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Analyzing the Dilemma Zone at Median Openings in Urban Areas to Enhance Safety and Efficiency

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Abstract—*A median opening is a designated area along divided urban highway that affords drivers the opportunity to execute a U-turn. When a driver executes a U-turn, it can produce a potentially dangerous merging scenario with oncoming traffic. The reason for this is that the U-turning vehicle must navigate through openings or gaps between the approaching vehicles, which other drivers can either allow or deny. In certain situations, drivers may pause to decide whether to accept or reject an available gap, as they may be uncertain about its safety. This decision-making zone is referred to as the "dilemma zone". This study focuses on analyzing the dilemma zone for U-turning vehicles at median openings in urban areas. Field data was analyzed using a cumulative distribution method to determine the boundaries of the dilemma zone. The study found that the length and location of the dilemma zone for a U-turning vehicle were influenced by several factors, including the size and type of both the U-turning and approaching mainstream vehicles, as well as the speed of the approaching mainstream vehicle. The results of the investigation revealed that the dilemma zone was situated farther away from the median nose when both the U-turning and approaching mainstream vehicles were more substantial in size. The length and location of the dilemma zone furnished insights into the severity of vehicular interaction conflicts at the median opening. These findings can be applied to improve the safety and efficiency of median openings. Furthermore, the investigation proposes that driver assistance systems could be designed to aid drivers in making informed decisions within the conflict zone.*

INTRODUCTION

Median opening is an opening provided in the median of a divided highway to facilitate U-turn movements. A U-turn movement allows a vehicle to change its direction by 180° and merge with the traffic incoming from the opposite direction. This leads to a merging conflict between the U-turning vehicles and the incoming vehicles. U-turning vehicle encounters gaps in between the incoming vehicles which may either be accepted or rejected by the U-turning driver. The basis of this gap acceptance and rejection is the driver's ability to judge whether a particular available gap is safe to accept or not. The decision to reject and accept very small and very large gaps respectively, is quite easy for a U-turning driver, however for a certain range of gap values of space and time, a U-turning driver faces difficulty in deciding whether the available gap is safe to accept or not. This decision-making zone is referred to as the "dilemma zone". The dilemma associated with a U-turn creates a chance of driver taking a potentially risky decision which can prove fatal for both the U-turning vehicle and the incoming vehicle.

The traffic condition in developing countries is not so appreciable. In a city like Srinagar, the situation is no better. With the available infra structure and road discipline of road users, the safety hazards at the median openings increase. This study focuses on analyzing the dilemma zone for U-turning vehicles at median openings in urban areas like that of Srinagar city.

Gazis et al. were the first authors who gave the concept of the dilemma zone at signalized intersection considering the driver's decision making process in response to the yellow light phase. The distribution of the dilemma zone was formulated by the Ghazis Herman Maradudin (GHM) model[1]. For a signalized intersection, the dilemma zone was modeled by different methods; one of them being a probabilistic approach which is based on the probability of the driver's decision to stop in response to the yellow light. Dilemma zone as defined by Zegeer is the road section where more than 10% and less than 90% of the drivers decide to stop[2]. Moon and Coleman reported that the dilemma zone is dependent on the speed of approaching vehicles. They also suggested that the boundaries of the dilemma zone depend on the acceleration-deceleration rate with time[3]. Gates et al. studied the driver behavior at the dilemma zone at signalized intersections by estimating deceleration rates and brake-response times[4]. Liu et al. studied the variation in the dilemma zone for different driver groups at the signalized intersections by categorizing the behavior of drivers into three different groups on the basis of their course of action. The authors claimed that there was significant discrepancy between the theoretically calculated dilemma zone and actual distribution of the dilemma zone[5]. The boundaries of the dilemma zone were established by Li on the basis of the 5% and 95% stopping probability of drivers[6]. Sharma et al. used the dilemma zone concept to develop the improved surrogate measure of safety for operations at an isolated intersection[7]. Pawar et al. studied the dilemma zone of pedestrians crossing at high speed uncontrolled mid-block crossings using an empirical approach[8]. The study team continued their research on dilemma zones and investigated the dilemma zone of the minor-street vehicle at unsignalized intersections by collecting field data from four uncontrolled intersections using a binary logit model[9]. From the test results, the authors reported that speed, time of the day, and vehicle type significantly influenced the location and length of the dilemma zone and also suggested that proper estimation of the dilemma zone could be helpful in developing an assistance system for improving the safety of vehicles. Khan. T and S.S. Mohapatra have recently analyzed the dilemma zone at midblock median openings. The authors reported the boundaries of the dilemma zone for different class of vehicles by analyzing 14 locations[10].

NEED AND OBJECTIVE OF STUDY

Most of the research for the dilemma zone has been performed considering the signalized intersections. Pawar et al. carried the research for uncontrolled intersections. Traffic movement at median openings is quite similar to that of the uncontrolled intersections[11]. Khan. T and S.S. Mohapatra have recently analyzed the dilemma zone at midblock median openings[12]. In the Srinagar city of Jammu and Kashmir, India, right turns at intersections have been restricted. This has been done by providing a median opening downstream of an intersection and thus replacing the right turn movements by the U-turn movements. As a result, the conflicts at the intersection have been reduced. However, this has led to merging conflicts at the median openings which still poses a potential threat to the safety of the drivers. Therefore, the demand for the study of the dilemma zone at the median openings has grown.

This research focuses on the case study of such a median opening which caters the right turning traffic at the intersection. Dilemma zone for different U-turning vehicles corresponding to different approaching mainstream vehicles has been evaluated.

DATA COLLECTION AND EXTRACTION

Data was collected at a median opening near Sanatnagar-Rawalpora intersection of Srinagar city. The section is a 2-lane highway and the data collection was done during the day. Geometric details were measured using a measuring tape while traffic data was recorded using a video camera. Video Camera was placed at a suitable distance, height and angle such that both the U-turning traffic and the mainstream traffic was recorded. Markings were marked on the approaching section for speed evaluation. Table 1. Represents the geometric details of the location.

A 2-hr traffic data at peak hour was recorded. The setup was done prior to the peak hour so that no disturbance in the traffic was caused. Classified traffic volume was recorded for both U-turning and approaching mainstream traffic. The different classes of vehicles recorded were: two wheelers(2W), three wheelers(3W), Cars, Light commercial vehicles (LCV) and heavy commercial vehicles (HCV). The percentage of heavy vehicles making U-turns was negligible, hence they have been ignored in the analysis. The details of the traffic volume for approaching mainstream traffic and the U-turning traffic is given in figures 1 and 2 respectively.

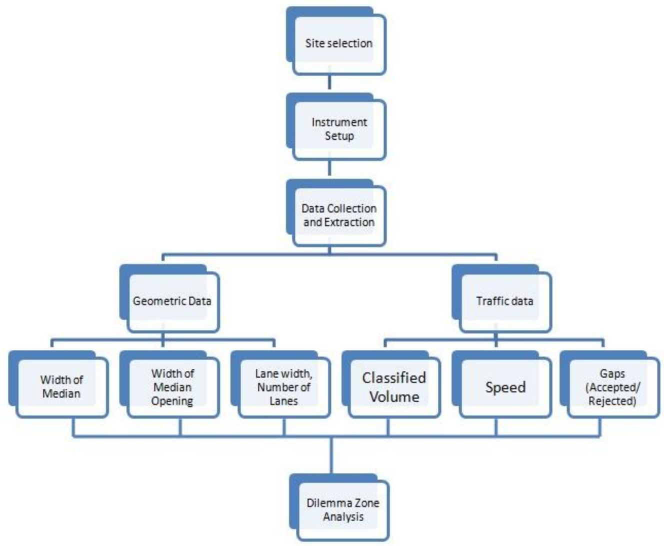

Figure 1: Methodology for the study.

Figure 2: Camera view of the location depicting the intending U-turn movement by a car.

Table 1: Geometric Details of the Median Opening

Study Site	No. of Lanes	Road width(m)	Width of Median Opening(m)	Width of Median (m)
Sanatnagar-Rawalpora Intersection	**2**	**7**	**17**	**4.5**

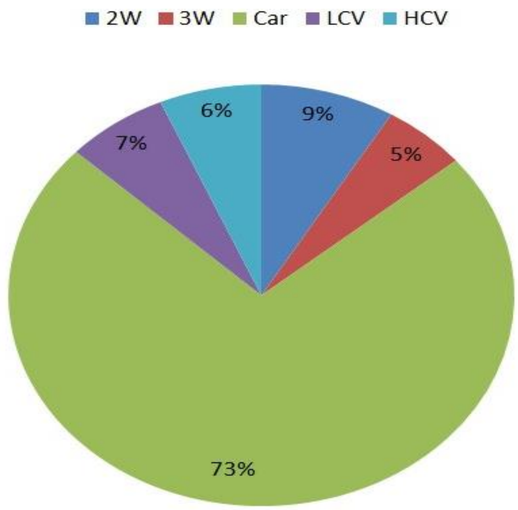

Figure 3: Traffic volume composition for approaching mainstream traffic.

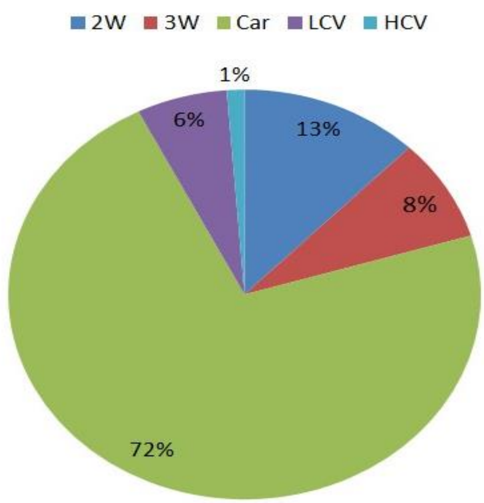

Figure 4: Traffic volume composition for u-turning traffic.

ANALYSIS OF DILEMMA ZONE

Dilemma zone at the median opening in this study was identified using a frequency distribution approach based on the definition of dilemma zone by Zegeer as stated earlier[2]. Available gaps for the U-turning traffic were recorded and driver's decision to accept or reject those gaps was also recorded. Cumulative percentage of gap acceptance and rejection was plotted on the Y-ordinate corresponding to spatial gaps on the X- abscissa. The upper and lower boundaries of the spatial dilemma zone was marked corresponding to the 10% of accepted gap and 90% of rejected gap. The dilemma zone boundaries (spatial) were obtained for different classes of U-turning vehicles in response to their interaction with different class of approaching mainstream vehicles. A total of 20 evaluations for spatial dilemma zone was performed. The plot for spatial dilemma zone boundaries for u-turning vehicle; car with respect to different classes of approaching mainstream traffic is given in figures 5-9. Similarly, plots for other class of vehicles was also used for finding the spatial dilemma zone corresponding to different classes of approaching mainstream vehicles. Table 2. gives the dilemma zone different class of u-turning vehicles corresponding to different class of approaching mainstream vehicles. Finally, a concise value for the dilemma zone was obtained for different class of u-turning vehicles by plotting a cumulative distribution considering all accepted and rejected gaps irrespective of the class of approaching mainstream vehicles. The results obtained suggested that the spatial dilemma zone for cars was 22 m long ranging from 28 m to 50 m from the nose of the median opening. Table 3. sums up the spatial dilemma zone for different classes of U-turning vehicles.

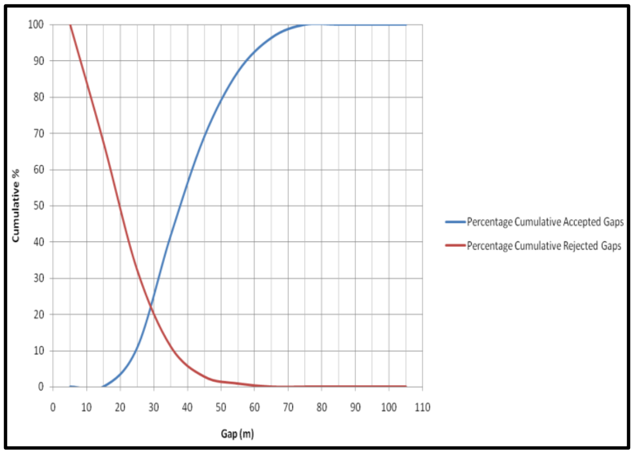

Figure 5: Cumulative Distribution for accepted and rejected gaps for U-turning Cars corresponding to mainstream 2W.

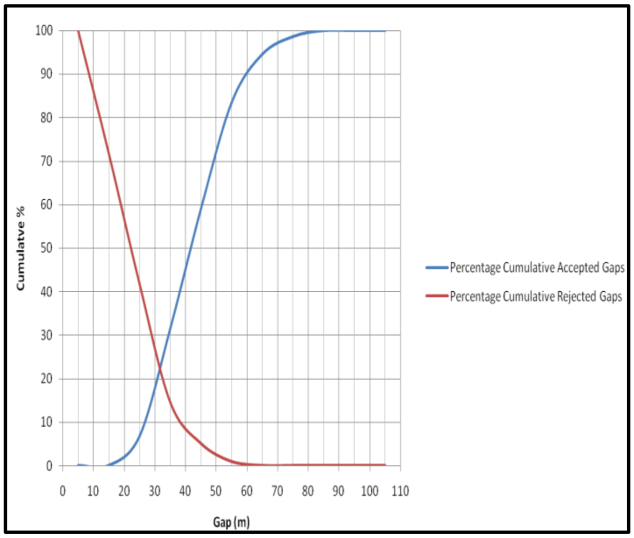

Figure 6: Cumulative Distribution for accepted and rejected gaps for U-turning Cars corresponding to mainstream 3W.

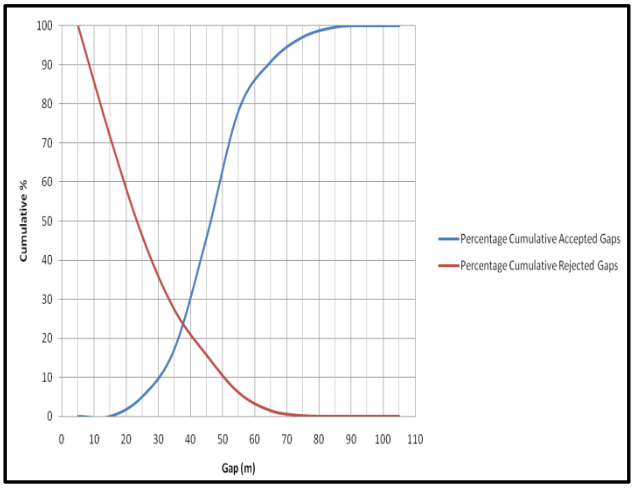

Figure 7: Cumulative Distribution for accepted and rejected gaps for U-turning Cars corresponding to mainstream Cars.

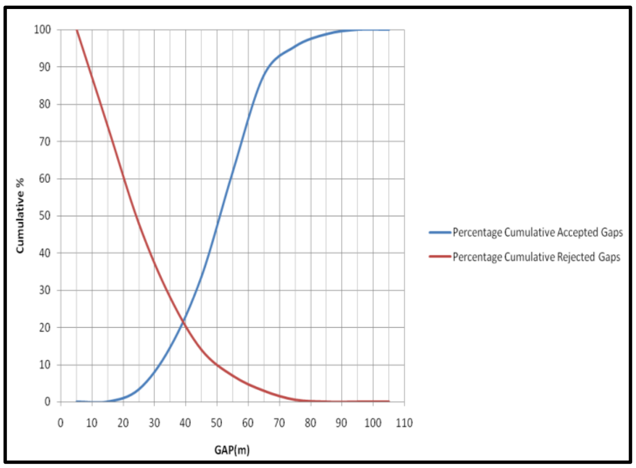

Figure 8: Cumulative Distribution for accepted and rejected gaps for U-turning Cars corresponding to mainstream LCV.

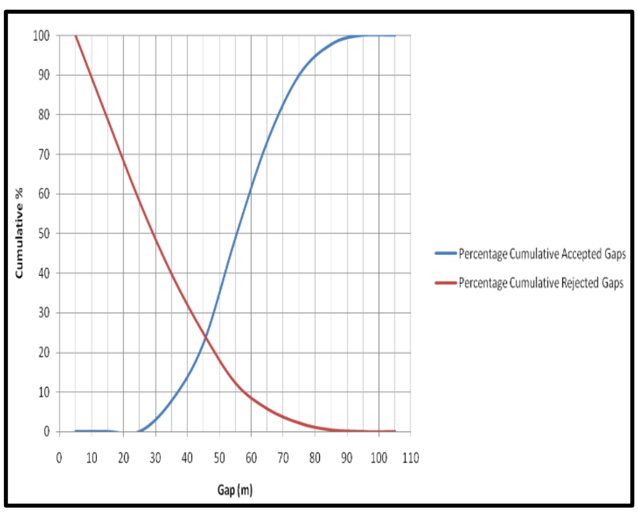

Figure 9: Cumulative Distribution for accepted and rejected gaps for U-turning Cars corresponding to mainstream HCV.

Table 2: Spatial Dilemma Zone Boundaries for Different Class of U-Turning Vehicles Corresponding to Different Class of Approaching Mainstream Vehicles

U-Turning Vehicle	Mainstream Vehicle	Lower Spatial Boundary (m)	Upper Spatial Boundary (m)	Spatial Dilemma Zone(m)
2W	2W	17	27	10
	3W	20	30	10
	Car	23	40	17
	LCV	26	41	15
	HCV	30	49	19
3W	2W	23	34	11
	3W	25	36	11
	Car	28	47	19
	LCV	30	47	17
	HCV	35	54	19
CAR	2W	24	36	12
	3W	26	38	12
	Car	30	50	20
	LCV	31	50	19
	HCV	36	56	20
LCV	2W	27	38	12
	3W	31	44	13
	Car	34	55	21
	LCV	36	55	19
	HCV	41	62	21

Table 3: Spatial Dilemma Zone Boundaries for Different Class of U-Turning Vehicles.

U-Turning Vehicle	Lower Spatial Boundary (m)	Upper Spatial Boundary (m)	Spatial Dilemma Zone (m)
2W	23	40	17
3W	26	46	20
Car	28	50	22
LCV	33	55	22

CONCLUSION

The study found that the length and location of the dilemma zone for a U-turning vehicle were influenced by several factors, including the size and type of both the U-turning and approaching mainstream vehicles, as well as the speed of the approaching mainstream vehicle. The dilemma zone for two wheelers was shortest and closer to the nose of the median, while the dilemma zone for light commercial vehicles was longest and farther away from the median nose. Also, for the same class of u-turning vehicle, it was observed that the dilemma zone boundaries moved away from the median nose as the size of vehicle increased, that is, dilemma zone corresponding to mainstream two wheelers was smaller and closer to the median nose, while that corresponding to mainstream heavy commercial vehicles was longer and farther away from the median nose. This can be explained by the fact that smaller vehicles take less time to make a u-turn and hence accept comparatively smaller gaps while larger vehicles wait for longer safe gaps. Also, a u-turning driver senses more danger when the mainstream vehicle offering the gap is a heavy vehicle because of its larger size. Though the quantitative analysis for the effect of speed on dilemma zone boundaries was not performed in this study, but it was observed that larger gap values were rejected when the mainstream vehicle was moving fast compared to when the mainstream vehicle was moving slow.

The length and location of the dilemma zone furnished insights into the severity of vehicular interaction conflicts at the median opening. The outcome of this study can be used by traffic engineers to design effective strategies to counter the dilemma of drivers that results in accidents. Furthermore, driver assistance systems could be designed to aid drivers in making informed decisions within the conflict zone. The dilemma zone can be reduced by lane widening and providing a dedicated lane for u-turning vehicles at the median openings. This not only will increase the safety of the vehicles but will also help in smooth operation of median u-turns as an alternative for intersections in the city.

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