior of the Right Turning Vehicles on the Major Road Stream for Uncontrolled Three-Legged Intersections under Mixed Traffic Conditions

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ABSTRACT

Uncontrolled intersections are the intersections where there are no external signs or signals to control the movement of vehicles. In mixed traffic conditions priority rules are often violated by the road users. In all-way-stop-controlled intersections (AWSC), the vehicle should stop themselves before they enter the intersection and should check whether any vehicles are present in the other approaches of the intersection. If no vehicle is present, then they can cross the intersection. For this study, data were collected from two uncontrolled three-legged intersections located at various parts of India and critical gap required for each vehicle combination to cross the intersection are extracted. Gap Acceptance method is used for mixed traffic condition because it is based on the critical gap and follow-up time, which in turn depends on the type of vehicles and traffic conditions. This study tries to analyze the effect of vehicle type on gap acceptance behaviour at uncontrolled three-legged intersection. From this study, it is observed that size of the vehicles and traffic volumes has an influence on the critical gap. Depending on the major road vehicle type combinations, the critical gap for each right turning subject vehicle varied from minimum of 1.4 s to a maximum of 8.7s.

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1. INTRODUCTION

Traffic in India is heterogeneous in nature consisting of the slow and fast moving vehicles, where the size, speed and the operational characteristics of the vehicles are significantly different. Due to these variations, vehicles do not follow the lane discipline and occupy any lateral position on the road. Such behavior of the road users makes the capacity determination of uncontrolled intersection very difficult. Even though some of the works considered the influence of geometric [1] and control features [1, 2] on the quality of traffic service including the driver behavior [3], these works are valid for controlled intersections or high speed corridors. The uncontrolled intersection gives priority to major road movement, while the minor road drivers have to find suitable gaps between the vehicles plying on the major road in order to make their maneuvers. The speed of vehicles on the major road varies widely during lean hours, vehicles on the major road crosses the intersection at higher speeds and gap accepted to cross the stream on minor road tends to be higher. Similarly, at higher volumes of traffic, the vehicles on minor road tend to wait for longer time to cross the intersection. Longer waiting time will increase the probability of the vehicles to accept the shorter gap. Gap estimation is an integral part in capacity estimation of uncontrolled intersection. Gap acceptance procedure is used for mixed traffic condition because it is based on critical gap and follow-up time, which depends on driver's characteristics, vehicle characteristics, site characteristics and other factors which include time of the day.

2. LITERATURE REVIEW

Most of the researchers conducted gap acceptance studies for homogenous traffic conditions. However, performing gap studies for heterogeneous traffic

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conditions prevailing in India is very difficult especially in understanding the gap acceptance behavior of right turning vehicles. Studies conducted for homogeneous traffic conditions follow lane discipline and priority rule. For heterogeneous traffic conditions rule of priority is often violated. Small sized vehicles are most likely to accept the shorter available gaps causing delay to the major stream traffic. In order to clearly define the critical gap, the term gap is to be explained Gap is the time, in seconds, from the front bumper of the second of two successive vehicles to reach the starting point of the front bumper of the first [4]. Gap is also defined as the minimum time between successive major stream vehicles, in which minor stream vehicle can make a maneuver [5]. However, critical gap is an important parameter in understanding the gap acceptance behavior of the drivers [6]. Critical gap is defined as the minimum time difference between the arrivals of major street vehicle during which a minor street vehicle can make its entry into the intersection [5]. Recently, the term critical gap is replaced with critical headway and is defined as the minimum headway in the major traffic stream that will allow entry of one-minor street vehicle into the intersection [7]. Further, the critical gap does not vary with the change in the approaching vehicle speed [8]. However, conflicting traffic speed has a significant influence on the mean accepted gap [9]. Several critical gap methods are available for analyzing the gap acceptance behavior of drivers for right turning traffic from the minor road. The type of maneuver has a significant influence on the length of the gap being accepted by the drivers [4, 10]. Binary probit model was used in the literature to determine the driver gap acceptance probabilities [11]. Researchers also used Probit, Raff's and Bissel's methods to calculate the driver behavior at stop controlled intersections [12]. Similarly, probability equilibrium method based on the accepted and rejected gaps was used for calculation of the critical gap [13]. Few of the researchers used maximum likelihood method to determine the influence of various factors on the gap acceptance behavior of the drivers [14]. In the similar manner, binary logit model was used to estimate the probability of vehicles accepting or rejecting the available gap or lag [15]. Raff's method is the earliest method used for estimating the critical gap, which is simple and popular method and is widely used in several countries. Raff's method is based on macroscopic model that depends on the accepted and rejected gaps. According to Raff's method, a critical gap is the time at which the sum of the cumulative number of accepted gaps and rejected gaps is equal to 1 [16]. In the past, a group of researchers compared methods including lag, Harder's, logit, modified Raff's and Hewitt and observed a variation of 12 to 38%. Further, they proposed a new method using clearing behavior of vehicles in combination with gap acceptance data that resulted in accurate estimation of critical gap and entry capacity [6]. Similarly, a group of other researchers used Raff's, logit, lag, Ashworth's, and maximum likelihood methods to estimate the temporal and spatial critical gaps and observed a variation in these values ranging from 3 to 3.9 s and 29 to 36 m, respectively. They reported that these critical gaps are lower than those in the Highway Capacity Manual and other published literature. Based on these observations, they commented that "the drivers in India are more aggressive" [17]. Critical gap is a significant parameter that affects the delay and capacity of uncontrolled intersections. Different drivers display different critical gaps under different scenarios. Thus, the main objective of this study is to analyse the effect of vehicle type on gap acceptance behaviour of drivers at uncontrolled three-legged intersection under mixed traffic conditions.

3. STUDY AREA AND DATA COLLECTION

Two intersections located in two different parts of India were selected for the study and both the intersections were AWSC. Both the sites were three-legged intersections with four lane divided carriageway for the major road whereas the minor at the first site is a single carriageway with one lane in each direction and the minor road for the second site is four lanes divided with two lanes in each direction. The first intersection is located at Kozhikode city, in the south-western state of Kerala and the second intersection is located at Karimnagar city, in the south-central state of Telangana. Both the intersections are located in urban area with heavy vehicular traffic.

Videographic method was used to collect traffic data and geometrical factors including lane width and median width were measured. Traffic data including traffic volume, turning volume in each direction, gap accepted, rejected, and follow-up times were extracted by using video player. The data was collected for a period of four hours covering the morning peak (8.00 a.m. to 10.00 a.m.) and the evening peak (4:00 p.m. to 6.00 p.m.) during the weekdays. Table 1 shows the traffic volume corresponding to each directional movement for both the intersections.

TABLE 1. Traffic volume for each directional Movement at both the intersections (veh/h)

Leg of intersection	Kozhikode			Karimnagar		
	TH	RT	LT	TH	RT	LT
EB	4566	0	984	7500	0	891
WB	8261	837	0	6964	2168	0
SB	0	833	337	0	1463	929

4. METHODOLOGY, RESULTS AND DISCUSSION

Total traffic is divided into six categories: two-wheelers (2w), three-wheelers (3w), four-wheelers(4w) including cars and jeeps, Light Commercial Vehicles (LCV), Heavy Commercial Vehicles (HCV), and Buses. These six categories of vehicles plying on the major road can be grouped into 36 combinations. However, the combinations of vehicles observed at Kozhikode intersection are: 2w-2w, 2w-3w, 2w-4w, 2w-lcv, 2w-hcv, 2w-bus, 3w-2w, 3w-3w, 3w-4w, 3w-lcv, 4w-2w, 4w-3w, 4w-4w, 4w-lcv, 4w-hcv, lcv-2w, lcv-4w, bus-4w. Similarly, the combinations of vehicles observed at Karimnagar intersection are: 2w-2w, 2w-3w, 2w-4w, 2w-lcv, 2w-hcv, 2w-bus, 3w-2w, 3w-3w, 3w-4w, 3w-lcv, 3w-bus, 4w-2w, 4w-3w, 4w-4w, 4w-lcv, 4w-bus, lcv-2w, lcv-3w, lcv-4w, bus-2w, bus-3w, bus-4w, hcv-3w, hcv-4w.Previous studies reported that satisfactory results can be obtained using maximum likelihood method, probability equilibrium method and Raff's method [18]. However, when compared to other two methods, Raff's method is considered simpler. Thus, in this study, critical gap of each right turning vehicle is determined using Raff's method. The accepted and rejected gaps are sorted by 0.1 s interval. For every 0.1 s interval, gaps accepted and gaps rejected were tabulated. Later, critical gap of each vehicle is determined using cumulative percentage of gap accepted and rejected for each 0.1 s interval.By using Raff's method, the critical gap of each vehicle type accepting the major road gap for different combinations is determined. The critical gap values of each vehicle type at each intersection are shown in Figures 1 to 16. These figures show the critical gap values for right turning of minor stream vehicles and major stream vehicles separately. These radar plots are generated for intersections in both the cities by considering the observed major stream vehicle combinations and the resulting gap acceptance behaviour of each type of right turning vehicle from the minor road (Figures 1 to 3 for Kozhikode intersection and Figures 8 to 11 for Karimnagar intersection). In all these radar plots, each radial line represents a major stream vehicle type combination and the scale represents the critical gap in seconds.Similarly, radar plots are generated for intersections in both the cities by considering the observed major stream vehicle combinations and the resulting gap acceptance behaviour of each type of right turning vehicle from the major road (Figures 4 to 7 for Kozhikode intersection and Figures 12 to 16 for Karimnagar intersection). For example, as shown in Figure 1, when the subject vehicle is 2w approaching towards the intersection from the minor road and turning right onto the major road, the critical gap for 2w-2w combination on major stream is observed as 2.6 s, and the critical gap for 4w-lcv is 7s. Similarly, the critical gap of each vehicle taking right turn from minor road with respect to major stream combinations and major stream right turn vehicles with respect to major stream through vehicles combinations are calculated. The critical gaps obtained from both the intersections are compared. The variation of the critical gap for each combination of major stream vehicle is analyzed.

At Kozhikode intersection, 2w, 3w, 4w and LCV are the subject vehicles accepting the gaps for different combinations in the major stream vehicles.

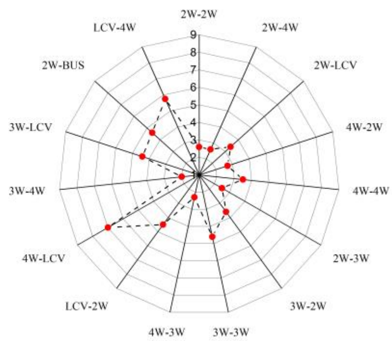

Figure 1. Critical gap in seconds for 2w in minor leg of Kozhikode intersection

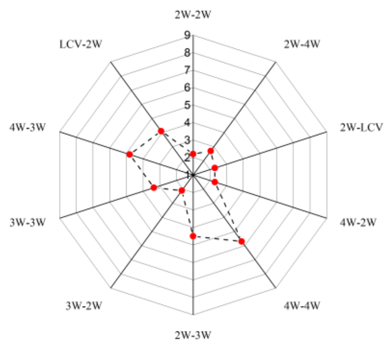

Figure 2. Critical gap in seconds for 3w in minor leg of Kozhikode intersection

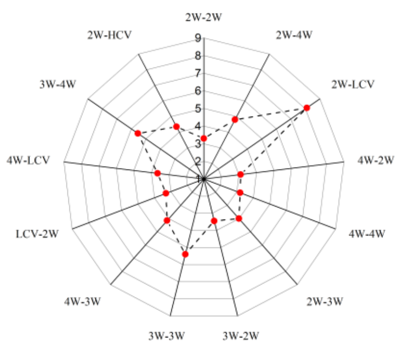

Figure 3. Critical gap in seconds for 4w in minor leg of Kozhikode intersection

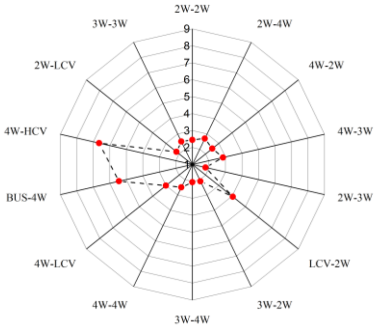

Figure 4. Critical gap in seconds for 2w in major leg of Kozhikode intersection

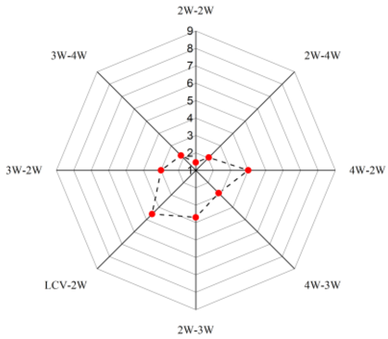

Figure 5. Critical gap in seconds for 3w in major leg of Kozhikode intersection

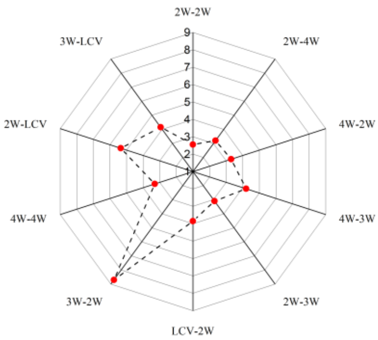

Figure 6. Critical gap in seconds for 4w in major leg of Kozhikode intersection

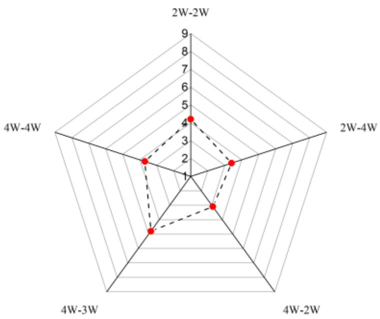

Figure 7. Critical gap in seconds for LCV in major leg of Kozhikode intersection

From the above figures (Figures 1 to 7), it is observed that for 2w and 3w as the subject vehicle type with different major stream combinations consisting of 2w, 3w, 4w as either lead or following vehicle are shown less critical gap values because smaller sized vehicles are forced to accept the available gap in the major stream as compared to other vehicle combinations consisting of LCV, HCV and buses as the lead or the following vehicle types.

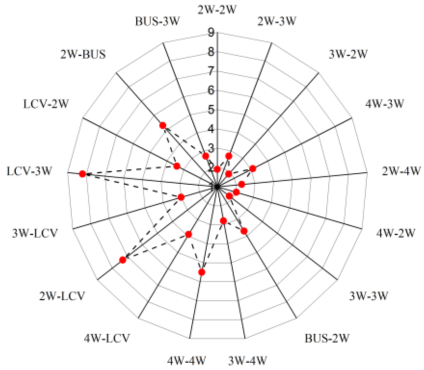

Figure 8. Critical gap in seconds for 2w in minor leg of Karimnagar intersection

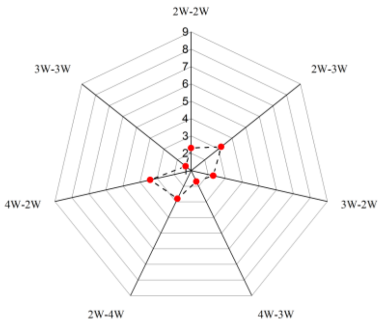

Figure 9. Critical gap in seconds for 3w in minor leg of Karimnagar intersection

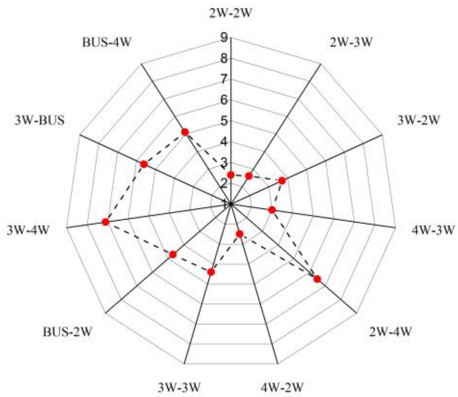

Figure 10. Critical gap in seconds for 4w in minor leg of Karimnagar intersection

It is also observed that irrespective of subject vehicle, the combination with LCV as the leading vehicle or following vehicle are shown in the higher critical gap values. When 4w is the following vehicle, that combination also shows higher critical gap. Due to lower acceleration characteristics of LCV, the critical gap values are observed to be higher. Similar observation can be made for other larger vehicles including HCV and Buses.

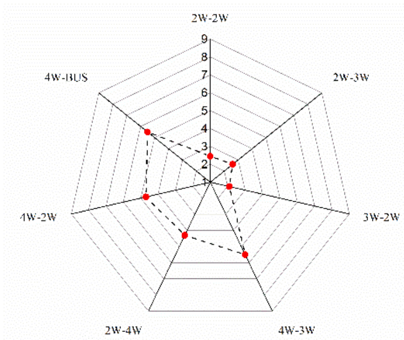

Figure 11. Critical gap in seconds for LCV in minor leg of Karimnagar intersection

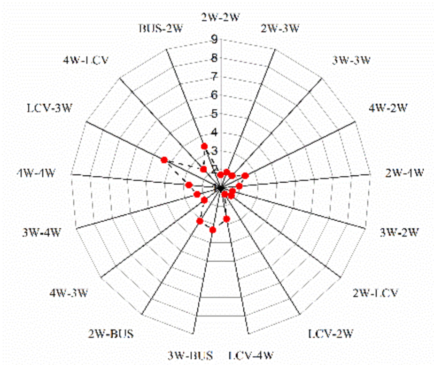

Figure 12. Critical gap in seconds for 2w in major leg of Karimnagar intersection

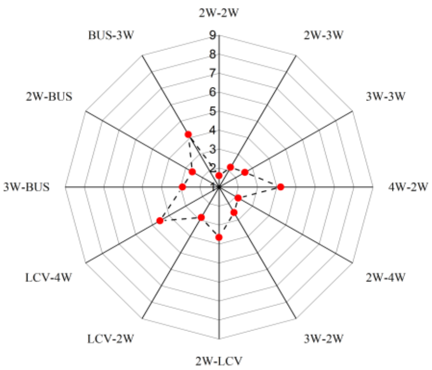

Figure 13. Critical gap in seconds for 3w in major leg of Karimnagar intersection

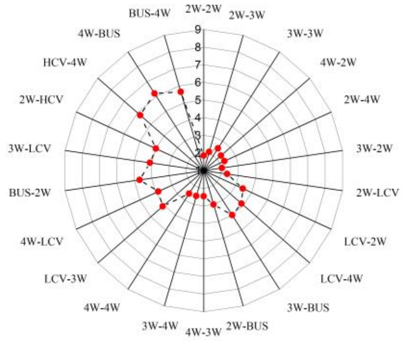

Figure 14. Critical gapin seconds for 4w in major leg of Karimnagar intersection

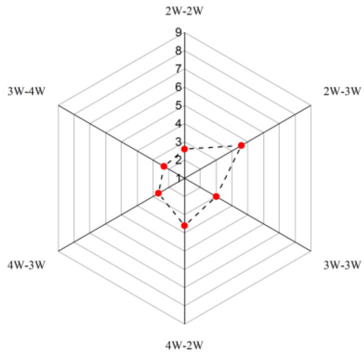

Figure 15. Critical gapin seconds for BUS in major leg of Karimnagar intersection

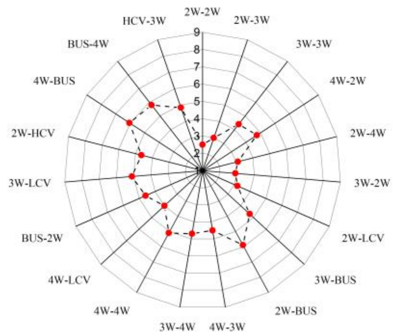

Figure 16. Critical gap in secondsfor HCV in major leg of Karimnagar intersection

At Karimnagar intersection, 2w, 3w, 4w, LCV, HCV and Buses are the subject vehicles accepting the gaps for different combinations in the major stream vehicles. The presence of different sized vehicles adversely affects the performance of the intersection. Larger vehicles require more time to manoeuvre because of lower acceleration and speed capabilitieswhereas2w and 3w utilize smaller gaps available in the traffic stream. It is important to note that even though the gap acceptance depends very much on the dimensional and performance characteristics of the subject vehicle, the driver behaviour also plays a significant role in accepting or rejecting the gap. The critical gap analysis was performed for each right turning vehicle for both the minor and the major roads. The critical gap is more for LCV, HCV and Bus as the subject vehicles, which shows that the presence of large sized vehicles in the minor stream will lead to reduction in the capacity of the intersection.

From the above figures (Figures 8 to 16), it is observed that irrespective of subject vehicle, the combination with large vehicle size irrespective of whether it is a leading vehicle or a following vehicle are shown higher critical gaps.

For Kozhikode intersection, the critical gap for the minor road right turning traffic varies between 2 to 8.1 s with major road combinations. Whereas, the critical gap for the major road right turning traffic varies between 1.45 to 8.7 s with major road combinations. Similarly, for Karimnagar intersection, critical gap for the minor and major road right turning traffic varies between 1.4 to 8.2 s and 1.4 to 6.2 s. Further, 2w-2w, 2w-3w, 3w-2w, 3w-3w combinations resulted in less critical gaps when compared with other vehicle combinations. However, the critical gap for different vehicle combinations for Kozhikod eand Karimnagar intersection varies between 1.45 to 8.7 s and 1.4 to 8.2s, respectively.

5. CONCLUSIONS

For each type of right turning vehicles in the minor road, gaps accepted and gaps rejected by the major road vehicle combinations are calculated. Similarly, the accepted and rejected gaps are calculated for each type of right turning vehicles in the major road and the critical gap for each vehicle with different combinations is calculated. It is observed that the critical gap of the subject vehicle taking right turn depends on the vehicle type of the major stream combination. Gap acceptance has been shown to vary with the conflicting vehicle type. If the size of the major stream vehicles is small, such as 2W and 3W, then the subject vehicle tries to accept shorter gaps. For example, the subject vehicle is accepting shorter gap in between 2w-2w, 2w-3w, and 3w-2w combinations, and accepting higher gaps in the combinations having large sized vehicles including buses and HCVs. If the following vehicle size is small in the major traffic stream, the subject vehicle is more likely to accept the gap. The combinations of the major stream vehicle depend on the gap accepting behavior of the right turning vehicles. For the conflicting major stream combination having large sized vehicles like buses or HCVs, the critical gap value is higher compared to other small sized vehicle type combinations. If the conflicting major stream vehicle is 2w, then the subject vehicles are more likely to accept shorter gaps.

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چکیده

تقاطع های کنترل نشده تقاطع هایی هستند که در آن نشانه های خارجی یا سیگنال هایی برای کنترل حرکت وسایل نقلیه وجود ندارد. در شرایط ترافیکی مرکب، قوانین اولویت اغلب توسط کاربران جاده ای نقض می شوند. در تقاطع های متقاطع توقف (AWSC)، خودرو باید قبل از ورود به تقاطع، خود را متوقف کند و باید در سایر روش های تقاطع نقشی داشته باشد. اگر هیچ وسیله نقلیه در تقاطع وجود نداشته باشد، آنها می توانند از تقاطع عبور کنند. برای این مطالعه، داده ها از دو تقاطع مستطیلی کنترل نشده سه ناحیه در نقاط مختلف هند جمع آوری شده و شکاف بحرانی مورد نیاز برای هر وسیله نقلیه برای عبور از تقاطع استخراج می شود. روش پذیرش گاف برای شرایط ترافیکی مخلوط استفاده می شود، زیرا بر اساس شکاف انتقادی و زمان پیگیری است که به نوبه خود به نوع وسایل نقلیه و شرایط ترافیک بستگی دارد. در این تحقیق سعی شده تا اثر نوع خودرو بر رفتار پذیرش شکاف در تقاطع بی نظیر سه پا بررسی شود. از این مطالعه مشاهده می شود که اندازه وسایل نقلیه و حجم ترافیک بر شکاف بحرانی اثر می گذارد. بسته به ترکیبات نوع وسیله نقلیه جاده ای، شکاف بحرانی برای هر وسیله نقلیه سوار سوئیچ راست از حداقل 1.4 ثانیه به حداکثر 8.7 ثانیه متغیر است.

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