Negotiation-Based Conflict Exposure Methodology in Roundabout Crash Pattern Analysis

Dongxi Zheng
Research Assistant
Department of Civil Engineering, University of Wisconsin - Madison
1415 Engineering Drive, Room 1241, Madison, WI, 53706
Phone number: 608-335-0889
E-mail: dzheng3@wisc.edu

Xiao Qin, Ph.D., PE
Assistant Professor
Department of Civil Engineering, South Dakota State University
CEH 148, Box 2219, Brookings, SD 57007
Phone number: 607-688-6355
E-mail: xiao.qin@sdstate.edu

Ross Tillman
Research Assistant
Department of Civil Engineering, University of Wisconsin - Madison
1415 Engineering Drive, Room B245, Madison, WI, 53706
Phone number: 608-358-7562
E-mail: rbtillman@wisc.edu

David A. Noyce, Ph.D., PE
Associate Professor
Department of Civil Engineering, University of Wisconsin - Madison
1204 Engineering Hall, 1415 Engineering Drive, Madison, WI, 53706
Phone number: 608-265-1882
Fax number: 608-262-5199
E-mail: noyce@engr.wisc.edu

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ABSTRACT

This paper provides a comprehensive analysis of roundabout crash patterns. First, an improved method was used to calculate crash type percentages for Wisconsin roundabouts. Second, the crash type patterns were compared between roundabout types and between at-fault driver residency types. It was found that the entering-circulating crash was the severest at single-lane roundabouts while the sideswipe crash had a higher percentage at multilane roundabouts. Local drivers were more involved in rear-end crashes while drivers from outside of the city committed more sideswipe crashes. Third, to provide an insight into crash patterns based on driving behavior, 12 types of inappropriate negotiations were defined and quantified through video data. The conflict exposure rates were then defined and measured to interpret the crash patterns. The results from the conflict exposure analysis showed why a high percentage of sideswipe crashes appeared at multilane roundabouts.

Keywords: roundabouts, crash pattern, inappropriate negotiations, conflict exposure rate

INTRODUCTION

A modern roundabout is a new type of intersection designed to have decreased crash exposure and lower crash severity than a traditional cross intersection. First, to reduce crash exposure, the "drive-around" mode, which is also used by other circular intersections, is applied at roundabouts to eliminate certain conflicts. For example, as shown in Figure 1, when a traditional cross intersection is converted into a roundabout, the number of vehicle conflict points decreases from 32 to 4, resulting in a decrease in conflict types. Figure 1 depicts the simplest of conditions where each intersection approach has only one lane. As the number of lanes increases, more conflict points and conflict types will appear at both types of intersections. However, since all kinds of vehicle movements (right-turn, though, left-turn, and U-turn) through a roundabout are generalized as a combination of entering, circulation, and exiting, a modern roundabout generally has fewer conflict points as well as fewer conflict types than the traditional intersection does. Second, to reduce crash severity, a roundabout is designed in a geometry that converts right angle crashes to sideswipes and encourages low speeds by providing a small circulating radius. The two safety control measures discussed above along with the fact that entering vehicles yield to circulating traffic create an altogether safer, and different, driving experience at roundabouts compared to traditional intersections.

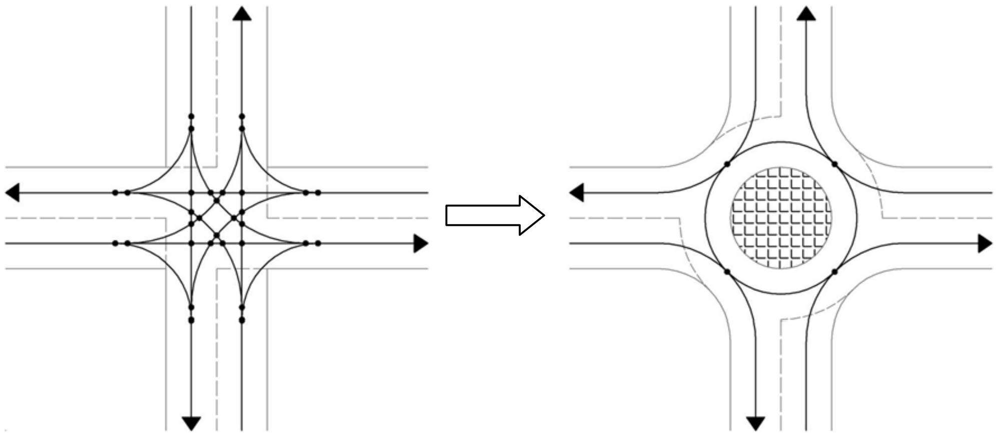


FIGURE 1 Conflict points at a cross intersection and at a roundabout.

Several studies on roundabout crash patterns have been reviewed and three main limitations have been observed. These limitations are: 1) estimate of crash type percentage was biased, 2) the relationship between the at-fault driver's residency and the city where the crash happened was not investigated, and 3) the exposure of having a conflict (mentioned as "conflict exposure" here after) in terms of driving behavior has not been studied.

In order to provide a more comprehensive roundabout crash pattern analysis, the following efforts were made. First, an improved method was proposed to calculate crash type percentages. Second, the Wisconsin roundabout crash patterns were analyzed by crash type percentage using the proposed method as well as by frequency. The differences between roundabout types and between at-fault driver residency types (city level) were discussed. Third, to provide an insight to the crash patterns from a driving behavior standpoint, several types of inappropriate negotiations were defined and quantified through video data. Conflict exposure rates were then defined and measured to interpret the observed crash patterns.

LITERATURE REVIEW

Research studies have been completed throughout the world to investigate crash patterns at roundabouts. Early in the 1980s, Maycock and Hall performed a study on crashes at 84 four-leg roundabouts in the UK *(2)*. In their study, entering-circulating crashes were found to be most prevalent (71.1%) among all types of crashes for 'small' roundabouts, roundabouts with a central island greater than 13 feet in diameter and with a large ratio of inscribed circle diameter to center island diameter. For conventional roundabouts, those having a larger diameter than 'small' roundabouts, entering-circulating crashes, approaching crashes (within approaches only), and single-vehicle crashes were found to be the three main crash types, proportioned as 20.3%, 25.3%, and 30.0% respectively. In 1998, Arndt and Troutbeck studied 492 crashes from 100 roundabouts in Queensland and found that 50.8% of crashes were entering-circulating, 18.3% were rear-end (for the entire roundabout here after if not specified), and 18.3% were single vehicle crashes *(3)*. In 2000, Robinson et al. showed in an FHWA report that entering-circulating, single-vehicle run off circulating lane, and rear-end at entry were the three major crash types among 16 roundabout collision types in Australia and in four European countries *(4)*. In 2003, Inman et al. evaluated FHWA method of calculating fastest path using the observations of path and speed at two double-lane roundabouts *(5)*. They also proposed a economic way of recording speed and path through approach, circulatory roadway, and departure. In 2007, Montella summarized 22 frequent crash types based on the 2003 to 2005 crash data of 15 roundabouts in Italy *(6)*. The angle-at-entry (entering-circulating/exiting) crashes took the highest portion of all crashes at 27.6%. The rear-end-at-entry crashes came in second with 14.6%. Each of the other 20 types of crashes represented no more than 6% of total. In the most recent study by Mandavilli et al., 283 crashes happening at 38 roundabouts in Maryland were classified into eight distinct types including an "other" type *(7)*. Four types of crashes were found to be a significant portion of the total: run-off-road, rear-end (at entry), entering-circulating, and sideswipe (in circulation). Field observations were also taken from sample roundabouts to provide guidance for countermeasures.

The previous studies provide evidential insights into roundabout crashes, but three limitations of analysis still exist.

First, in all of the previous studies, the percentage of a certain crash type was estimated as the number of this type of crash over the number of total crashes (or sub-total crashes), regardless of the variation among the sample sites. This may result in a biased estimate under certain conditions.

Second, the effect of at-fault driver's residency has not been investigated. Based on the literature review, most of the researchers mainly focused on the relationship between the crashes and the roundabout's geometric features (i.e., single-lane or multilane); none of them performed analysis of crash pattern by driver residency (i.e., local-city driver or outside-city driver). Since residency can imply the driver's familiarity with a certain roundabout, it is helpful in identifying the crash patterns resulting from the drivers' unfamiliarity with navigating in roundabouts so that appropriate lane guidance can be designed.

Third, no conflict exposure concerning driving behaviors was defined and measured. In previous studies, only general inspections had been conducted, such as the Arndt and Troutbeck observation of lane transition behavior and the Mandavilli et al. report on center/edge line crossing and high approaching speed problems *(3, 7)*. Their conclusions primarily focused on the design features, including geometry, signing, and marking. It is understood that geometric treatments can only improve highway safety to a certain level as human factors eventually accounts for most of the crashes *(8)*. With that being said, driver behavior at roundabouts needs to be thoroughly studied to strengthen the understanding of the interaction between roadway (roundabout) design and drivers. Traffic conflict studies are important tools used widely in traffic studies to provide rapid evaluation of safety performance of an entity without waiting for several years to obtain a sizeable crash list. They can also reveal the extra information regarding confusing and erroneous movements that may lead to a collision. It is often considered a more proactive approach to identifying potential safety issues and concerns. Thus, it is important to identify a variety of inappropriate driving behaviors that would possibly lead to vehicle (including bike and motorcycle) conflicts.

METHODOLOGY

In terms of crash categorization, this study adopts seven out of the eight crash types suggested by Mandavilli et al. *(7)*:

a) Run-off-road (or loss of control)
b) Rear-end (at entry)
c) Entering-circulating
d) Sideswipe (in circulating lanes)
e) Exiting-circulating
f) Pedestrian/bike
g) Other.

Estimate of Percentages

There are 41 ($K = 41$) sample roundabouts (24 single-lane roundabouts and 17 multilane roundabouts) under study. For the k^{th} roundabout, the following variables are defined:

$p_k^{(i)}$ = the percentage of the i^{th} type of crash, %;

n_k = the total number of crashes at this roundabout;

$n_k^{(i)}$ = the number of the i^{th} type of crash at this roundabout.

It is assumed that $p_k^{(i)}$ is a nonnegative variable independent from n_k and follows $\sum_{i=a}^{h} p_k^{(i)} = 1$. The variable $n_k^{(i)}$ depends on $p_k^{(i)}$ and n_k in the following definition equation:

$$n_k^{(i)} = \frac{p_k^{(i)} n_k}{100} \tag{1}$$

In practice, one can only directly observe $n_k^{(i)}$ and n_k. The observed $p_k^{(i)}$ should be derived from Equation 1.

The estimated average percentage of the i^{th} type of crash then should be:

$$p^{(i)} = \frac{\sum_{k=1}^{K} p_k^{(i)}}{K} \tag{2}$$

Where

$p^{(i)}$ = the estimated average percentage of the i^{th} type of crash, %;
$p_k^{(i)}$ = the observed percentage of the i^{th} type of crash at the k^{th} roundabout, %;
K = the number of sample roundabouts.

It can be easily proven that $\sum_{i=a}^{h} p^{(i)} = 1$, which ensures the basic validity of the estimate.

In the previous studies, a different way of estimating the average percentage of the i^{th} type of crash was formulated as below *(2-4, 6, 7)*.

$$p_{previous}^{(i)} = \frac{\sum_{k=1}^{K} n_k^{(i)}}{\sum_{k=1}^{K} n_k} \times 100 \tag{3}$$

Where

$p_{previous}^{(i)}$ = the previous estimated average percentage of the i^{th} type of crash, %;
$n_k^{(i)}$ = the number of the i^{th} type of crash at the k^{th} roundabout;
n_k = the total number of crashes at the k^{th} roundabout;
K = the number of sample roundabouts.

Whether Equation 3 is an unbiased estimate of the average individual-roundabout crash type proportion depends on the distributions of $p_k^{(i)}$ and n_k and that Equation 2 is more appropriate than Equation 3 in providing a robust and unbiased estimate. Therefore, Equation 2 was used in the current study to calculate the crash type percentages.

Estimate of Crash Frequencies

For an individual roundabout opening in year Y, only the crashes happening between year $Y + 1$ and August 2008 were taken into account. Thus, the time span of crash data for the k^{th} individual roundabout is:

$$T_k = 2008 + \frac{8}{12} - (Y + 1) = 2007.67 - Y \quad (4)$$

Where

T_k = the time span of crash data for the k^{th} roundabout;
Y = the opening year of the k^{th} roundabout.

And the crash frequency of the i^{th} type of crash at the k^{th} roundabout is:

$$f_k^{(i)} = \frac{n_k^{(i)}}{T_k} \quad (5)$$

Where

$f_k^{(i)}$ = the crash frequency of the i^{th} type of crash at the k^{th} roundabout, crashes/year;
$n_k^{(i)}$ = the number of the i^{th} type of crash at the k^{th} roundabout;
T_k = the time span of crash data for the k^{th} roundabout.

Further, the average crash frequency of the i^{th} type of crash is:

$$f^{(i)} = \frac{\sum_{k=1}^{K} f_k^{(i)}}{K} \quad (6)$$

Where

$f^{(i)}$ = average crash frequency of the i^{th} type of crash, crashes/roundabout/year;
$f_k^{(i)}$ = the crash frequency of the i^{th} type of crash at the k^{th} roundabout, crashes/year;
K = the number of sample roundabouts.

Definitions of Conflict Exposure Rates

Conflicts generally happened when drivers broke the rules of roundabout negotiation. Among all the roundabout negotiation requirements, ‘yield to circulating’ and lane-usage are the two basic rules to ensure safe operations. Thus, within a multilane roundabout quadrant (refer to Figure 2), the following inappropriate negotiations were listed:

1. C1→C2;
2. C1→Ex2;
3. C2→C1;
4. C2→Ex1;
5. En1→C2;
6. En1→Ex2;
7. En2→C1;
8. En2→Ex1;
9. C2→C2;
10. CVOL (Circulating Vehicle On lane Line): A vehicle enters the quadrant in either of the circulating lanes, travels on the lane line for a while, and exits mostly in the right

exiting lane. This is similar to C1→Ex2;

11. FY: An entering vehicle fails to yield to the upcoming circulating vehicle;
12. WY: A circulating vehicle wrongly yields to the entering vehicle.

The inappropriate negotiations 1 – 9 were denoted in the following way: The text on the left side of the arrow stands for the lane in which the vehicle enters the quadrant and the text on the right stands for the lane in which the vehicle exits the quadrant. C1 and C2 stand for left (inner) and right (outer) circulating lanes respectively, En1 and En2 stand for left and right entering lanes, and Ex1 and Ex2 stand for left and right exiting lanes. C1→Ex2, for example, stands for the situation when a vehicle enters the quadrant in the inner circulating lane but exits in the outer exiting lane.

For a time period (i.e., 2 hours), the conflict exposure rate (ER) is calculated as:

$$ER_i = \frac{Count_i}{Volume_i} \quad (7)$$

Where

ER_i	=	the conflict exposure rate of the i^{th} type of inappropriate negotiation;
$Count_i$	=	the count of the i^{th} type of the inappropriate negotiation during the given time period;
$Volume_i$	=	the count of vehicles that get into the quadrant in the same lane as the vehicles making the inappropriate negotiations do during the given time period; for inappropriate negotiations 10 – 12 the count includes both lanes.

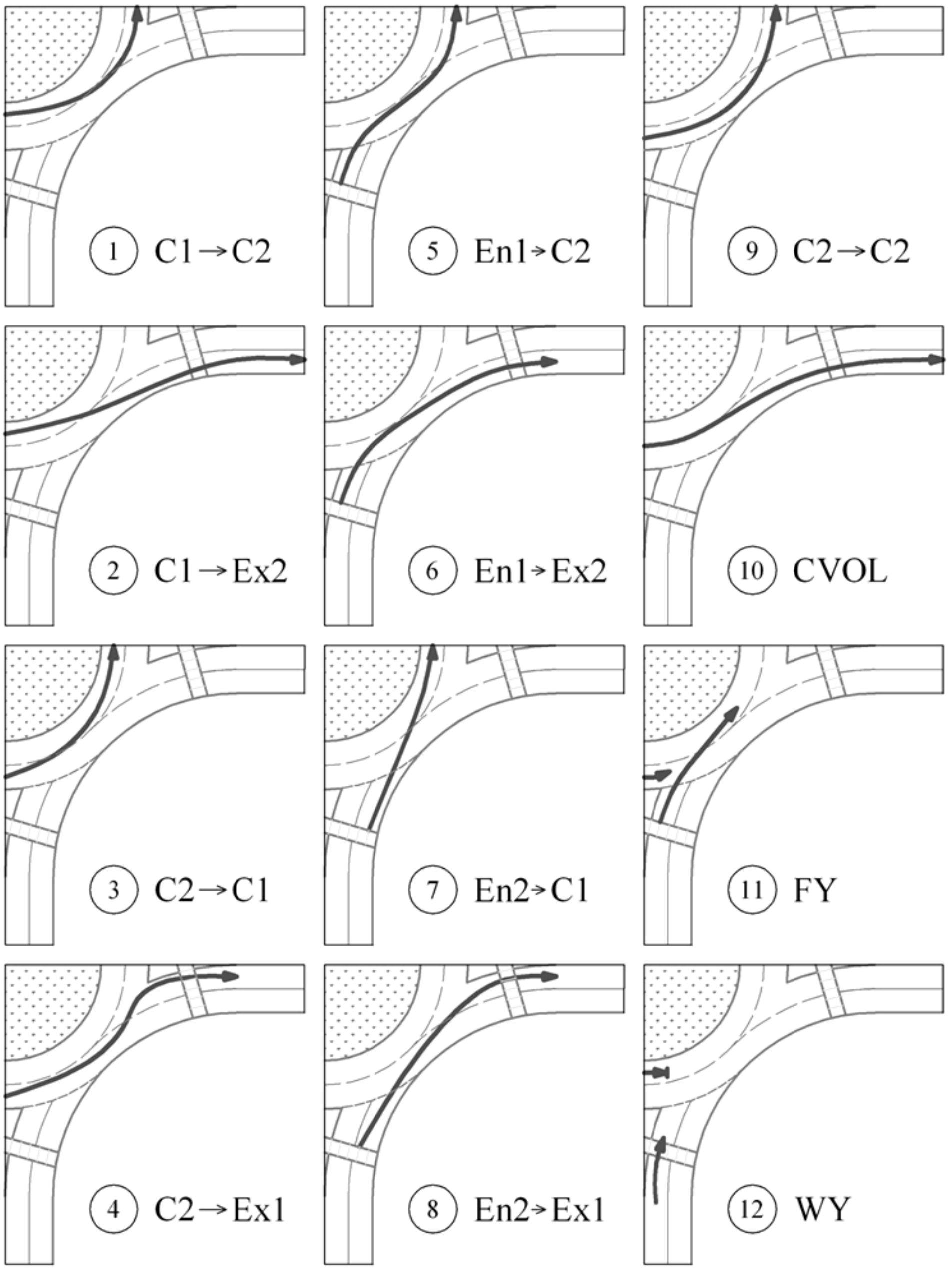


FIGURE 2 Inappropriate negotiations.

DATA COLLECTION

Two data sources were used in the study: one was crash data and the other was field observed inappropriate negotiations defined in the methodology section. Crash data was summarized by crash type, roundabout type, and at-fault driver's residency type.

Crash Data

The crash data was retrieved from the WisTransportal online crash data system, a combination of data from WisDOT and Milwaukee Traffic Operation Centers and the WisDOT MV4000 crash database. The areas searched contained all the roundabout sites constructed before 2008 in Wisconsin, with crash records dating from March 2001 to August 2008.

After the raw data was retrieved, five steps of categorization were conducted by manually reviewing the scanned police reports. First, for each of the retrieved crashes, the location was labeled as ‘roundabout’ or ‘not roundabout’. Second, if a crash was identified as a roundabout crash, a crash type (a – g mentioned in the methodology section) was assigned to it according to the narration and drawing in the police report. Third, the roundabout crash was further labeled “single-lane” or “multi-lane” based on the number of circulating lanes in the roundabout. Fourth, depending on the relationship between the crash date and the roundabout opening year, each roundabout crash was further labeled as A, B, or M. ‘A’ stands for a crash after the roundabout open year; ‘B’ stands for a crash before the roundabout open year; and ‘M’ stands for a crash which happened in the roundabout open year. Last, the city where the at-fault driver lived was found and compared to the city where the roundabout was in. If they were the same city, the crash was labeled ‘local’ (local city). If they were different, the crash was labeled ‘outside’ (from another city).If the at-fault driver’s city was not given, the crash was labeled ‘unknown’.

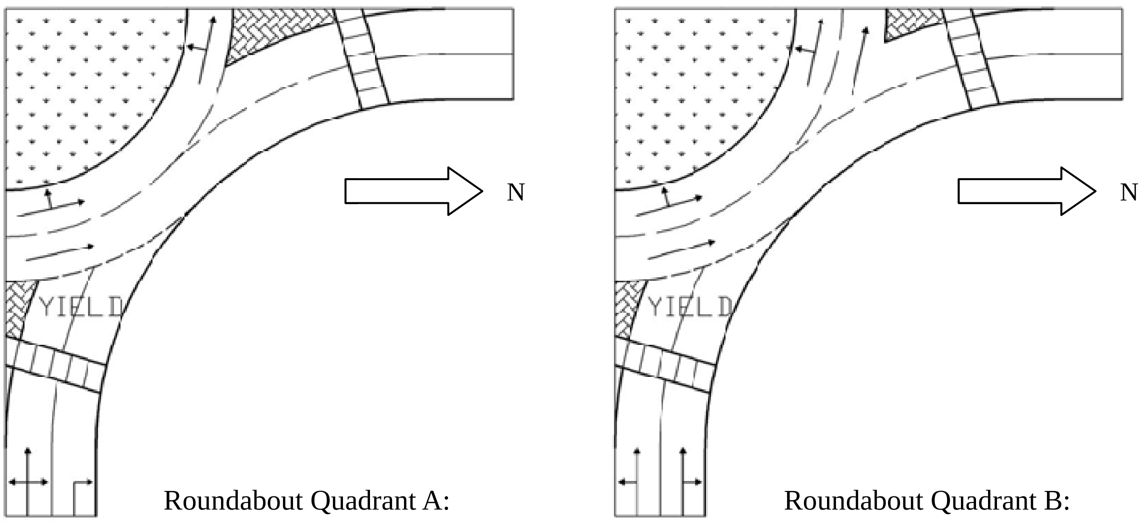
Only those crashes labeled with ‘A’ and assigned a crash type were selected for analysis use. The total number of selected crashes was 358, with 132 crashes at 24 single-lane roundabouts and 226 crashes at 17 multilane roundabouts.

Inappropriate Negotiation and Related Data

The inappropriate negotiation related data was collected via recorded videos at the roundabout locations. Two multilane 4-leg roundabouts were chosen for video recording from 7:00 am to 7:00 pm. A video system, consisting of a video camera on a 25 foot tripod and a Miovision unit, was located about 15 feet from the sidewalks on a corner between two roundabout approaches. The video camera fixed at the top of the tripod captured the whole roundabout area and stored the video in the Miovision unit. Since the video system was located between two adjacent approaches, the view of the roundabout quadrant where the video was located was relatively larger and more focused (Figure 3), leading to a quadrant-based video review.

FIGURE 3 Video review system.

After obtaining the video data, a self-developed program (Figure 3) was used to review the videos and record the time stamps of two groups of events: 1) vehicles entering the quadrant and 2) inappropriate negotiations. The reviewed quadrants of the two roundabouts are illustrated in Figure 4. The selected time periods were 7:00 am – 9:00 am and 2:00 pm – 4:00 pm for both roundabouts. The final counts of different events are presented in Table 1.



Roundabout Quadrant A: Industrial Dr. @ S Towne Dr., Madison

Roundabout Quadrant B: N Thompson Dr. @ Commercial Ave., Madison

FIGURE 4 Channelization of reviewed roundabout quadrants.

TABLE 1 Conflict Exposure Related Event Counts

	Quadrant A		Quadrant B	
	7:00 am | 9:00 am	2:00 pm | 4:00 pm	7:00 am | 9:00 am	2:00 pm | 4:00 pm
Traffic Counts				
C1	354	676	642	875
C2	420	677	239	360
En1	54	147	767	466
En2	185	239	126	119
Inappropriate Negotiations				
C1→C2	–	–	2	4
C1→Ex2	132	324	28	57
C2→C1	0	0	0	1
C2→Ex1	1	1	0	0
En1→C2	–	–	1	0
En1→Ex2	0	1	0	0
En2→C1	3	1	8	9
En2→Ex1	6	5	1	3
C2→C2	–	–	2	7
CVOL	82	53	38	23
FY	0	1	2	3
WY	0	0	1	0

NOTE: Dash (–) indicates data not applicable.

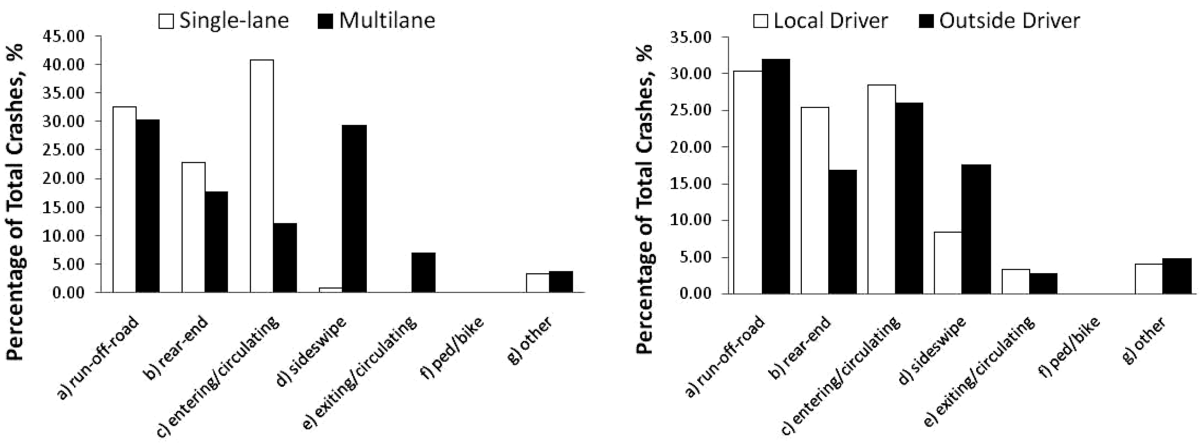
CRASH PATTERN ANALYSIS AND DISCUSSION

In this section, both crash type percentages and crash frequencies were estimated. They provided the insights of the roundabout crash type distributions as well as the absolute amounts in Wisconsin.

Estimate of Crash Type Percentages

Figure 5a gives the results of crash patterns at single-lane roundabouts and at multilane roundabouts. First of all, both types of roundabouts in Wisconsin have an equivalently high percentage of run-off-road crashes and rear-end crashes, around 30% and 20% respectively. The similarity could be explained by the fact that these two types of crashes generally happen when a vehicle approaches the roundabout, a similar maneuver regardless of the number of circulating lanes. Second, the single-lane roundabouts have a significant portion of entering-circulating crashes while the multilane roundabouts do not. A possible reason is, for single-lane roundabouts, it is difficult for entering vehicles to determine in advance whether or not a circulating vehicle will exit or continue through the adjacent quadrant, resulting in a potential entering-circulating conflict. Third, the multilane roundabouts have a large portion of sideswipe crashes while the single-lane roundabouts have few. This is because sideswipe crashes generally happen between vehicles in adjacent circulating lanes.

Figure 5b compares the crash patterns between local and outside drivers. The major differences between the two exist in the rear-end crashes and the sideswipe crashes. The supposition for local drivers having a higher percentage of rear-end crashes is that the familiarity with the roundabout encourages a high enough approaching speed that they cannot safely brake for a yielding vehicle if unexpected. For the higher percentage of sideswipe crashes in outside drivers, the unfamiliarity could be an important attributor that leads to wrong or improper navigations within the circulating lanes.



(a) **(b)**

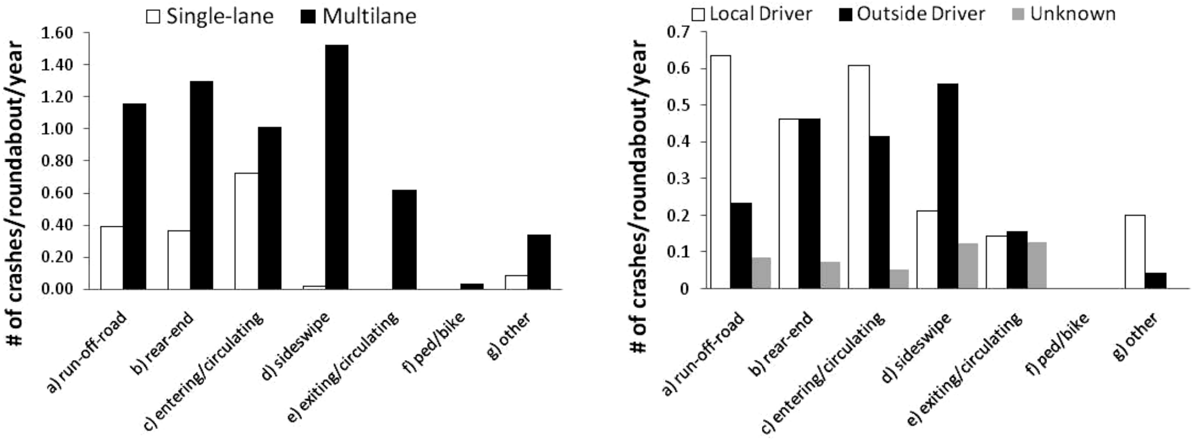
FIGURE 5 Crash type percentages: (a) crash type percentages of different types of roundabouts, (b) crash type percentages of different at-fault driver residencies.

Estimate of Crash Frequencies

In order to compare the absolute amounts of different types of crashes, the crash frequencies were estimated and shown in Figure 6.

From Figure 6a, it is easy to tell that the multilane roundabouts have higher crash frequencies in all types of crashes than the single-lane roundabouts do. Although both types of roundabouts have similar percentages of run-off-road and rear-end crashes (Figure 5a), the multilane roundabouts have more than double the frequencies than the single-lane roundabouts. A possible explanation is that the multilane roundabouts have more approaching traffic than the single-lane roundabouts do, resulting in higher crash exposures.

Figure 6b further supports the implications of Figure 5b. The local drivers show higher frequencies in the first three types of crashes which are related to high approaching speeds, and the outside drivers show the highest frequency in sideswipe crashes that generally result from inappropriate lane choice. More importantly, for local drivers, the order of crash rate from high to low is run-off-road, rear-end, entering/circulating, and sideswipe. In contrast, for outside drivers, the order is totally reversed with sideswipe as the highest, followed by entering/circulating, rear-end and run-off-road. The opposite patterns between local drivers and outside drivers suggest a possible difference in driving behavior. These differences are: 1) local drivers tend to have higher navigation speeds because of their familiarity with the roundabout layout and lane usage; 2) outside drivers perform more cautiously because of the unfamiliarity about roundabout negotiation.



(a) (b)

FIGURE 6 Crash frequencies: (a) crash frequencies of different types of roundabouts, and (b) crash frequencies of different at-fault driver residencies.

CONFLICT EXPOSURE ANALYSIS

According to Equation 7, the conflict exposure rates were calculated and presented in Table 2. Since the observations were within the quadrants and focused on the circulating parts, the corresponding conflict exposure rates only accounted for the entering-circulating, sideswipe, and exiting-circulating crashes at multilane roundabouts (Figure 6a).

TABLE 2 Measures of Volume Based Conflict Exposure Rates

	Quadrant A				Quadrant B			
Inappropriate Negotiation	7:00 am | 9:00 am	2:00 pm | 4:00 pm	Average	Percent (%)	7:00 am | 9:00 am	2:00 pm | 4:00 pm	Average	Percent (%)
C1→C2	–	–	–	–	0.003	0.005	0.004	2.03
C1→Ex2	0.373	0.479	0.426	78.53	0.044	0.065	0.055	27.92
C2→C1	0.000	0.000	0.000	0.00	0.000	0.003	0.0015	0.76
C2→Ex1	0.002	0.001	0.0015	0.28	0.000	0.000	0.000	0.00
En1→C2	–	–	–	–	0.001	0.000	0.0005	0.25
En1→Ex2	0.000	0.007	0.0035	0.65	0.000	0.000	0.000	0.00
En2→C1	0.016	0.004	0.010	1.84	0.063	0.076	0.070	35.53
En2→Ex1	0.032	0.021	0.027	4.98	0.008	0.025	0.017	8.63
C2→C2	–	–	–	–	0.008	0.019	0.014	7.11
CVOL	0.106	0.039	0.073	13.46	0.043	0.019	0.031	15.74
FY	0.000	0.003	0.0015	0.28	0.002	0.005	0.0035	1.78
WY	0.000	0.000	0.000	0.00	0.001	0.000	0.0005	0.25

NOTE: Dash (–) indicates data not applicable.

It can be seen from the results that both roundabout quadrants have high exposure rates of C1→Ex2 and CVOL. C1→Ex2 was also the most common inappropriate negotiations observed by the previous studies *(3, 7)*. By taking this wrong negotiation, the vehicle creates a possible conflict if another vehicle travels close to it in the outer circulating lane, possibly resulting in a sideswipe or exiting-circulating crash. The CVOL negotiation has a similar effect as C1→Ex2. However, since the vehicle occupies both circulating lanes for a longer time when a CVOL happens, the possibility of a conflict or crash is higher.

The exposure of En2→C1 is also high in both roundabout quadrants, being the highest in quadrant B and fourth highest in A. This is because there were two circulating lanes to exit quadrant B, and lane En2 was also used for through movements. Meanwhile, quadrant A had only one circulating lane to exit and all vehicles in lane En2 were supposed to take a right-turn. The vehicle making En2→C1 would easily lead to conflicts between two circulating vehicles or between an exiting vehicle and a circulating vehicle. As a result, this type of inappropriate negotiation contributes to sideswipe and exiting-circulating crashes.

En2→C1 followed by C1→Ex2 forms a through path in the roundabout, which allows the driver to avoid the small deflection radius and maintain a high speed *(3)*. This is a possible reason why these two negotiation types have high occurrence rates.

En2→Ex2 also yields high exposures in both quadrants. This kind of negotiation increases the vehicle's interaction with the circulating lanes as well as the possibility of a sideswipe.

C2→C2 only applies to quadrant B and the corresponding conflict exposure rate is considerable. In high volume scenarios, this kind of negotiation would always result in exiting-circulating conflicts or even crashes, because the exiting vehicle from the inner circulating lane does not expect the vehicle of the outer lane to circulate.

The above conflict exposures explain the high percentage of sideswipe crashes at multilane roundabouts to some extent. But the percentage of exiting-circulating crashes is not as high as one would infer from the conflict exposures. Additionally, more studies are needed to interpret both the high percentage of entering-circulating.

SUMMARY AND DISCUSSION

The crash pattern analysis for Wisconsin reveals different safety performances between single-lane roundabouts and multilane roundabouts, as well as between local drivers and outside drivers. For single-lane roundabouts, it is difficult for entering vehicles to determine in advance whether or not a circulating vehicle will exit or continue, resulting in a potential entering-circulating conflict. Single-lane roundabouts generally have inadequate approaching-sight-distances that result in a higher percentage of entering-circulating crashes. Multilane roundabouts have more sideswipe crashes because most sideswipes happened between circulating vehicles. Multilane roundabouts have higher frequencies in all types of crashes than single-lane roundabouts, possibly explained by the heavier traffic at multilane roundabouts. Local drivers are more involved in rear-end crashes, resulting from the high approaching speeds encouraged by familiarity. On the contrary, outside drivers have a larger percentage of sideswipe crashes related to improper negotiations due to unfamiliarity. In terms of crash frequency, local drivers are higher in those crashes which are mainly caused by high speed (run-off-road, rear-end, and entering-circulating), and outside drivers have more sideswipe crashes which are commonly caused by inappropriate negotiation.

The conflict exposure analysis helps explain the high percentage of sideswipe crashes at multilane roundabouts. Vehicles traveling from the inside circulating lane to the outside exiting lane play the most significant role for multilane roundabout conflict exposure.

Two major things need to be done in the future to improve the analysis. First, more inappropriate negotiations should be defined along the approaching lanes and the exiting lanes, accounting for both single-lane and multilane roundabouts. This would help uncover the hidden explanations for crash patterns other than that of sideswipes. Second, actual conflict rates should be defined and measured. The actual conflict rate is going to be a bridge that explains the relationship between the conflict exposure rate and the crash rate.

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