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Modelling Merging Behaviour of Drivers in Heterogeneous Traffic at Roundabouts

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Abstract

Roundabouts are among the widely used traffic control infrastructures, which function by defining priorities for various entry approaches and circulating traffic. In many developing countries, the priority rules are not implemented through pavement markings or road signs and drivers are also unaware of these rules. Thus, available gaps become the only criteria for merging and movement of vehicles through the roundabout. It has been observed that the gap acceptance behaviour of drivers also depends on the type of vehicle in heterogeneous traffic streams. The main objective of this study is to investigate the difference in gap acceptance behaviour of motorcycle riders and car drivers at roundabouts. The gaps accepted by car drivers and motorcycle riders under different traffic conditions are measured from the recorded video of the traffic stream at a selected roundabout using an unmanned aerial vehicle. The critical gap is estimated using Raff's method and its relationship with circulatory volume and approach speed is analysed. The results show that the critical gap for motorcycles (2.46 seconds) is 23.3% smaller than the critical gap for cars (3.21 seconds). Motorcycles can move through smaller gaps in comparison with cars due to their size and ease of manoeuvring. Results also show that motorcycles tend to merge with greater approach speed as the available gap within the circulating vehicles reduces, whereas the cars are observed following an opposite trend.

Keywords: Raff's method, Roundabout, Speed, Volume, Critical Gap, Motorcycle, Cars.

1. Introduction

Roundabouts are considered one of the efficient and safe provisions to control conflicting movements of traffic. Roundabouts are widely implemented as transportation infrastructure which facilitates drivers with more capacity and minimum delay by providing efficient traffic movement as compared to other unsignalized intersections (Sandaruwan et al., 2019). Numerous research studies indicate that roundabouts successfully reduce both the frequency and severity of crashes (Persaud et al., 2001). Roundabouts operate on the principle of approaching vehicles yielding to vehicles present in the roundabout and circulating the central island. The vehicles in a roundabout always move in a single direction that is either clockwise or anticlockwise.

In many developing countries, traffic flow exhibits significant heterogeneity due to the diverse static and dynamic attributes of vehicles. Consequently, there is a lack of discipline when it comes to following lanes, and vehicles tend to move freely across the entire width of the road, depending on the availability of space. This creates complexity in the interaction of vehicles at uncontrolled intersections including roundabouts (Ashalatha & Chandra, 2011). At un-signalized intersections, drivers are assumed to wait until they find a safe gap to enter the intersection area. Within the traffic stream, multiple gaps are available for drivers to choose from. When a driver intends to enter the intersection area, they must skilfully navigate and merge into the conflicting stream of traffic, ensuring a smooth and coordinated movement. The decision of whether to merge into the traffic stream is contingent upon the individual driver's behaviour.

There is a discrepancy in the literature regarding the definition of a gap. Ashworth and Green (1966) describes a gap as the distance between the backend of one vehicle and the forefront of the subsequent vehicle following it. Adebisi (1982) provided definition of a gap as the total available major stream headway that a waiting vehicle has from the minor road. According to Polus (1983), a gap is the time interval that exists between two consecutive vehicles within the major road stream. Adebisi (1982) and Solberg and Oppenlander (1966) introduced another terminology called "lag" which is the temporal gap between a vehicle's arrival at the stop line on a minor road and the arrival of the first vehicle on the major road at a location directly across from this line.

The concept of critical gap plays a crucial role in determining gap acceptance behaviour. This parameter represents the smallest gap a driver will accept when merging into a conflicting stream. Due to the influence of factors such as individual driver characteristics, time of day, and traffic conditions, measuring the critical gap directly in the field poses a challenge. As a consequence, several models and techniques have been developed to estimate this parameter, each with its own set of advantages and limitations and based on various assumptions. While some models are empirical, others have a more robust theoretical basis.

With time, numerous authors have modified the definition of a critical gap. Greensheild was among those who made an early contribution to defining the concept of a critical gap. According to the Greensheild method, the accepted gaps and rejected gaps were plotted on the positive y-axis and negative y-axis, respectively. The critical gap was identified as the gap size that had an equal number of accepted gaps and rejected gaps. In cases where there was no equal number of accepted and rejected gaps, the critical gap was determined as the gap with the minimum difference. According to Raff (1950), the number of gaps that are rejected and exceed the critical gap is equal to the number of gaps that are accepted and are shorter than the critical gap. HCM (1985) defined critical gap as the median time headway between two successive vehicles in the major street traffic stream that is accepted by a driver in a subject movement who intends to cross or merge with the major street flow. The 1985 edition of the Highway Capacity Manual (HCM) defines the critical gap as the median time interval between two consecutive vehicles on a major road that is considered acceptable for a vehicle on a minor road to merge. HCM 2000 introduced slight modifications to the definition of a critical gap by defining it as the minimum temporal interval between two successive vehicles on a major road, allowing a vehicle from a minor road to safely merge into the flow.

Estimating critical gaps in heterogeneous and undisciplined traffic streams is more intricate than in standard traffic streams. In many developing countries, there is a diverse range of vehicles with distinct operating functionality, including speed, manoeuvrability, dimensions (length and width), acceleration, braking and their responses when encountering other vehicles in traffic. The lack of physical segregation on the roadway for these vehicles makes the gap acceptance process complex due to various factors like lack of lane discipline, complex queue formation, non-adherence to the rule of priority of movements, absence of proper lane marking, and substantial speed variation among vehicle types (Ashalatha & Chandra, 2011). The combined effect of these factors poses a significant challenge in estimating critical gaps in such scenarios.

Over the past forty years, there have been many studies on gap acceptance, although most of these are limited to the traffic scenarios characterized by uniformity and consistency. Numerous methodologies have been devised to ascertain the critical gap with utmost precision, often relying on the utilization of accepted and rejected gaps as fundamental elements in the estimation process. Serag (2015) states that Raff's and Greenshield's methods are prominent instances of deterministic approaches used to estimate critical gaps. Some researchers have employed the Maximum Likelihood Estimation technique as an alternative method to estimate critical gaps at two-way stop-controlled intersections (Troutbeck, 2016). Numerous studies have been conducted to evaluate and enhance the gap acceptance models created by Gattis and Low (1999), Fitzpatrick (1991), Guo et al. (2014), Brilon et al. (1999) and Ma and Zhao (2020).

In their study, Brilon et al. (1999) found that the maximum likelihood estimation technique and Hewitt's method provided the most accurate estimates of critical gaps. In contrast, Siegloch's method was found to be applicable exclusively in situations of extensive traffic congestion. They also noted that Harders's method had a tendency to overstate the assessed extent of critical gaps. However, according to Gattis and Low (1999), Raff's method resulted in lower values of critical gaps in contrast to probit, Greenshield's, and Siegloch's methods, whereas the logit method yielded higher estimations. In contrast, Fitzpatrick (1991) found that the logit method produced more accurate estimates of critical gap values based on a study that evaluated gap acceptance values using three methods: Greenshield, Raff, and logit. A study conducted by Ma and Zhao (2020) to examine the gap acceptance behaviour at 14 two-way stop-controlled intersections in China revealed that both Raff's and the maximum likelihood methods yielded almost the same critical gap values, with no noticeable disparities. This suggests that these two methods can be used interchangeably in estimating critical gaps at such intersections. Gattis and Low (1999) has introduced two innovative techniques for assessing critical gaps. These methods rely on the fundamental principles established by Raff, providing a solid foundation for their functionality. The first method involved plotting the exponential distribution of headways against the rejected gaps. In the second method, known as the revised Raff's method, the critical gap was obtained by considering both accepted and rejected gaps. When comparing these methods to Ashworth's method, it was observed that the latter had more stringent requirements. Ashworth's method necessitated strict adherence to the assumption of a normal distribution for both critical gaps and accepted values. In contrast, the newly developed methods offered more flexibility in their application and did not rely heavily on the normal distribution assumption. This made them more suitable for a wider range of scenarios and increased their practicality in gap evaluation studies (Guo et al., 2014). However, the deterministic approach, specifically Raff's method, continued to be the prevailing choice in numerous studies investigating gap acceptance. This can be attributed to its straightforwardness and real-world applicability, which have made it a widely adopted technique across various locations. Its simplicity and practicality have contributed to its enduring popularity in the field of gap acceptance research Troutbeck (2016), Guo et al. (2014), Gattis and Low (1999) and Ma and Zhao (2020).

Similar to the cities of other developing countries, Karachi's urban landscape presents a diverse and heterogeneous traffic composition, characterized by a lack of adherence to lane discipline and an absence of organized vehicular movements within designated lanes. The traffic in Karachi comprises a larger proportion of motorcycles and cars. The primary agenda of this research is to analyse the merging pattern of motorcycles and cars under heterogeneous traffic flow at a roundabout and examine the difference in their microscopic characteristics such as merging speed, gap acceptance and gap rejection. These parameters were extracted for both types of vehicles from the video of the traffic stream recorded using an unmanned aerial vehicle (UAV). Utilizing the method introduced by Raff, critical gaps for cars and motorcycles were evaluated from these microscopic parameters.

This study helps understand the gap acceptance behaviour of car drivers and motorbike riders in heterogeneous and undisciplined traffic streams. As the traffic in Karachi city is dominated by motorcycles and cars in comparison to other vehicles, this study is focused on merging the behaviour of these two types of vehicles. Furthermore, the effect of average merging speed and circulatory volume on gap acceptance was analysed for the two types of vehicles. The main contribution of this study is to highlight the significant difference in the behaviour of motorbike riders which constitute more than 50% of the traffic stream in various developing countries.

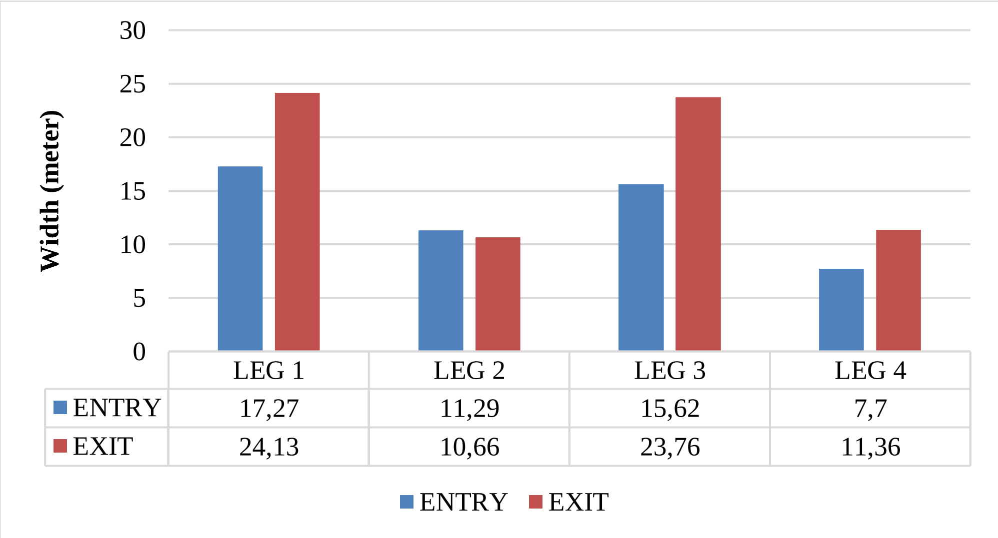
2. Methodology

2.1 Study area

The fundamental parameters for this research were collected at an un-signalized roundabout known as Powerhouse Roundabout in Karachi City located in the extreme southern part of Pakistan. This roundabout has four legs. Each leg has one entry and one exit, as shown in Figure 1. The length of the inscribed circle diameter and circulatory roadway width are 64 m and 16.5 m, respectively. Other geometric parameters of the roundabout have been mentioned in Figure 2. The lane markings on the roads surrounding the Powerhouse Roundabout, as well as near its entry and exit points, are insufficient, leading to unrestricted merging of vehicles into the circulating traffic.

Video of traffic at the roundabout was recorded during the peak evening hour (5:30 PM to 6:30 PM) on 26th January 2022 by using the DJI's UAV Phantom-4 Professional V2.0. UAVs have recently been included in the acquisition of offline and real-time traffic data and have been extensively utilized to observe traffic networks. The entire area of the roundabout (measuring 228.8 m x 112 m) was captured within the field of vision of the UAV. Throughout the recording process, the UAV maintained a steady altitude of 250 m above ground level, employing the auto-adjust location function to remain stationary directly above the roundabout's centre. To ensure an optimal level of detail, the videos were captured in 4K ultra-high-definition resolution, boasting a pixel count of 4096 x 2160.

Figure 1: Aeriel view of Powerhouse Roundabout captured using the UAV



	LEG 1	LEG 2	LEG 3	LEG 4
ENTRY	17,27	11,29	15,62	7,7
EXIT	24,13	10,66	23,76	11,36

Figure 2: Geometric parameters of the roundabout under study

2.2 Extraction of traffic flow

Classified traffic volumes were extracted manually at each leg of the roundabout. The entering traffic was counted in seven selected modes, including cars, motorcycles, rickshaws, trucks, buses, minibuses and loading pickups. The videos made from the drone were played on the computer, and an application named 'KeyCounter' was run simultaneously. This application records the number of keystrokes made for each vehicle that passed a predetermined point on each leg. The total number of keystrokes recorded represented the total number of vehicles of each type for each leg. In this manner, the classified counts were obtained for all legs of the roundabout. The counts of seven vehicle types were converted into passenger car units (PCUs) by using the passenger car equivalent (PCE) factors estimated for local traffic (Ahmed et al., 2022). These PCE factors were as follows: 1 for cars, 0.25 for motorcycles, 0.5 for rickshaws, 1.5 for pickups, 2 for minibuses, 2.5 for buses, and 3 for trucks.

2.3 Average speed

The average speed of two major selected modes (i.e., motorcycles and cars) was determined by measuring the time taken by the vehicle to travel across the specific segment just before entry to the roundabout. To capture the prevalent traffic dynamics of motorcycles and cars, a sampling of five motorbikes and two cars per minute was selected for speed assessment, which is according to their proportion in the traffic mix at the selected roundabout. Throughout the recorded video, the average speeds of motorcycles and cars were calculated on a per-minute basis.

2.4 Gap estimation

A gap is a spatial or temporal opening within the continuous flow of vehicles, which allows an entering vehicle to seize an opportunity for integration. When the driver of an approaching vehicle declines to merge with the circulating flow, the gap is termed a "rejected gap". Conversely, when the driver perceives it as secure to merge, the gap is referred to as an "acceptable gap" (Shaaban & Hamad, 2018). In order to determine the critical gap for motorcycles and cars, the gaps that were accepted and rejected by motorcycles and cars for each approach were retrieved from the video. The gaps which were linked to the interaction of cars and motorcycles were considered only. That is the gap accepted or rejected for the merging manoeuvre between bike and car, car and bike, bike and bike, and car and car.

2.5 Estimating critical gap using Raff's method

This method is widely employed in numerous countries to estimate the critical gap due to its ease of use (Gavulová, 2012).This approach is alternatively known as the graphical method (Gazzarri et al., 2012). The method is based on constructing both a gap acceptance graph and a gap rejection graph, which together allow for the determination of the critical gap. Two cumulative curves are created by plotting the number of acceptances and rejections versus the gap size. The acceptance curve is created by plotting the cumulative values of the gaps accepted. The rejection curve is created by plotting the reverse cumulative values of the gaps rejected. The point where the acceptance curve coincides with the rejection curve provides the critical gap (Guo et al., 2014; Leong et al., 2019; Troutbeck, 2016). Alternatively, Equation 1 can be utilized to determine the critical gap (Guo et al., 2014; Ma & Zhao, 2019).

$$F_a = 1 - F_r \quad (1)$$

Here, "F_a" represents the cumulative probability function of the accepted gap, while "F_r" represents the cumulative probability function of the rejected gap.

3. Results and discussion

3.1 Entry Volume

Analysis of the volume data indicates that motorcycles constitute about three-fourths of the traffic mix, which is 76%, during the time the data was collected. Figure 3 provides additional details illustrating the distribution of various modes within the traffic flow, expressed as percentages. It is to be noted that the percentage of cars at the selected roundabout is comparatively lower than other places in the city. This is due to the reason that the selected roundabout is located in a comparatively lower-income area where the motorbike is the main mode of transport. Furthermore, three-wheelers which include rickshaws and chinchis are popular alternative modes of public transport. The distribution of traffic at each leg for vehicle type is shown in Table 1. Leg 1 and Leg 4 contribute a significant proportion of the traffic, which is 4001 PCU/hr and 2823 PCU/hr respectively, as these legs are along the major arterial road of the city, whereas Leg 2 and Leg 3 are along the minor intersecting road. Leg 3 exhibits a smaller portion of the traffic stream (i.e., 1484 PCU/hr) than the other legs, whereas Leg 2 possesses a slightly higher portion of the traffic stream (i.e., 1542 PCU/hr) than Leg 3 with greater numbers of pickup vans.

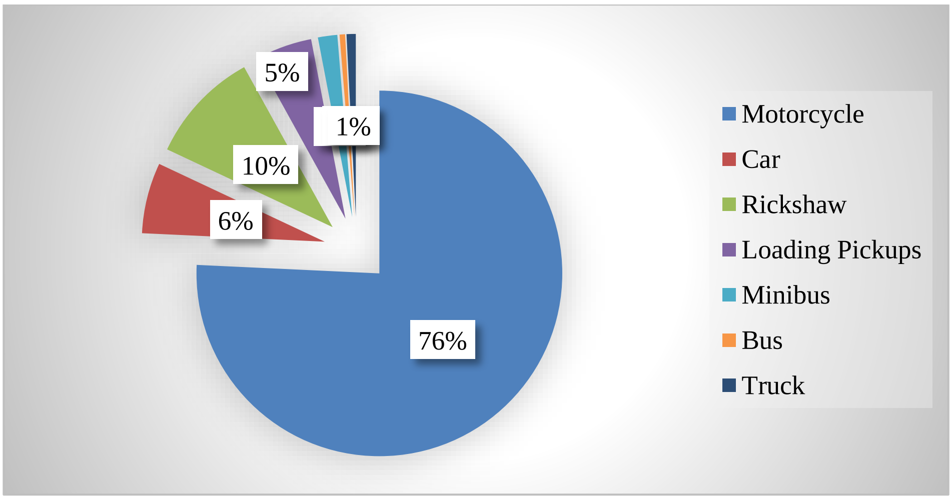


Figure 3: Percentage of the selected modes in the traffic mix

TABLE 1: Volume of traffic at each leg with vehicle types

Vehicle Type	*Leg 1*	*Leg 2*	*Leg 3*	*Leg 4*
Motorcycles	8060	1463	2708	4427
Cars	655	214	170	336
Rickshaws	832	241	319	800
Loading Pickups	268	315	171	352
Minibus	131	108	40	97
Bus	73	11	6	17
Truck	131	108	40	97

3.2 Speed

Speed is considered one of the best indicators to understand the traffic flow characteristics and behaviour of individual drivers. Vehicles that possess more manoeuvrability can achieve higher speeds as compared to the ones with less manoeuvring capabilities. It was found that the merging speed of motorcycles was greater as compared to cars on all the legs. It was further observed that the legs with greater volumes of motorcycles and cars exhibit smaller differences within the speeds of these two types of vehicles as compared to the legs with smaller volumes as shown in Table 2. Excessive speed is recognized as a primary contributor to motorcycle accidents. In some cases, speed may not be the primary factor leading to an accident, but other factors such as the driver reacting too late on the mistake of another road user or another unexpected event might be the cause. However, speed is mostly suspected as the primary factor resulting in an accident. Speed not only escalates the likelihood of encountering an accident but also exacerbates the repercussions that ensue (Elvik, 2014). Unlike other modes of transport, motorcycle riders exhibit assertive driving behaviour within the traffic stream. Motorbike riders have a higher propensity for accidents because of their aggressive behaviour in preserving longitudinal and lateral spacing and changing lanes (Ahmed et al., 2021).

Based on the accident data compiled by Karachi's Road Traffic Injury Research & Prevention Centre (RTIRPC) spanning from 2007 to 2015, motorbike riders constituted 61% of the overall 298,654 reported injuries within this timeframe (Jooma & Shaikh, 2016, 2017). This was demonstrated in the study conducted by Temmerman and Roynard (2016), which highlighted that motorcyclists exhibit a more prevalent issue with excessive speed compared to car drivers. Consequently, motorcyclists are disproportionately represented among the casualties resulting from traffic incidents. In our area of study, the heterogeneous behaviour of motorcyclists was observed while manoeuvring within circulatory flow at each separate leg. Most of the motorcyclists were involved in force merging and were not following lane discipline. The speed difference between the motorcycle and the car is between 30% and 40% at each leg. Four-wheeled or three-wheeled vehicles possess lesser manoeuvrability as compared to motorcycles, therefore, they tend to merge at a slower speed comparatively. This is evident from the difference in speed between the cars and the motorcycles, as shown in Table 2. It was also observed that car drivers behaved quite non-aggressively when merging. Although the speeds of both motorcycles and cars were different at each separate leg, both were significantly dependent upon the geometry and adjacent land use of the immediate leg.

TABLE 2: Average entry speeds of cars and motorbikes

Legs	*Average Entry Speed (Km/Hr)*		*Variation (%)*
	Motorbike	*Car*	
Leg 1	*15.64*	*10.67*	*31.77 %*
Leg 2	*20.80*	*13.48*	*35.19 %*
Leg 3	*32*	*19.69*	*38.46 %*
Leg 4	*17.79*	*12.10*	*31.98 %*

3.3 *Estimation of critical gaps*

The critical gap serves as the primary parameter for gap acceptance, characterizing the interrelation between the merging flow and circulating flow at roundabouts (Giuffrè et al., 2016). It refers to the specific magnitude of a gap that a driver would willingly accept if it were larger while rejecting it if it were smaller. The accepted gap has conventionally been employed as the critical gap in determining roundabout capacity according to the Highway Capacity Manual, but it would be unjustifiable to disregard the importance of the rejected gap (Fitzpatrick et al., 2013). Consequently, Raff's Method has been utilized to determine the critical gap for motorcycles and cars.

After the extraction of data from the video, it was determined that there were 327 accepted gaps and 181 rejected gaps for motorcycles. Similarly, for cars, the data revealed a total of 224 accepted gaps and 144 rejected gaps, as illustrated in Table 3. It was observed that both motorcycles and cars accepted gaps greater than 6 sec, therefore, such gaps were not taken into account.

TABLE 3: Frequency of accepted and rejected gaps for each gap magnitude by motorcycles and cars.

Gap (s)	*Motorcycle*		*Car*	
	Number of accepted gaps	*Number of rejected gaps*	*Number of accepted gaps*	*Number of rejected gaps*
0	0	0	0	0
0.5	0	0	0	0
1	7	22	0	16
1.5	37	64	5	36
2	73	51	21	47
2.5	62	28	36	16
3	60	6	46	23
3.5	33	4	41	5
4	23	2	20	1
4.5	19	4	16	0
5	5	0	17	0
5.5	3	0	13	0
6	5	0	9	0
Total	327	181	224	144

Critical gap value has been obtained using Raff's method. The cumulative values of accepted gaps and reverse cumulative values of rejected gaps are plotted in Figure 3 and Figure 4 for motorcycles and cars respectively. The critical gap was obtained at the intersection of the gap acceptance curve and gap rejection curve. The critical gap for motorcycles was found to be 2.46 seconds, as shown in Figure 4. The majority of motorbike riders (55%) accept the gap when the available gap is 2.5 seconds or less. whereas only 28% of car drivers accept the gap when it is 2.5 seconds or less. Only 2% of motorbike riders accept the gap when it is 1 second or less. About 75% of motorbike riders reject gaps of 2 or less than 2 seconds. Because of the driver's behaviour and the dimensions of the vehicle, the gap acceptance behaviour of a car differs significantly from that of a motorcycle. The critical gap of the car was found to be 3.21 sec as shown in Figure 5.

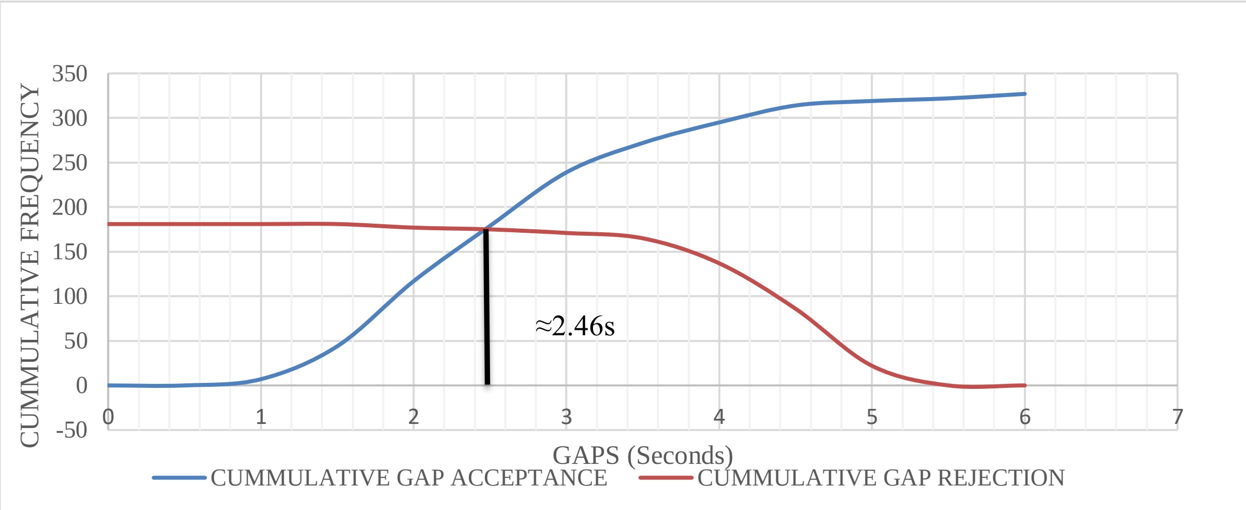


Figure 4: Critical gap estimation for motorcycles using Raff's method

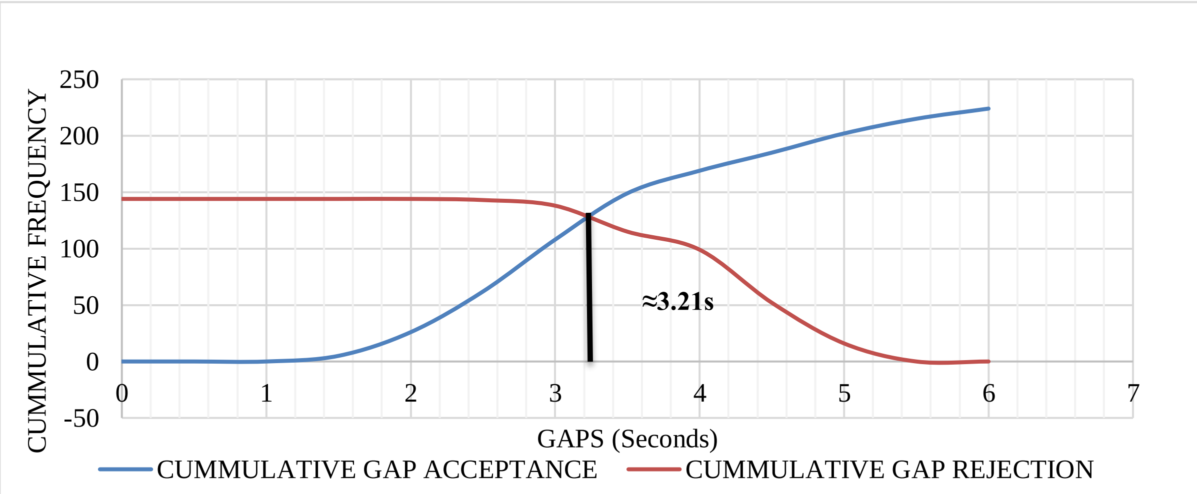


Figure 5: Critical gap estimation for cars using Raff's method

3.4 Comparison of estimated critical gap values of motorcycles and cars with other studies

It is worth noting that the critical gap values determined for motorcycles and cars in this study are considerably higher than the values reported for heterogeneous traffic and lower than the values for standard traffic. This could be because, in standard traffic streams, the drivers wait at the yield sign for the appropriate gaps before making the manoeuvre. The critical gap values reported by Fajaruddin Mustakim (2021), Xu and Tian (2008), Kyte et al. (2006) and HCM (2010) are significantly higher as compared to the values found in this study because the traffic on the roads of Malaysia, the US and Germany is more disciplined. The values of critical gaps reported by Mwesige and Tindiwensi (2011), Ahmad and Rastogi , Ahmad et al. (2015) for Indian traffic are slightly lower than the values estimated in this research. Table 5 compares the estimated values of the critical gap with the values of the critical gap reported in the literature.

TABLE 5: Comparison of The Estimated Values of Critical Gap with Previous Studies

Author	Location	Traffic Type	Critical Gap	
			Motorcycle	**Car**
(Mwesige & Tindiwensi, 2011)	Uganda	Heterogeneous mix traffic	2.67 s	----
(Ahmad & Rastogi)	India	Heterogeneous mix traffic	1.65 s	2.32 s
(Ahmad et al., 2015)	India	Heterogeneous mix traffic	1.60 s	2.10 s
(Xu & Tian, 2008)	US (California)	Homogenous traffic	-----	4.80 s
(HCM, 2010)	US	Homogenous traffic	-----	4.11-5.19 s
(Kyte et al., 2006)	Germany	Homogenous traffic	-----	4.40 s
(Fajaruddin Mustakim, 2021)	Malaysia	Homogeneous traffic (Un-signalized Intersection)	4.75 s	5.90 s
This research	Karachi City, Pakistan	Heterogeneous mix traffic	2.46 s	3.21 s

3.5 Effect of circulatory volume on gap acceptance

After extracting all necessary data (circulating flow, gap acceptance, and entry speed), the statistical analysis using linear regression was performed to study the effect of traffic flow parameters on the merging behaviour of motorcycles and cars. Figure 6 depicts the relationship between the accepted gaps of the motorcycle and the circulatory flow at each leg. A strong relationship between these two parameters was found in which the average of the gaps accepted by the motorcycle at each leg was plotted against the circulatory flow of the respective leg. When the circulatory flow increases, the accepted gap by motorcycle decreases. This indicates that as the circulatory flow increases, the size of the gap between two conflicting vehicles decreases, and motorcyclists tend to take what is available in front of them, even if the available gap size is smaller than what they desire. A similar study was conducted by (Azhari et al., 2020) and (Macioszek, 2020) in which alike results were found. The R-squared value for the relation between the accepted gaps of the motorcycle and the circulatory flow was found to be 0.9172 thus showing a significant connection. Contrary to this, a direct relation is found between the gap acceptance of cars and circulating traffic volume. This could be because of the cautious behaviour of the drivers toward their cars. This implies that drivers tend to wait until they feel the gap is big enough before merging into it. The R-squared value for the relation between the accepted gaps of cars and the circulatory flow was found to be 0.615 as shown in Figure 7.

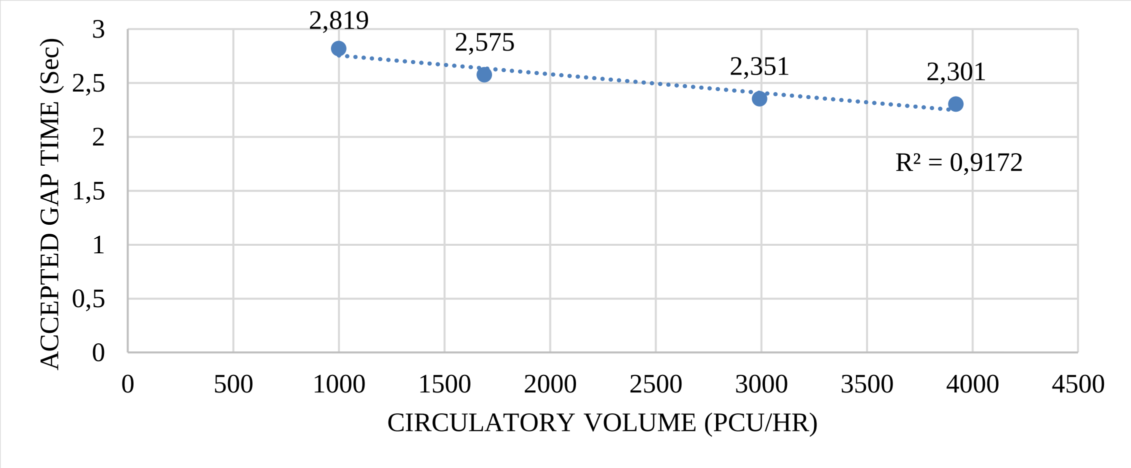


Figure 6: Relationship between accepted gap by motorbike riders and circulating volume

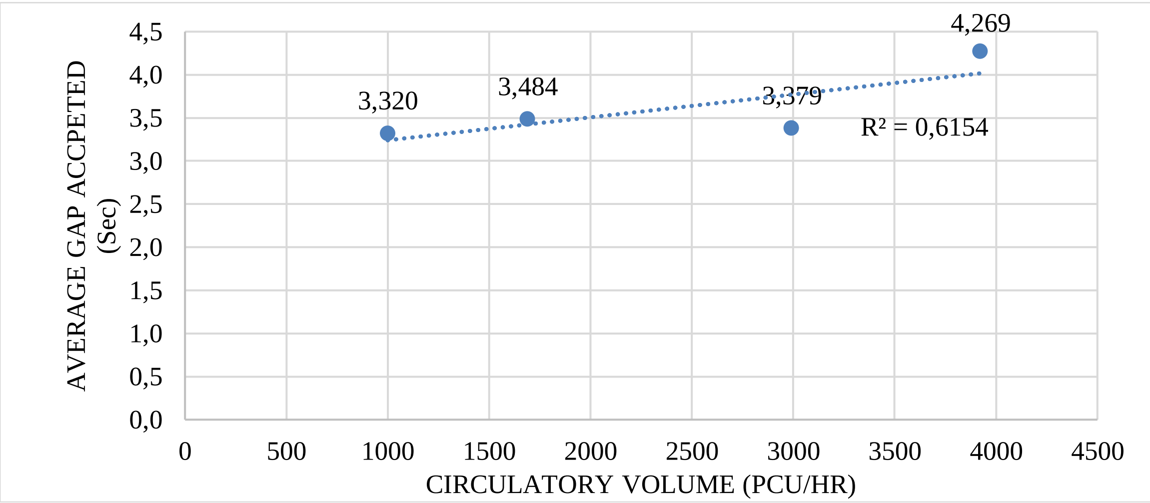


Figure 7: Relationship between accepted gap by cars and circulatory volume

3.6 Effect of approach speed on gap acceptance

Numerous studies have been conducted in the past to examine gap acceptance behaviour. Most of them focused on the gap acceptance decision only. Few of them investigated the vehicle manoeuvre process and related driving behaviour. The speed at which a vehicle merges into a gap is an essential parameter to judge the driver's behaviour. The merging could be possible when the available gap is sufficiently large (greater than the critical gap); otherwise, vehicles should wait for the next suitable gap (Sil et al., 2016). Contrary to this norm, the behaviour of motorcyclists in the study area was found to be quite disruptive and impolite. Riders accepted shorter gaps by merging aggressively into the circulating traffic. Figure 8 depicts the inverse relationship between motorcycle merging speed and the average gap accepted. This result shows that as motorcycle merging speed increased, the accepted gap time decreased significantly. Motorcyclists merge into large gaps at low speeds; this could be because they drive aggressively and can easily merge into the gaps at low speeds. Whereas, in the case of shorter gaps, the rider tends to take more risk and increase the speed of its motorcycle to merge within the available gap. The R-squared value for the relation between the merging speed of motorbikes and the accepted gaps was found to be 0.6444 seconds. In contrast, a weak and direct relationship was found in the case of cars, as shown in Figure 9. This indicates that drivers merge into large gaps with greater speed and small gaps with lower speed. It could be because car drivers always show vigilant behaviour while manoeuvring around the roundabout. Car drivers tend to merge slowly into smaller gaps as this may avoid any damage to their vehicles. Drivers accelerate to merge when the gap within the circulating vehicles is large because there are fewer such gaps available during peak hours.

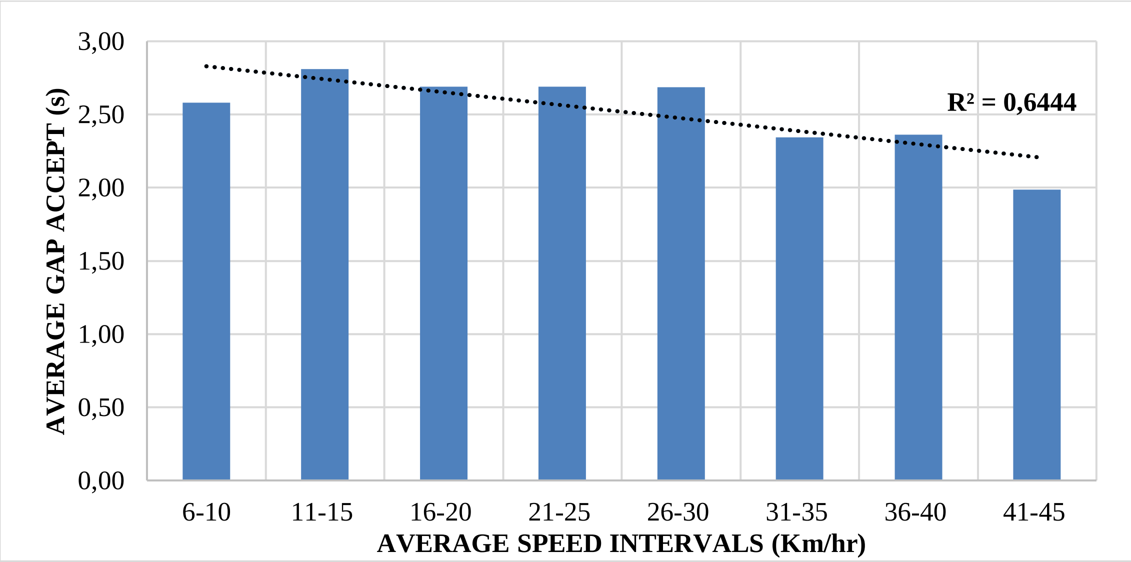


Figure 8: Relationship between merging speed and average gap accepted by motorcycles

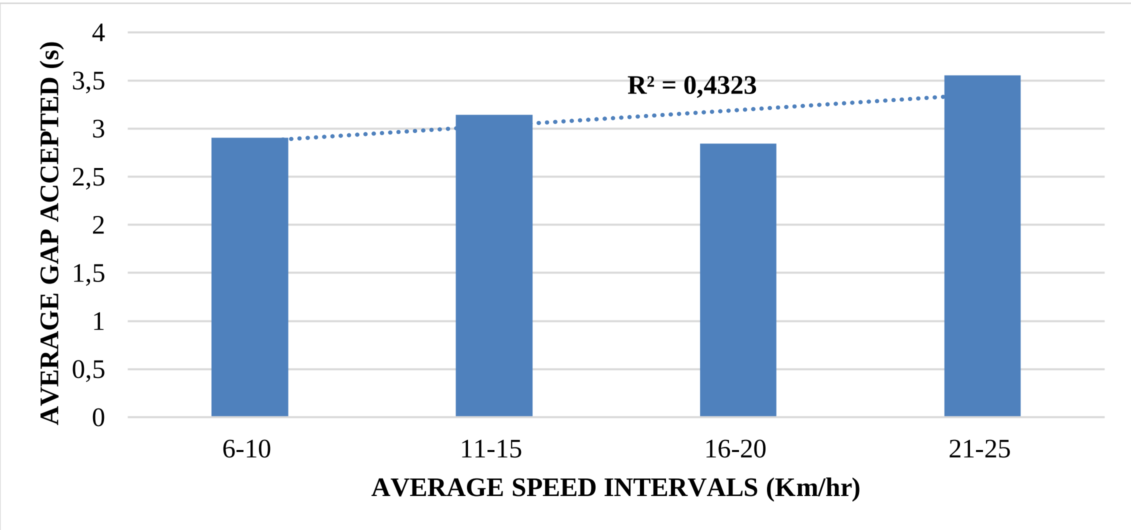


Figure 9: Relationship between merging speed and average gap accepted by cars

4. CONCLUSIONS AND RECOMMENDATIONS

Merging behaviour at roundabouts in developing countries largely depends upon the vehicle type and driving behaviour. A heterogeneous traffic environment prevails in most developing countries. A lack of enforcement and driving discipline results in risk-taking by drivers while entering the roundabout. Rules of yielding and waiting for the appropriate gap are neglected and the drivers tend to create gaps by forcing the circulating vehicles to slow down and give way to the approaching vehicles. This is more common for motorcycles, among the approach vehicles, as compared to cars. The results of this study conclude that motorcycles accept smaller gaps in contrast to cars. As a consequence, the critical gap obtained for motorcycles was lesser than that of cars. This phenomenon is conformal with their smaller size and greater manoeuvrability which provides motorcyclists the ability to cut corners and merge with the circulating traffic more quickly as compared to cars. Identical results were obtained in other studies available in the literature.

The analysis of the association between the gap size accepted by motorcycles and circulating volume indicated an inverse relationship, that is, the higher the circulating volume the smaller the gap size accepted. Whereas, a direct relationship was observed between cars and circulating volume, that is, the higher the circulating volume the greater the gap size accepted. Examination of another association between the gap size accepted and merging speed revealed that motorcyclists tend to merge at higher speeds in smaller available gaps while car drivers merge at lower speeds in smaller available gaps. Thus, the comparison between the two types of vehicles shows that motorcyclists behave in a riskier manner in comparison with cars. This risky behaviour may lead to road crashes and create a safety hazard for themselves and other road users.

The results of this study are based on a particular roundabout located in the city of Karachi. Since the study does not incorporate multiple sites, therefore these results cannot be generalised. However, the methodology can be easily replicated and the results present a glimpse into prevailing merging behaviour at roundabouts. It is further recommended that similar investigations should be carried out at other roundabouts for better generalisation. This study does not incorporate the effect of geometric parameters on the merging behaviour of drivers. Extended studies should also consider the effect of geometric parameters on merging behaviour. Moreover, further investigations of the effect of merging behaviour on road crashes and conflicts be carried out.

5. ACKNOWLEDGMENTS

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