Safety performance evaluation of driveway left turning alternatives using traffic conflicts

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Abstract

Safety of left turning vehicles from driveways onto major arterials carrying high traffic volumes is of particular importance. Left turn movement at such locations could be accommodated either through direct left turns (DT) or right turns followed by U-turns (RUT). The study summarized in this paper evaluated the effects of these two alternatives where the safety comparison using traffic conflicts is described here. This was achieved through field data collection of traffic and traffic conflict data at locations where one or both of the two alternative treatments were utilized. Two types of conflict rates, conflicts per hour and conflicts per thousand involved vehicles were used in comparing the safety of the two left turning alternatives. Average number of conflicts per hour for DT and RUT were 6.35 and 4.20, respectively. When data were separated into peak and non-peak periods, average peak hourly conflicts were 7.01 and 3.98 for DT and RUT respectively. When average number of conflicts per thousand involved vehicles was considered, the rates for DT and RUT were 26.43 and 16.08 respectively. RUT conflict rate was 39% lower as compared to DLT conflict rate. Severity of conflicts for DT and RUT was also analysed by using two approaches based on Risk of Collision and Time to Collision scores. In both cases, average DT conflict severity was significantly larger than that of RUT. Both conflict rates and severity indicated more favourable safety effects due to RUT, where a case study of converting a DT location into a RUT location confirmed the findings.

Keywords – road safety; traffic conflicts, risk of collision

1. Introduction

Mobility and accessibility are the two major functions of any highway, which often contradict with each other. Arterial streets are commonly used to meet both these functional needs to a certain level. Level of combination of mobility and accessibility is directly associated with the density of access points. Whether an arterial provides higher level of mobility with fewer access points or higher level of accessibility through frequent access points, driveways play a very important role in the operational and safety performance of arterials. Accordingly, urban arterials are required to address wide range of traffic movements in various forms. AASHTO Green Book, "A Policy on the Geometric Design of Highways and Streets" indicates that "Driveways are, in fact, at-grade intersection's and should be designed consistent with the intended use. The number of crashes is disproportionately higher at driveways than at other intersections; thus their design and location merit special consideration." [1]

Majority of safety concerns at driveways are associated with left turning vehicles. Left turn movement from driveways could be accommodated either through direct left turns (DT) or right turns followed by U-turns (RUT) as illustrated in Figure 1. A driveway that could facilitate a direct left turn has a full median opening on the arterial allowing all possible traffic movements. A driveway that forces the left turning vehicles to first make right turns followed by U-turns in order to achieve a left turn, could either have a directional median opening or no opening at all. The number of conflict points at a full median opening is 32, whereas there are only 8 conflict points at a directional opening as indicated in Figure 2. Accordingly with fewer conflict points, RUT could theoretically be expected to be safer than RUT.

This study was aimed at evaluating and comparing the practical safety situations of the two left turning alternatives from driveways on major urban arterials. This was accomplished through field data collection of traffic conflicts and volumes where one or both of the left turning alternatives were utilized. A traffic conflict in this case is defined as an event involving two or more road users, in which the action of one user causes the other to make an evasive action or manoeuvre to avoid a collision.

2. Objectives

The materials described in this paper are a part of a much larger study that evaluated both traffic operational and safety impacts of DT and RUT. This paper describes the safety analysis conducted by using the traffic conflict technique. In order to supplement each other, safety analysis was also carried out by using crash data of a much larger sample of sites and the findings are published elsewhere [2]. The objectives of this part of the study were:

1) to estimate the average number of traffic conflicts for both direct left turn and right turn followed by U-turn manoeuvres and to make a comparison between the two values,
2) to estimate the average conflict rates for each of the two left turning alternatives from the driveways and to compare these values,
3) to evaluate the severity of conflicts generated by direct left turn and right turn followed by U-turn manoeuvres and to compare the severities,
4) to make general recommendations as to what left turn alternative is safer.

3. Literature

3.1 Conflict studies

Conventional and most commonly used approach in detecting and evaluating most of the traffic safety problems is to collect and analyse crash data at a particular site. Some of the concerns associated with the accuracy of this method include the reliability of the police reported crash records, human error associated with coding and input of crash data into electronic format, and most importantly the time that has to be waited until a sufficiently large enough sample size is obtained [3, 4, 5, 6]. This waiting time could have serious implications since several crashes might occur before any correction could be made to treat or correct a deficiency [7, 8].

Alternatively, traffic conflict studies have been accepted for several reasons even though it also suffers some disadvantages due mainly to its subjective nature [9, 10, 11, 12, 13]. First, data can be collected within a short period of time so that it is not necessary to wait for the occurrence of several crashes to improve the conditions of a site. Second, the effectiveness of a treatment can be evaluated within a short period and if it fails to correct the problem then the countermeasure can be changed again. Third, traffic conflicts include human factors because the behaviour of drivers can directly be observed in the field. Fourth, traffic conflict studies can be used with or without crash data since each type of conflict is associated with a particular type of crash. Finally, traffic conflict studies could also be used to gather information about traffic volumes, routine conflicts, moderate conflicts, erratic manoeuvres, severe conflicts or near-miss crashes, and other minor crashes not reported to the police. Accordingly, irrespective of some inconsistent past research findings regarding the relationship between conflicts and crashes, traffic conflicts have been and could be effectively used as a surrogate of crashes.

Even though there were no published documents that explained the direct use of conflicts to compare the safety of different left turning alternatives from driveways or side streets, there have been numerous past studies that used traffic conflicts as a tool for evaluating various other relationships. Some of these include the relationships between crashes and conflicts, conflicts and traffic volumes, and ranking of hazardous intersections.

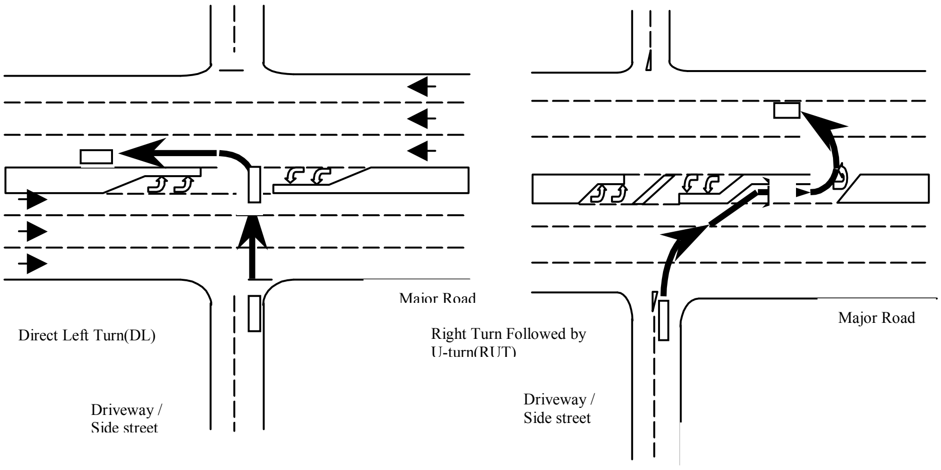

Fig. 1 – Driveway Left Turning Alternatives Considered

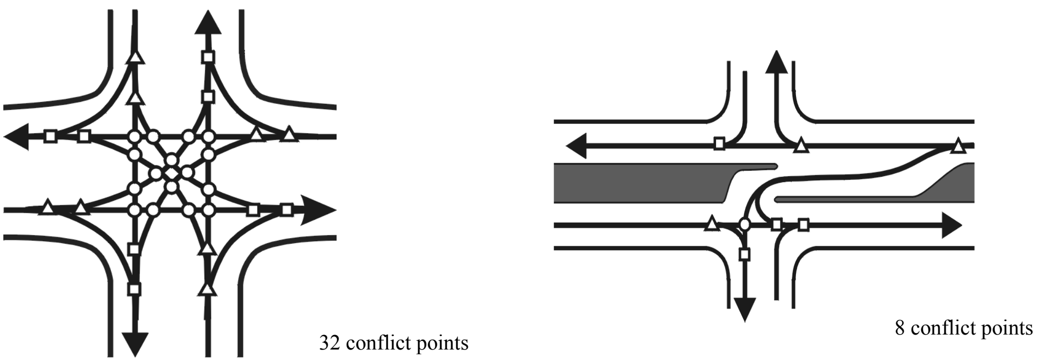

Fig. 2 – Conflict points at full and directional median openings

3.2 Conflict severity

Severity of traffic conflicts are commonly evaluated either by using objective methods involving measurable properties such as time, distance, and speed or by subjective measures that rely on human observers to record the perceived risk at the time of the conflict. Hayward developed the concept of Time to Collision (TTC) to differentiate severe near misses from other conflicts by using physical properties such as distance and time [14]. TTC is defined as the time required by two vehicles to collide if they continue at their present speeds on same paths, without taking any evasive action. Minimum TTC is considered as the perception and reaction time of drivers because failing to react to an event would result in a collision. According to the findings by Hayward, the mean TTC value was 1.46 seconds and that the conflicts with less than 1.0 second of TTC could be considered as near misses.

Sayed et al considered both objective and subjective methods for evaluating the risk of conflicts because if only objective methods were used, they could over-estimate the risk factor (6). Thus, it was recommended to combine these two (subjective and objective measures) for obtaining a reasonable risk value. For the subjective evaluation, observers assigned a value known as Risk Of Collision (ROC), based on the severity of the risk perceived while collecting data in the field. The TTC and ROC values had equal weight for low, moderate, and high risk conflicts.

Other methods that have been used in evaluating the severity of conflicts include the concept of Encroachment Time (ET) [15], gap time (GT) concept, zonal braking technique, Deceleration Rate (DR), and Post Encroachment Time (PET). Katamine evaluated the relationship between conflicts and secondary conflicts at 15 unsignalized intersections based upon a severity grading system created by Glauz and Migletz [16, 17]. Salman and Almaita also used a severity grading system for evaluating the safety of three-leg unsignalized intersections to rank the intersections according to the amount of risk [4].

4. Methodology

4.1 Site selection

According to the objectives of the study, sites that utilized one or both of direct left turns (DT) or right turns followed by U-turns (RUT) were selected for field data collection. One type of sites corresponds to locations where the driveway vehicles in need of making left turn could either turn to the left directly or turn to the right and make a U-turn. The second type corresponds to those sites where only turning to the right was allowed, so that, only RUT movements would be expected but not DLT movements [20]. Each of the selected sites satisfied the following requirements, some of which depend on the type of the left turn alternative.

1) Major road or arterial with three or more lanes in each direction.
2) Posted speed on the major road equal to or greater than 45 mph (72 kmph).
3) Raised non-traversable medians existing on the major road.
4) Considerable distance between the driveway and the U-turn location so that drivers can make RUT without much difficulty or serious safety concerns. This weaving distance at each of the RUT site was essentially greater than safe stopping distance that is defined in [1].
5) Downstream signal located at a considerable distance away from the driveway in order to avoid the effects of possible spillbacks.
6) Relatively high traffic volume on the driveway. (The intention was to make the data collection process more efficient by enabling more turning vehicles to be studied within a shorter period of time).

7) For RUT sites, U-turn facilitated at median openings, not at signalised intersections.
8) Sites located in non-industrial areas so that there is no significant impact due to heavy vehicles.
9) All the sites having similar characteristics as much as possible, except the left turn alternative and the geometry associated with that.

Accordingly 8 sites that satisfied above requirements were selected for field data collection. At each site, left-turning rivers from the driveway had one or both of the left turn alternatives.

4.2 Data collection

This study utilized the video camera technique to record all the traffic operations around the driveway area and within the weaving section between the two median openings in the case of RUT sites, so that the conflict data could later be extracted from the tapes. Setting up of the video cameras at ground level was insufficient to record traffic conflicts clearly. In the locations with no appropriate buildings or other structures to set up the cameras, they were set up on top of 15 feet high, two-story scaffoldings as shown in Figure 3. The locations of the scaffoldings were selected carefully, so that they would attract least driver attention while providing a good view of the traffic movements. Major road through-traffic volume was obtained using an automatic traffic recorder. The field data were collected for two weeks at each site for at least four hours a day, including both peak and non-peak hours. A total of about three hundred-hours of traffic data was recorded by video cameras. All data were collected during daytime under good weather conditions while avoiding unusual traffic conditions such as crashes and construction work. Left turning traffic volumes on the driveway varied from 30 veh/hr to 300 veh/hr. Total volume on the major roads varied from 2500 veh/hr to 6500 veh/hr with an average of 4300 veh/hr.

4.3 Identification of traffic conflicts

Recorded videotapes were later reviewed in the laboratory by a single observer and the conflict data together with corresponding severities were obtained. Evasive manoeuvres such as applying brakes, swerving, or noticeably decelerating in order to avoid a collision were treated as conflicts. Some concerns of considering braking as a conflict include 1) braking as a precautionary action which could be misunderstood as a conflict, 2) vehicles accelerating or changing lanes to avoid collisions instead of applying brakes, and 3) brake lights having mechanical failures [15].

Fig. 3 – Field setting-up of video cameras

Even though these concerns exist, brake applications, swerving, and noticeable deceleration could be and have successfully been used as indicators of occurrence of traffic conflicts, which is a useful tool in highway safety analyses [4, 14, 16, 18, 19]. However, not all such actions were considered as conflicts and extra care was taken in the conflict identification process to not to count usual manoeuvres and actions as conflicts.

It has been noted by several researchers that observers are the most important element when conducting a traffic conflict study since their reliability has serious impacts on the validity of the data [10, 15]. Therefore special care was taken in training the observer properly so that higher reliability and uniformity could be achieved. The objective was focused towards making a fair comparison between two left turn alternatives rather than to prove a certain hypothesis. Vehicles were tracked as they departed from the driveway to see if the movement was a DT, RUT, or neither of them. If the manoeuvre was either a DT or RUT, it was carefully observed for possible conflicts. In case of a conflict, the time of occurrence, conflict type, risk of collision perceived during the evasive action, and the distance were recorded. A specifically designed data collection form was used in recording the conflict data extracted from the videotapes.

4.4 Types of studied conflicts

Even though there are many different conflict types defined in previous studies, not all those types are important for the manoeuvres evaluated in this study [13]. Accordingly, nine relevant types of conflicts were identified as given in Table 1.

4.5 Conflict severity categories

The Risk of Collision (ROC) was evaluated by assigning a score according to the level of severity of the evasive action as perceived by the observer. The score values ranged from 1 to 3, where 1 represented a low-risk conflict and 3, a high-risk conflict. Time to Collision (TTC) which is defined as the time required by two vehicles to collide if they continue at their present speeds on same paths, was also categorized into three categories. If TTC value was greater than 1.50 seconds, it received score 1 which referred to a low risk conflict. TTC values from 1.00 to 1.50 sec. was score 2, medium risk and TTC from 0 to 0.99 sec. was score 3, the highest risk category. Each conflict received both ROC and TTC scores in order to evaluate the severity of conflicts for both DT and RUT manoeuvres. In the analysis, ROC was considered as Severity Index I and the sum of scores of ROC and TTC was considered as the Severity Index II.

4.6 Data analysis

Two conflict rates were considered in the analysis of the collected conflict data. They are:

$$R_1 = \frac{Number\ of\ Conflicts}{Number\ of\ hours\ of\ Observation}$$

and

$$R_2 = \frac{Number\ of\ Conflicts}{\sqrt{(V_1)\times(V_2)}}\times 1000$$

where, R_1 = Conflicts per hour, R_2 = Conflicts per thousand involved vehicles, V_1 and V_2 are traffic volumes of the two manoeuvres related to the conflict type being considered.

Tab. 1 – Types of Traffic Conflicts Considered

LT Alternative	Type Code	Type Name	Description
RUT	C1	*Right-Turn out of the driveway*	A vehicle (offending vehicle) waiting at a driveway turns right and gets into the major road, placing another vehicle (conflicting vehicle) on the major-road in danger of a rear-end or sideswipe collision.
	C2	*Slow-Vehicle, Same-Direction Conflict*	A slow right turning vehicle already on the major road begins to accelerate while on the path of a major road vehicle, encountering it with a danger of a rear-end collision.
	C3	*Lane Change Conflict*	A right turned vehicle from a driveway changes from one lane to another (weaving) until it reaches the U-turn bay, placing through vehicles in danger of rear-end or sideswipe collisions.
	C4	*U-turn Conflict*	A vehicle making U-turn places vehicles coming from the opposing direction in danger of a sideswipe or angle accident.
	C5	*Slow U-Turn Vehicle, Same-Direction Conflict*	A vehicle that completed the U-turn maneuver accelerates, placing danger an oncoming major-road vehicle of a rear-end collision.
DT	C6	*Left-Turn out of driveway: conflict from right*	A vehicle on the driveway turns left and places a major-road vehicle with the right-of-way in danger of sideswipe and right-angle collision.
	C7	*Direct-Left Turn and Left-Turn in From-Right Conflict*	A left turning vehicle from the driveway places a vehicle turning into the same driveway in danger of sideswipe or angle collision.
	C8	*Direct-Left-Turn and Left-Turn in From-Left Conflict*	A left turning vehicle from the driveway places a vehicle turning into the opposite driveway in danger of sideswipe or angle collisions.
	C9	*Left-Turn out of driveway: Conflict From Left*	A left turning vehicle located on the median storage area places an oncoming major-road vehicle in danger of a rear-end or sideswipe collision

Tab. 2 – Summary of the Total Number of Observed Conflicts (N/A not applicable)

Site	Type of Left Turn Maneuver	Conflict Type									Total
		C1	C2	C3	C4	C5	C6	C7	C8	C9	
1	RUT	64	22	23	15	28	N/A	N/A	N/A	N/A	152
2	DT/RUT	4	9	3	3	0	75	221	5	36	356
3	DT/RUT	1	9	2	2	0	37	18	0	12	81
4	DT/RUT	2	11	2	1	0	39	22	3	17	97
5	DT/RUT	1	12	3	9	2	24	1	2	11	65
6	DT/RUT	2	15	5	0	0	41	14	1	21	99
7	RTUT	26	22	22	18	18	N/A	N/A	N/A	N/A	106
TOTAL	Number	155	153	164	172	97	366	347	29	171	1654
	Percentage	9.4	9.3	9.9	10.4	5.9	22.1	21.0	1.7	10.3	100

5. Analysis results

5.1 Conflicts per hour

Total number of conflicts observed at each of the seven sites separated by the conflict type is given in Table 2. These observed conflict data were separated into DT and RUT to estimate the conflict rates (R_1) by considering the number of hours of observation. Average hourly conflict rates for DT and RUT are given in Figure 4. The rates were considered in three categories, non-peak, peak, and overall periods. According to these, the average conflicts per hour during the non-peak period for DT and RUT were 5.69 and 4.41 respectively. The difference was much more evident in the case of peak periods where average number of conflicts per hour were 7.01 and 3.98 respectively for DT and RUT. When considering the total time period, the corresponding rates for DT and RUT were 6.35 and 4.20. These numbers indicate that DT experienced 29%, 76%, and 51% more traffic conflicts as compared to RUT during non-peak, peak, and total time periods respectively.

5.2 Conflicts per thousand involved vehicles

In order to account for the effects of traffic volume on conflicts, in addition to the number of conflicts per hour, conflicts per thousand involved vehicles were also taken into consideration. Based on the results of previous studies, the square root of the product of the two manoeuvring volumes involved in conflicts was selected as the most appropriate method for calculating the conflict rate. The total number of conflicts, through traffic volumes, manoeuvring volumes, and conflict rates were obtained for each site. Table 3 presents the number of conflicts per thousand involved vehicles at each site. The values given in Table 3 indicated that except for one site all the other sites had lower conflict rates for RUT movements. The average conflict rates for DT and RUT were 26.43 and 16.08 respectively per thousand involved vehicles. DT rate was 64% more than the RUT rate or alternatively, RUT rate was 39% lower as compared to DT conflict rate.

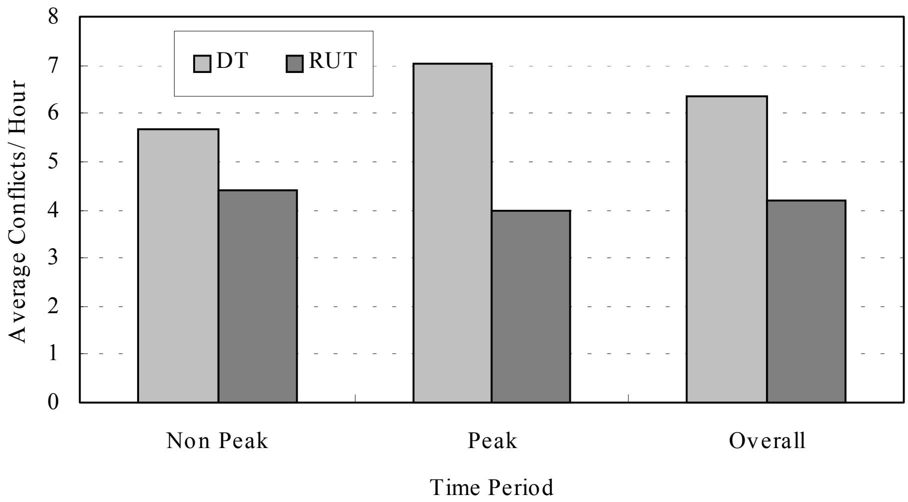

Fig. 4 – Comparison of Average Conflicts per Hour for DT and RUT

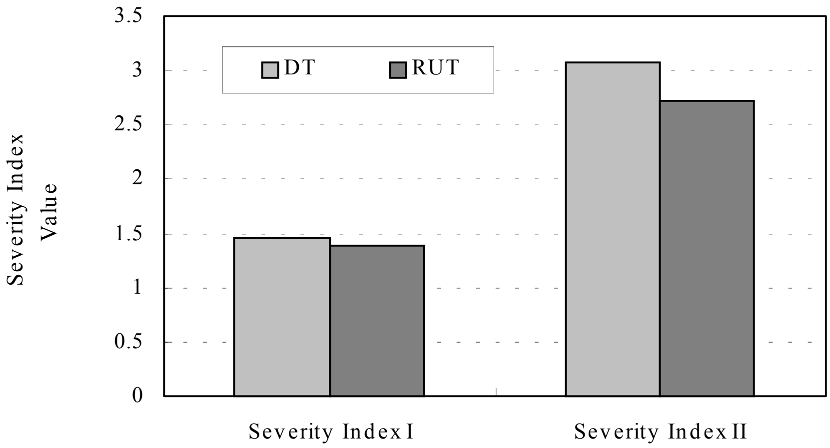

Fig. 5 – Comparison of DT and RUT Conflict Severities Using Severity Index I (Based solely on ROC Score) and Severity Index II

Tab. 3 – Average Conflicts per Thousand Involved Vehicles

Site	DT	RUT
1	N/A	19.61
2	39.36	10.12
3	28.46	11.69
4	26.90	12.10
5	11.33	17.74
6	26.12	12.41
7	N/A	28.90
Average	26.43	16.08

5.3 Conflict severity

Severity of DT and RUT conflicts were analysed and compared by using two indices, based on Risk of Collision (ROC) and Time to Collision (TTC) scores. Severity Index I was purely based on ROC score and varied from 1 to 3 and Severity Index II was the summation of scores for ROC and TTC and therefore varied from 2 to 6. Figure 5 graphically illustrates the average severity values for both DT and RUT movements using Severity Index I and II respectively. Both figures indicated that conflicts generated by RTUT movements have a lower severity than conflicts generated by DLT movements.

Tab. 4 – Results of the ANOVA Tests to Compare Severities of DT and RUT Conflicts

Type of Index	Movement	Mean	Variance	*F* Statistic	*P* Value	$F_{critical}$
Severity Index I (ROC Score)	DLT	1.45	0.405	6.788	0.009	3.84
	RTUT	1.38	0.287			
Severity Index II (ROC + TTC Scores)	DLT	3.07	1.294	35.586	0.000	3.84
	RTUT	2.72	0.906			

Tab. 5 – Comparison of Number of Conflicts per Hour During Before and After Time Periods

Number of Conflicts/Hour						Reduction %
Before Period			After Period			(Before-After) x 100 / Before
Due to DLT	Due to RTUT	Total	Due to DLT	Due to RTUT	Total	
Peak Period						
23.92	3.20	27.12	0	13.14	13.14	51.5 %
Non Peak Period						
19.00	4.25	23.25	0	12.06	12.06	48.1 %
Total Average						
21.46	3.72	25.18	0	12.60	12.60	49.9 %

Tab. 6 – Average number of conflicts per thousand involved vehicles during before and after time periods

Time	Conflicts Per Thousand Involved Vehicles Before	After
7:00 - 8:00	118.71	26.82
8:00 - 9:00	97.94	27.85
9:00 - 10:00	54.68	37.08
10:00 - 11:00	55.31	53.63
11:00 - 12:00	51.00	61.96
12:00 - 13:00	73.64	27.48
13:00 - 14:00	62.43	32.82
14:00 - 15:00	55.62	44.86
15:00 - 16:00	72.22	34.49
16:00 - 17:00	77.54	46.28
17:00 - 18:00	65.59	28.04
AVERAGE	71.33	38.30
Average Reduction = 46.3 %		

To determine if the severity of DLT conflicts was significantly different from the severity of RTUT movements, Analysis of Variance (ANOVA) tests were conducted. The null and alternative hypothesis were: H_o: Severity of RUT and DT movements are similar and H_a: Severity of RUT movements is different from that of DT movements. A 0.05 level of significance (a) was selected for the ANOVA tests, and the results of the analysis conducted using both Severity Index I and Score II are summarized in Table 4. In both approaches, the estimated F statistic was much larger than the critical F statistic. Alternatively, the P value was much smaller than the selected level of significance, 0.05. Thus, the null hypothesis of similar severities could not be accepted. In other words, severity of DT conflicts was significantly higher than the severity of RUT.

6. Case study

From the 8 sites at which data were collected for evaluating the left turn alternatives, one site was a case study, which provided an excellent opportunity to study the safety effects of converting a full median opening into a directional median opening. Data collected at the site were used in making a before-and-after comparison of conflicts and severities. Before period was accommodating both DT and RUT whereas a temporary barrier constructed at the full median opening converted it into a directional median opening requiring left turn vehicles from the driveway to make RUT.

Average number of conflicts per hour at this site during before and after periods categorized by peak, non-peak and overall time periods are summarized in Table 5. Remarkably, the reductions in average hourly conflicts were 51.5 %, 48.1 %, and 49.9 % respectively for peak, non-peak and overall time periods. Similar to the rest of the study, conflicts per thousand involved vehicles were also estimated as an effort to account for the changes in traffic volumes. These conflict rates based on the hour of the day are listed in Table 6 for the before and after time periods. Each and every hour indicated a reduced number of conflicts per thousand involved vehicles where the average overall reduction was 46.3 %. The case study also confirmed the previous finding with regard to the severity of conflicts, that is RUT conflicts in general less severe than DT conflicts.

7. Conclusions

A safety comparison of two left-turn alternatives, DT and RUT, from driveways using traffic conflicts analysis was conducted in this study using field data collected at eight sites. A comparison of the number of conflicts per hour of RUT and DT movements suggested that RUT movements generate fewer conflicts per hour. In addition, when the effect of traffic volumes was taken into consideration by means of conflict rates per thousand involved vehicles, results also showed DT as generating more serious safety concerns than RUT.

Not only did RUT movement experience reduced number of conflicts, but also the severities of conflicts were much lower. The findings regarding the severity were consistent in both approaches. A case study in the form of a before-and after study confirmed these findings. Accordingly, it could be indicated that driveways facilitating RUT experience lower number of conflicts, conflict rates, and conflict severity as compared to DT and therefore can be considered as the safer left turn alternative. These findings were consistent with the crash data analysis results conducted for the same purpose (2).

Acknowledgement

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