Exploring Roundabouts
Safety and Operation in the Context of Design Consistency


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As noted in the U.S. Department of Transportation Federal Highway Administration's publication *Roundabouts: an Informational Guide*, modern roundabouts (or roundabouts in this study) were developed in the 1960s to address problems associated with traffic circles.[1] However, there still may exist some confusion between the roundabout and similar circular intersections (i.e. rotaries and traffic circles). This confusion may lead to opposition in considering a roundabout as a viable alternative for intersection-related projects. There are safety, operational, environmental, and economic benefits associated with roundabouts. Hence, it is important that the differences between roundabouts and other circular intersection forms be communicated accurately.

To illustrate the differences between roundabouts and other circular intersections, a case study was performed using data from the state of New Jersey. The aim of the study was to show the differences between roundabouts and traffic circles as they relate to safety and operational performance metrics and geometric features. Defining safety, operational, and geometric characteristics may help promote the implementation of roundabouts by eliminating the confusion that exists between roundabouts and traffic circles.

Background

Roundabouts differ from traffic circles (or rotaries) in two primary ways:

- Roundabouts require yield at entry, i.e. the traffic in the roundabout has right of way, and;
- Roundabouts have deflection at entry.

Several other characteristics of roundabouts that differ from traffic circles include inscribed circle diameter, speed, pavement markings, and driver's lane selection. In general, roundabouts tend to be small in diameter, and vehicles are forced to enter at low speeds, usually under 25 miles per hour (mph) with a high deflection approach.[2] Traffic circles have larger diameters and offer little to no deflection with speeds ranging from 30 to 40 mph.[2,3] Roundabouts mark lanes with striping and signage and promote the selection of a lane prior to entry compared to traffic circles that allow for drivers to weave in and out of lanes.[4] Moreover, roundabouts have yield control at entry whereas rotaries give priority to entering vehicles without signage to slow down their approach.[3] The misunderstanding of traffic circles and roundabouts may have led to public perceptions of roundabouts tending to be more negative than positive.[5] Roundabouts are generally a newer form of intersection design for the United States; this unfamiliarity may create confusion for users.[6] Understanding these operational differences help distinguish roundabouts from rotaries and would improve user perception, confidence, and performance.

Numerous studies have shown that converting signalized intersections or those with poor crash history into roundabouts has led to overall crash reduction.[7] Roundabouts' operational features force drivers to reduce their speed when approaching the intersection, regardless of the speed limit of the area, promoting safety.[8]

A study examining twenty-four roundabouts concluded that types of crashes at intersections are attributed to the geometric aspects, markings, and speed. Because roundabouts minimize angle crashes, there are generally less injuries and total crashes.[9]

Further improvements that can be made to promote the safety and operational efficiency of roundabouts include striping, signage, greater island diameters, and shorter flare lengths. These help reduce speeds and mitigate yielding, lane change, and turn violations.[10,11,12] With such improvements along with further data from similar studies, roundabouts will be designed and used in the most efficient and safe manner.

Research Needs and Objective

While roundabouts provide exceptional safety and operational benefits compared to traditional intersections, there still exists some confusion between roundabouts and traffic circles/rotaries in some locations.[7,8] The goal of this paper is to synthesize and identify various features of the roundabouts versus traffic circles to help practitioners and drivers promote not only roundabout implementation, but also provide observations that would support the benefits associated with roundabouts. For the purpose of this study, traffic circles will be used to represent circular intersections that are not roundabouts. In summary, the objectives of this study are to compare:

- Geometric, operational, and safety features between roundabouts and traffic circles; and
- Site attributes to explore and identify design features that may be linked to differences in crash performance.

Figure 1. Study Sites' Locations Details

Dataset

Based on the availability of traffic operational data and comprehensive collision incident reports, the state of New Jersey was selected as the broad jurisdiction for this research. Using an online database and other searchable resources, twenty sites were selected.[13,14,15]

Available traffic data included posted speed and annual average daily traffic (AADT). These are critical operational features with significant impacts on driver safety and optimal vehicle control during the circular maneuver. Geometric features of interest include inscribed diameter and the presence of proper deflection angle. This is because a roundabout by definition presents a relatively small inscribed diameter and employs entry/exit flares for speed control and traffic safety. Figure 1 presents twenty selected study sites in this study, while Table 1 denotes the catalogue of the study sites' features. Examples of typical roundabout and traffic circle are presented in Figure 2.

Table 1. Descriptive Statistics and Features of Study Sites

Features			Roundabouts	Traffic circles
Number of Sites			11	9
Geometric Features	Inscribed Diameter	Average	131 ft.	287 ft.
		Maximum	210 ft.	393 ft.
		Minimum	100 ft.	200 ft.
		Standard Deviation	32 ft.	81 ft.
	Deflection angle at all approaches?		Yes	Inconsistent
Operational Features	Speed Limit	Average	25 mph	35 mph
		Maximum	40 mph	45 mph
		Minimum	25 mph	25 mph
		Standard Deviation	5 mph	8 mph
	AADT *	Average	10,505	14,846
		Maximum	16,837	24,488
		Minimum	5,427	7,897
		Standard Deviation	3,548	5,053
	Yield Drivers in the circle?		Yes	Inconsistent

** Sites where AADT is available*

Crash records over a 10-year period from 2003–2012 were obtained from the Plan4Safety (P4S) database.[16] These records contained crash type, severity level, crash time, and site condition at the time of crash. Crash records were then analyzed in the scope of roundabouts and traffic circles to explore crash pattern per category such as crash severity level and type. The crash database contained a total of five crash severity levels as shown in Table 2.

Analysis Results

Analysis Process

The review of site features in Table 1 serves to differentiate roundabouts from traffic circles based on traffic, geometric design, and speed limit categories. This process will help to quantify the impact of the identified different element. Upon completion of the categorization, the crash data were analyzed to identify the distribution of crash severities and types at each site. A pairwise crash rate comparison analysis

Figure 2a. Sample Study Sites Example of Roundabouts

Figure 2b. Sample Study Sites Example of Traffic Circles

Table 2. Crash Frequency Distribution

	Roundabouts (11 sites)	Traffic circles (9 sites)
Crash Severity		
Property Damage Only (PDO)	381	1,674
Pain	62	374
Moderate Injury	15	55
Incapacitate Injury	1	3
Fatal	0	1
Crash Type		
Rear-end	113	921
Side swipe	164	537
Right Angle	71	260
Head On	3	22
Struck Parked Vehicle / Fixed Object	67	202
Backing / Left Turn / U Turn / Other	25	147
Pedestrian / Cyclist	16	18

was also performed to further support the importance of design consistency. This analysis process is presented in Figure 3.

Crash Frequency-based Analysis

The absolute crash frequency per crash type and severity level was reviewed first. Since the crash frequency highly depends on the traffic exposure, the normalized average percentage values were analyzed. Table 2 shows the resulting crash frequency distribution.

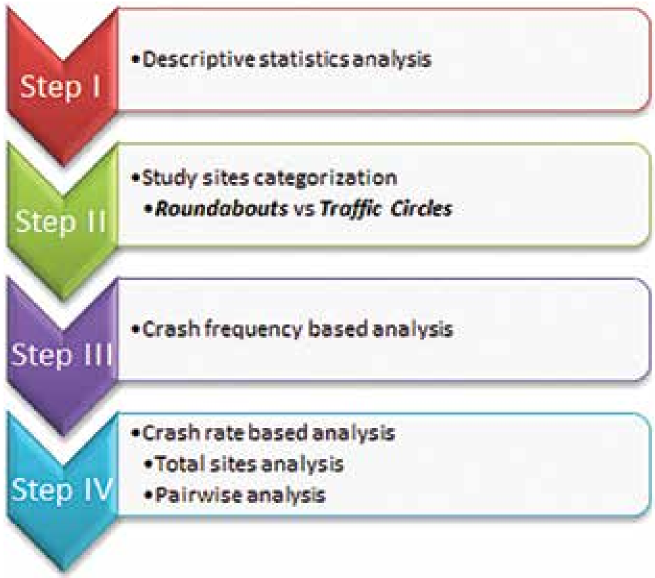
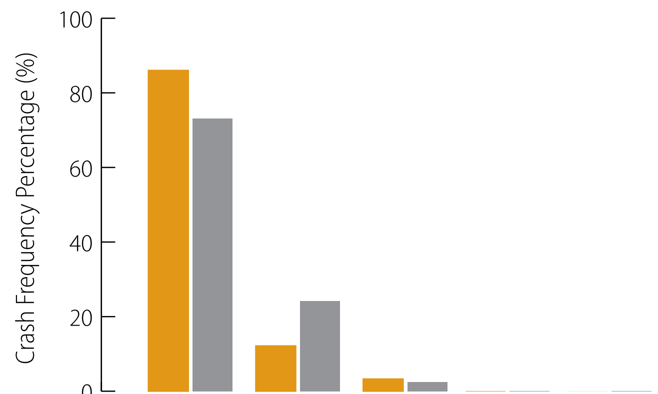


Figure 3. Data Analysis Flow Chart

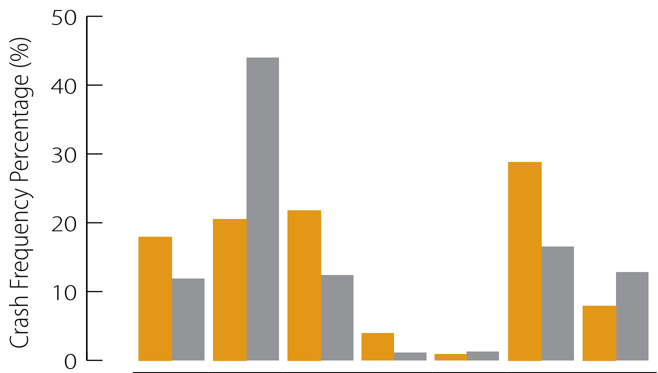
Figure 4a, which represents the crash severity frequency distribution, shows that PDO was highest for both categories. The crash severity data were later assigned speed limit threshold values (25 mph, 35 mph, and 45 mph) in order to further analyze the conditions that facilitate more severe collisions. Analysis results showed more frequent and severe collisions at higher speeds, which is consistent with the inherent danger of high-speed collisions.



	PDO	Pain	Moderate Injury	Incapacitating Injury	Fatal
Roundabouts	86.03%	12.16%	3.29%	0.09%	0.00%
Traffic Circles	73.07%	24.21%	2.52%	0.10%	0.10%

Figure 4a. Crash Frequency by Crash Severity (Speed Limit Less Than 25 mph)

In the analysis of crash data at a given site, it is crucial to note trends in the types of crashes occurring. This will potentially link more severe crash types to unsafe site conditions. Figure 4b compares average crash type frequencies for roundabouts and traffic circles operating at or below 25 mph.



	Right Angle	Rear End	Side Swipe	Ped/ Cyclist	Head On	Parked Veh/Fix Object	Back/ Turn/ Other
Roundabouts	17.88%	20.46%	21.73%	3.96%	0.92%	28.75%	7.86%
Traffic Circles	11.86%	44.03%	12.36%	1.10%	1.30%	16.54%	12.80%

Figure 4b. Crash Frequency Percentage by Crash Type (Speed Limit Less Than 25 mph)

Per site category, the correlation between crash severity and crash type was also investigated. Regardless of speed limit threshold values, it was observed that:

- The main crash type contributing to a crash severity level of PDO was side swipe for roundabouts and rear end for traffic circles.
- For both site categories, rear end was the most frequent crash type.
- In the moderate injury crash level, fixed object collision and rear-ends were the main types for roundabouts and traffic circles respectively.
- A limited number of incapacitating crashes were observed at both study sites; one crash at roundabouts and three crashes at traffic circles. Due to the limited number of these collisions, pattern investigation was not conducted.
- With one incapacitating crash and no fatalities associated over a 10-year period at the study sites, the corresponding observation is an encouraging report in promoting roundabout safety.

Crash Rate based Analysis

Traffic volume must be considered in addition to the total number of crashes at a site to yield a crash rate, determined by the following formula:

$$CR = \frac{1{,}000{,}000\ A}{365\ T \times V}$$

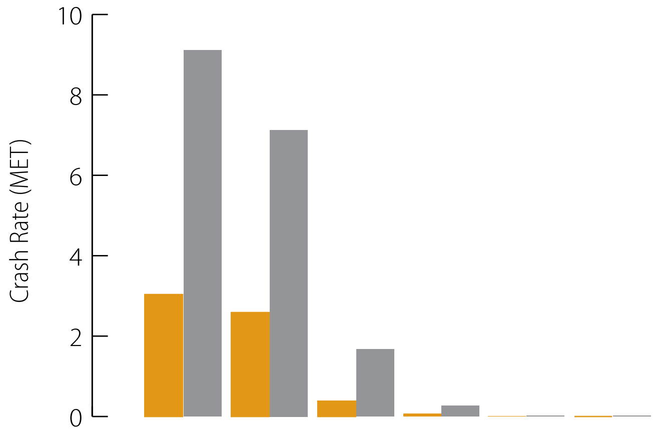
where:

CR = site crash rate (crash per million entering vehicles)
A = number of reported crashes
T = analysis time frame in year
V = AADT

The corresponding analysis only included sites with AADT information. In most cases, it was observed that traffic circles show a higher crash rate than roundabouts (Table 3). This pattern was more noticeable for lower speeds (25 mph) compared to higher speeds case. This may indicate a target operational speed between 25 and 45 mph for traffic circles. To establish rigorous design guidelines, a more comprehensive dataset analysis is needed. Except for sample sizes smaller than two it is apparent that traffic circles exhibit a higher rate of every collision type (Table 4). As Figure 5a shows, traffic circles exhibit higher crash rate across all injury levels. Another safety consideration was the crash rate per crash type. Figures 5b illustrates the crash rate distribution at a speed limit of 25 mph. Similar to Figure 5a, traffic circles present a higher crash rate for all crash types, especially in rear-end collisions.

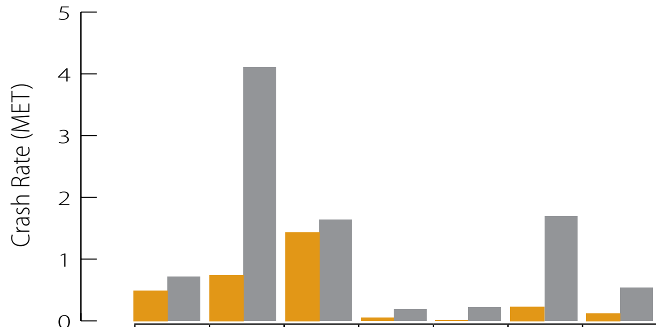
Table 3. Observational Comparison of Average Crash Rates of Roundabouts

			Average Crash Rate by Severity (MEV)				
N	**Category**	**Speed Limit Criteria**	**PDO**	**Pain**	**Moderate Injury**	**Incapacitating Injury**	**Fatal**
5	Roundabouts	<= 25 mph	2.586	0.381	0.064	0.010	0.000
2	Traffic circles	<= 25 mph	7.127	1.677	0.269	0.017	0.017
2	Roundabouts	> 25 mph	0.364	0.107	0.044	0.000	0.000
6	Traffic circles	> 25 mph	3.893	0.884	0.132	0.009	0.000
6	Roundabouts	<= 35 mph	2.257	0.346	0.068	0.008	0.000
4	Traffic circles	<= 35 mph	4.586	1.099	0.150	0.009	0.009
1	Roundabouts	> 35 mph	0.115	0.038	0.000	0.000	0.000
4	Traffic circles	> 35 mph	4.816	1.066	0.182	0.013	0.000
7	Roundabouts	<= 45 mph	1.951	0.302	0.058	0.007	0.000
8	Traffic circles	<= 45 mph	4.701	1.083	0.166	0.011	0.004
0	Roundabouts	> 45 mph	-	-	-	-	-
0	Traffic circles	> 45 mph	-	-	-	-	-



	Total	PDO	Pain	Moderate Injury	Incapac-itating Injury	Fatal
Roundabouts	3.034	2.586	0.381	0.064	0.010	0.000
Traffic Circles	9.107	7.127	1.677	0.269	0.017	0.017

Figure 5a. Crash Rate Analysis by Crash Severity (Speed Limit Less Than 25 mph)



	Right Angle	Rear End	Side Swipe	Ped/ Cyclist	Head On	Parked Veh/Fix Object	Back/ Turn/ Other
Roundabouts	0.482	0.734	1.428	0.050	0.010	0.221	0.115
Traffic Circles	0.713	4.106	1.640	0.191	0.226	1.693	0.539

Figure 5b. Crash Rate Analysis by Crash Type (Speed Limit Less Than 25 mph)

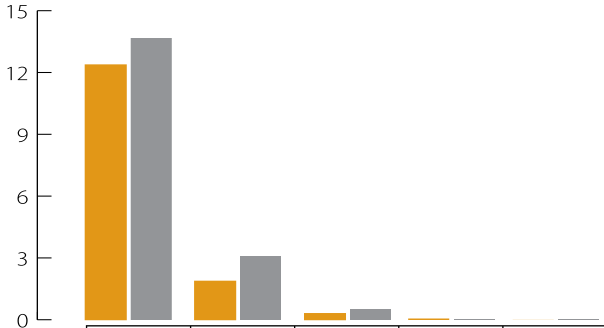
To further explore the safety and operational performance of roundabouts and traffic circles, sites that exhibit the same speed limit, similar AADT values, and differ but only in geometric layouts were compared. A total of three pairs were reviewed and the results are presented in Table 5. Table 5 illustrates that in most cases, traffic circles show higher crash rates across all crash severity levels, especially for rear-end crashes. It is the hypothesis of the authors that the geometric design differences such as non-presence of deflection, and the lack of yield upon entry at traffic circles may contribute to higher rear-end crash rate and greater severity levels when compared to roundabouts. The greater speed differential from approach to intersection may also contribute to the increase in rear end collisions.[17]

Figures 6 and 6b illustrate site comparison of Pair 1. Even though these two sites share similar traffic operational attributes, the difference in design features and right-of-way designation resulted in consistently lower crash rates for roundabouts across all severity levels. For Pair 2, as noted in Table 5, although their right-of-way designation is the same, due to the deflection angle dissimilarity, crash rates distributions were considerably different. These observations support the importance of design consistency, by demonstrating desirable safety performance metrics at roundabouts.

Table 4. Observational Comparison of Average Crash Rates of Roundabouts

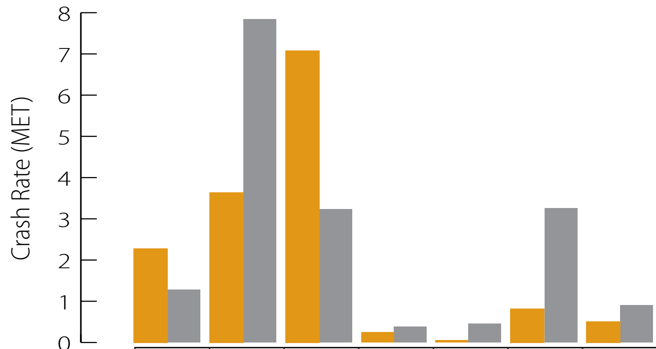
			Average Crash Rate by Type (MEV)						
N	**Category**	**Speed Limit Criteria**	**Right angle**	**Rear end**	**Side swipe**	**Head on**	**Pedestrian/ Cyclist**	**Parked Vehicle/ Fixed Object**	**Other**
5	Roundabouts	<= 25 mph	0.482	0.734	1.428	0.010	0.050	0.221	0.115
2	Traffic circles	<= 25 mph	0.713	4.106	1.640	0.226	0.191	1.693	0.539
2	Roundabouts	> 25 mph	0.088	0.239	0.019	0.000	0	0.063	0.107
6	Traffic circles	> 25 mph	0.618	2.148	1.368	0.029	0.016	0.337	0.401
6	Roundabouts	<= 35 mph	0.431	0.685	1.190	0.008	0.042	0.199	0.125
4	Traffic circles	<= 35 mph	0.715	2.740	0.969	0.123	0.095	0.896	0.313
1	Roundabouts	> 35 mph	0.000	0.038	0.038	0.000	0	0.038	0.038
4	Traffic circles	> 35 mph	0.569	2.535	1.903	0.032	0.025	0.456	0.558
7	Roundabouts	<= 45 mph	0.370	0.592	1.025	0.007	0.036	0.176	0.113
8	Traffic circles	<= 45 mph	0.642	2.638	1.436	0.078	0.06	0.676	0.436
0	Roundabouts	> 45 mph	-	-	-	-	-	-	-
0	Traffic circles	> 45 mph	-	-	-	-	-	-	-

Where PDO : Property Damage Only



	PDO	Pain	Moderate	Incapacitating	Fatal
Roundabouts	12.37	1.87	0.30	0.05	0.00
Traffic Circles	13.67	3.09	0.52	0.03	0.03

Figure 6a. Crash Rate Comparison of Pair 1 by Crash Severity (Speed Limit = 25 mph)



	Right Angle	Rear End	Side Swipe	Ped/ Cyclist	Head On	Parked Veh/Fix Object	Back/ Turn/ Other
Roundabouts	2.27	3.63	7.07	0.25	0.05	0.81	0.50
Traffic Circles	1.28	7.84	3.23	0.38	0.45	3.26	0.90

Figure 6b. Crash Rate Comparison of Pair 1 by Crash Type (Speed Limit = 25 mph)

Conclusion

This study aimed to synthesize design features that differentiate roundabouts from traffic circles by providing examples that support the importance of design consistency. This information could help clarify the existing confusion, and also benefit practitioners, engineers, and drivers. Findings showed:

- For both roundabout and traffic circle sites, PDO was the most frequently observed crash severity level.
- Based on crash rate analyses, in most cases roundabouts show lower crash rates.
- Pairwise crash rate analyses showed similar crash rate distribution in severity level and type compared to total crash rate analyses.
- The pairwise comparison supports a) larger inscribed diameters, b) absence of deflection, and c) no yield upon entry at the traffic circles may contribute to higher crash rate of rear-ends and severity of all crash types compared to the roundabouts.
- The above observations are consistent with the research goals, supporting the roundabouts' design consistency in safety and operation.

Table 5. Pairwise Comparison

		Pair 1		Pair 2		Pair 3	
		Roundabout	**Traffic Circle**	**Roundabout**	**Traffic Circle**	**Roundabout**	**Traffic Circle**
Operational Features	Speed Limit (mph)	25	25	25	25	40	40
	AADT (vpd)	5,427	7,898	14,639	15,485	14,339	16,927
	Yield to drivers in the circle?	Yes	No	Yes	Yes	Yes	No
Geometric Features	Inscribed Diameter (ft)	164	384	104	262	120	392
	Deflection for all approaches?	Yes	No	Yes	No	Yes	No
Crash Rate by Severity	Property Damage Only (PDO)	12.37	13.67	0.00	0.58	0.11	1.05
	Pain	1.87	3.09	0.00	0.27	0.04	0.18
	Moderate Injury	0.30	0.52	0.02	0.02	0.00	0.03
	Incapacitate Injury	0.05	0.03	0.00	0.00	0.00	0.00
	Fatal	0.00	0.03	0.00	0.00	0.00	0.00
Crash Rate by Type	Rear-end	3.63	7.84	0.00	0.37	0.04	0.92
	Side swipe	7.07	3.23	0.00	0.05	0.04	0.10
	Right Angle	2.27	1.28	0.00	0.14	0.00	0.02
	Head On	0.05	0.45	0.00	0.00	0.00	0.00
	Struck Parked Vehicle / Fixed Object	0.81	3.26	0.02	0.12	0.04	0.08
	Backing / Left Turn / U Turn / Other	0.50	0.90	0.00	0.18	0.04	0.15
	Pedestrian / Cyclist	0.25	0.38	0.00	0.00	0.00	0.00

Future research will include a more comprehensive and larger dataset that also includes drivers' information for more rigorous analyses.

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Endnotes

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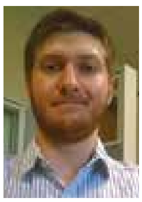

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