Examining Multi-lane Roundabouts in Minnesota.

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Abstract

Due in a large part to the success of single lane roundabouts there has been a significant increase in the planning and construction of Multi-Lane roundabouts within the United States. Estimates from Kittleson and Associates suggest that as of 2013 over 500 multi-lane and upwards of 1,400 single lane roundabouts in the United States[1].

Though multi-lane roundabouts have become a popular tool for intersections with high volumes, it is not always clear where and when they are the correct choice. Engineers and transportation officials have noted significant operational challenges; including: driver perceptions, driver confusion, lane choice decisions, striping and signing issues, bicycle and pedestrian concerns, ADA (Americans with Disabilities Act) compliance, and traffic safety/crash concerns. This has led to far from a clear picture of when and how these traffic control devices should be used.

In light of the above, the purpose of this project is to examine and highlight the main challenges of multi-lane roundabouts with a view toward setting realistic expectations for transportation designers and managers, as well as the general public. The crash data is meant to be exploratory and provide clarity to the other issues that multi-lane roundabouts are experiencing.

List of Acronyms and Terms

AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
A Crash	Vehicle crash were at least one person was severely injured and will have possible lifelong incapacitation or disability
ADA	Americans with Disabilities Act (1990 Federal Law)
A Rate	Serious injury (A crash) crashes are totaled, multiplied by one hundred million, and divided by the total number of entering vehicles in the same time span
B Crash	Vehicle crash were at least one person has a major injury but will recover.
B Rate	Major Injury (B crash) crashes are totaled, multiplied by one million, and divided by the total number of entering vehicles in the same time span.
C Crash	Vehicle crash were at least one person has a minor injury or complaint
C Rate	Minor injury (C crash) crashes are totaled, multiplied by one million, and divided by the total number of entering vehicles in the same time span.
Crash Rate	Total number of crashes in a given time span, multiplied by one million, and divided by the total number of entering vehicles in the same time span
CSAH	County State Aid Highway
CTL	Channelized Turn Lanes
FA (K+A) Rate	Fatal(K crash) and Serious(A crash) injury crashes are added, multiplied by one hundred million, and divided by the total number of entering vehicles in the same time span
F(or K) Rate	Fatal(K crash) crashes are totaled, multiplied by one hundred million, and divided by the total number of entering vehicles in the same time span
FHWA	Federal Highway Administration
HAWK	High Intensity Activated Pedestrian Beacon/ Pedestrian activated flasher
K Crash	Vehicle crash were at least one person was killed
MEV	Million Entering Vehicles (into an intersection).
MnDOT	Minnesota Department of Transportation
MUTCD	Manual of Uniform Traffic Control Devices
NCHRP	National Cooperative for Highway Research Programs
O&M Specialist	Operation and Mobility Specialist
OCPPM	Office of Capital Programs and Performance Measures (MnDOT)

OTST	Office of Traffic, Safety, and Technology (MnDOT)
PDO Crash	Vehicle crash were there is only property damage to either vehicle or personal property. No person suffered any injury.
PDO Rate	Property Damage (PDO crash) crashes are totaled, multiplied by one million, and divided by the total number of entering vehicles in the same time span.
PROWAG	Public Right of Way Accessibility Guidelines
RRFB	Rectangular Rapid Flashing Beacon
TH	Trunk Highway
TWLTL	Two Way Left Turn Lane

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Introduction

In Minnesota, as of 2016 there are over 160 roundabouts throughout the state[2]. Most of these roundabouts are single-lane roundabouts and located in urban areas. Traffic and transportation engineers accept that roundabouts are a safer intersection choice then signalized and thru-stop (minor leg stops, major leg does not) type intersections, especially when considering fatal and serious injury crashes. However, single lane roundabouts have capacity limitations, especially when the total Average Daily Traffic exceeds 20,000 vehicles per day[3]. There is also concern with large trucks being able to navigate the tighter single-lane roundabouts. With the success of single lane roundabouts in regards to traffic safety, increased capacity at moderate volumes, and increasing public acceptance, officials have sought to attempt higher volume intersections. The solution to the capacity limitations and truck maneuvering has been the multi-lane roundabout. For the purposes of this paper, multi-lane roundabouts will be defined as any roundabout that has two lanes in the circulating roadway center on any given leg. Further descriptors that will be used will include “unbalanced”, which means that different legs have a different number of circulating lanes (sometimes called 1 by 2, 2 by 1, 1.5 lanes, etc.). The term “dual lane” will mean a roundabout that has two circulating lanes on all four legs. Multi-lane roundabouts can likely handle double the amount of traffic volume compared to single-lane roundabouts, often handling more traffic than signalized intersections with much less delay.

However, as deployment of multi-lane roundabouts has begun, officials have noticed several problems with multi-lane roundabouts. These problems include driver perceptions, driver confusion, proper lane choice decisions, striping and signing issues, bicycle and pedestrian concerns, ADA (Americans with Disabilities Act) compliance, and concerns with traffic safety and the frequency of crashes.

Transportation officials must be sensitive to public opinion. Citizens have expressed concern about the confusion of navigating roundabouts, and are more perplexed when it comes to multi-lane roundabouts. Transportations officials need to properly educate and engage the public with this type of intersection control. Officials must set realistic expectations when telling the public what is being delivered. When setting expectations that are unrealistic, there could be a public backlash against this important tool.

This study will elaborate and explore these issues.

Success with Single Lane Roundabouts

Single Lane Roundabouts started appearing in Minnesota in the late 1990's and early 2000's[2]. Roundabouts are succeeding with reduced traffic crashes and reduced congestion. With this success, they continue to be used and built as a traffic control device.

The crash data from single lane roundabouts is showing a clear reduction in nearly all crashes, and most importantly for fatal and serious injury crashes. These numbers are largely consistent with other studies and research reports around the country after the installation of roundabouts. The figures below show the change in crashes of sites treated with roundabouts. Crashes with a severity injury of K and/or A are shown as the number of crashes per 100 million vehicles entering. All other crash rates are expressed as crashes per one million vehicles entering the intersection.

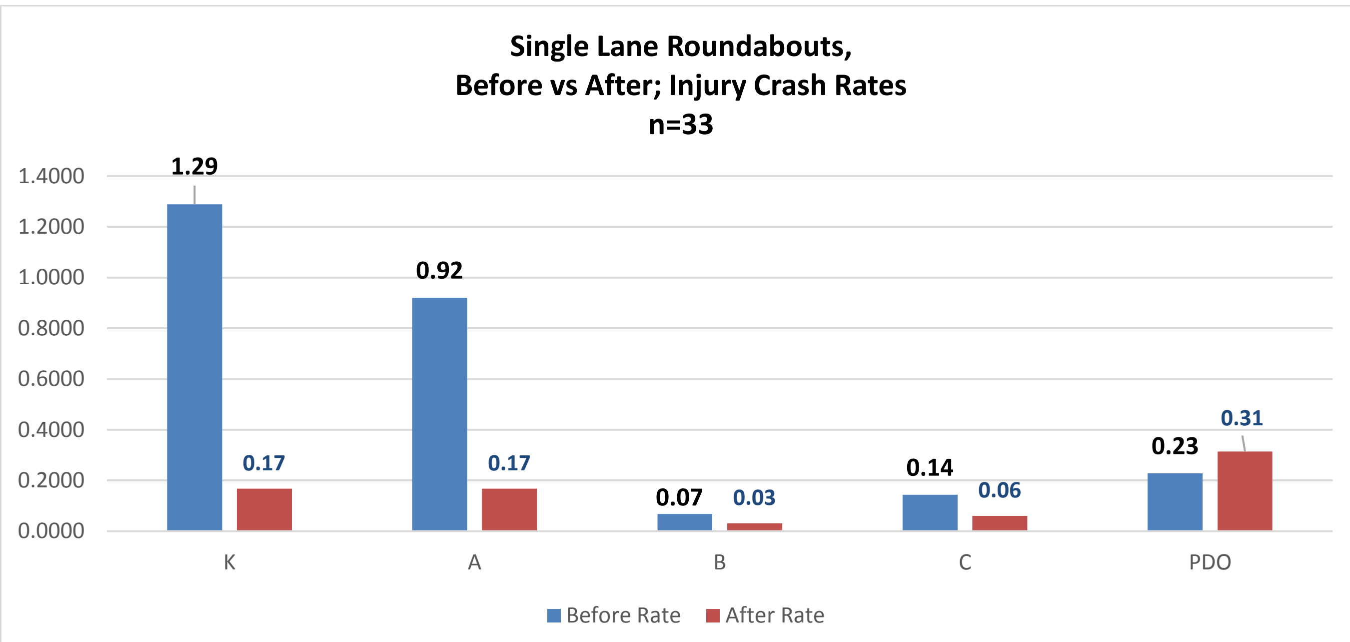

Figure 1: *Single Lane Roundabouts; Before versus After, by Injury Crash Rates.*

The crash data from Figure 1, Figure 2 and Figure 3 was taken from 33 single lane roundabouts that had at least 3 years of before crash data and at least 3 years of after crash data. Crashes were those that occurred within 300 feet of the intersection center. Crashes that were coded as "non-intersection", "unknown relation to junction", "animal related", "collision with a parked vehicle", or "collision with a train" were excluded from this analysis.

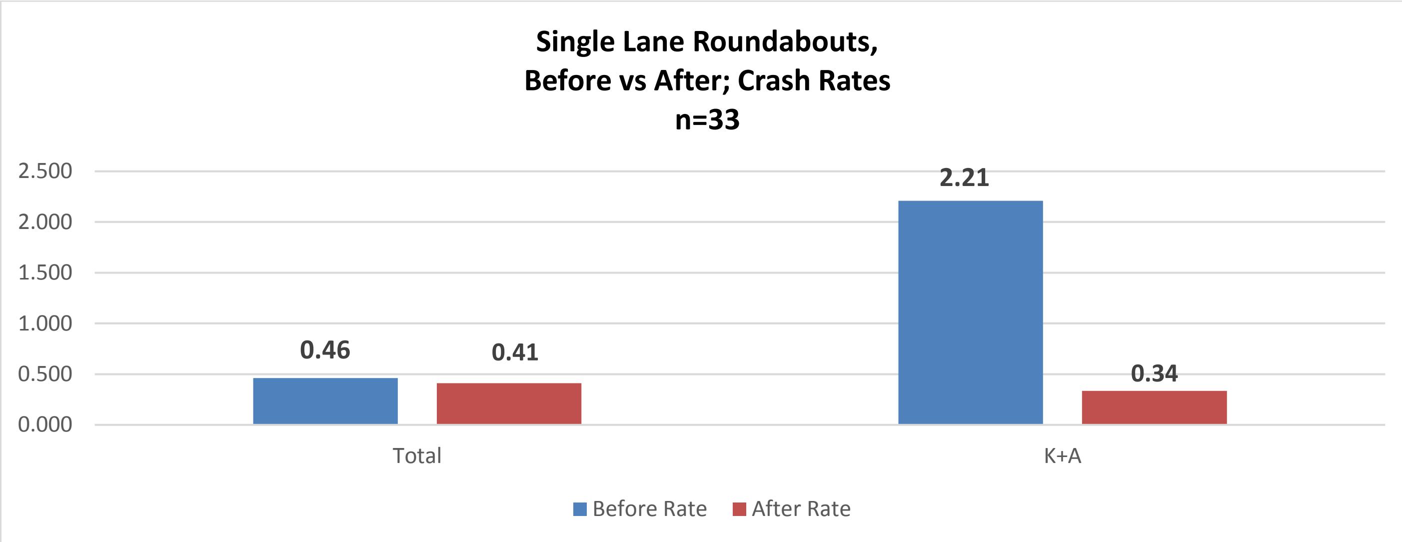

Figure 2: *Single Lane Roundabouts; Before vs. After, by selected Crash Rates*

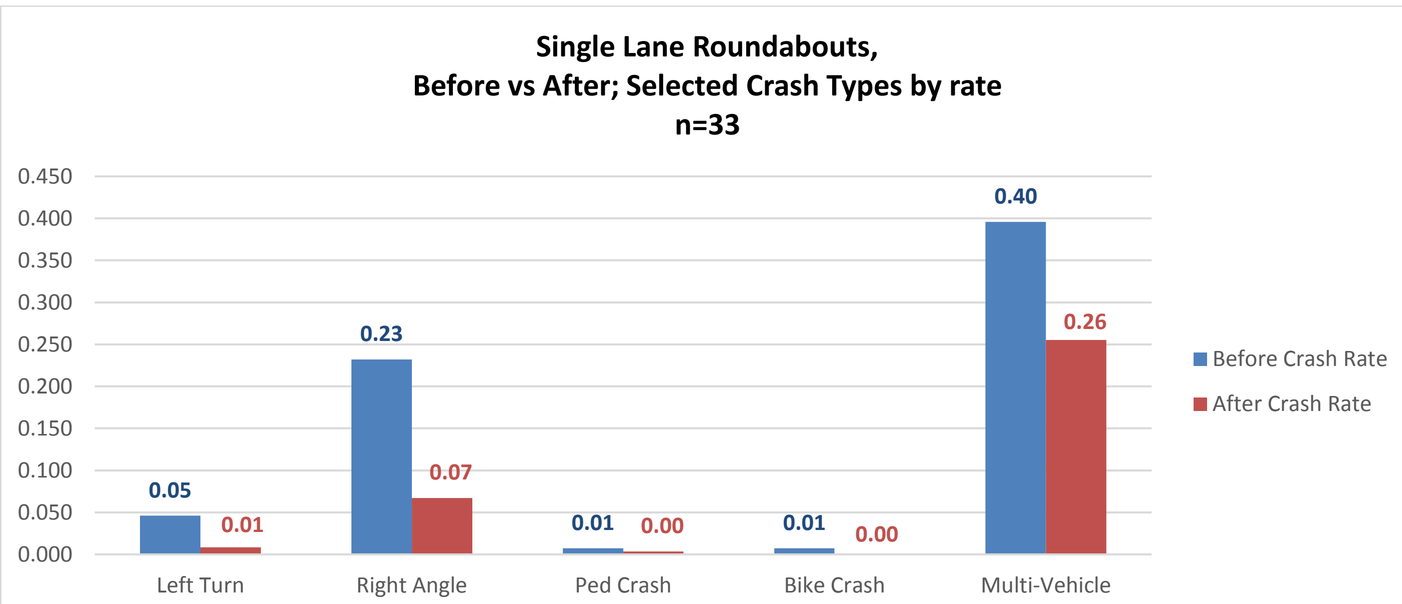

Figure 3: *Single Lane Roundabouts; Before vs. After, by selected Crash Types*

The use of single lane roundabouts has shown a reduction of 11% in total crash rate, and an 85% reduction in the severe (K+A) crash rate. Left turning and right angle crashes have reduced by 81% and 71% respectively in single lane roundabouts. Right angle crashes tend to be the most severe crashes, and contributes to more fatalities than any other crash type in Minnesota.

With the success of single lane roundabouts, multi-lane roundabouts seem to be the next logical step. Multi-lanes can offer greater capacity and reduced delay.

Capacity of Roundabouts

Traffic Volumes

The capacity of roundabouts is a continuing on-going study. The *FHWA Roundabout Guide* has an estimated guide for the anticipated capacity of various roundabouts based on the traffic ratios of the major versus minor legs. The report estimates that a multi-lane roundabout can operate at 40,000 to 50,000 entering vehicles per day. Though written in 2000, it still provides a good planning level outline for the appropriate traffic volumes that a single lane and a multi-lane can handle.

Several software packages have also been released that try too effectively model the level of service and capacity of roundabouts based on the geometrics and traffic turning movements.

The largest benefit of multi-lane roundabouts appears to be the high volumes that can flow thru them. Multi-lane roundabouts reduce congestion and reduce delay. As an example, the MNTH 22 and Madison Avenue ICE Report modeled an upgraded signal (there is an existing signal today) and a multi-lane roundabout. MNTH 22 and Madison Avenue is located in Mankato, Minnesota. The existing configuration in the year 2032 will operate from Level of Service (LOS) D-F with an overall LOS of D (42.6 seconds of overall delay). The upgraded signalized intersection will operate from LOS D-E, with an overall LOS C (32.6 seconds of overall delay). The multi-lane roundabout will operate from LOS C-E, with an over LOS C (24.7 seconds of delay).

This is the largest strength of multi-lane roundabouts. The increased capacity and reduced delay (for drivers) will need to be highlighted if a multi-lane is the decided intersection control type.

However, as the next few sections will highlight, multi-lane roundabouts are suffering from several operational challenges. These challenges include driver perceptions, driver confusion, proper lane choice decisions, striping and signing issues, bicycle and pedestrian concerns, ADA (Americans with Disabilities Act) compliance, and concerns with traffic safety and the frequency of crashes.

Current Issues with Multi-Lanes

Driver Perception

In many areas of the United States and within Minnesota, there is still a strong negative reaction to the idea of roundabouts. In NCHRP Report 264[6], though an older survey (1998), found there to be considerable negative opinions about roundabouts before construction. Since NCHRP 264 was published, a considerably larger number of roundabouts are built and operating around the country. NCHRP Report 264 may be outdated. However, it does highlight that after a roundabout is complete and operational, the opinion swings too positive and neutral, with very few negative opinions.

This information and experience has been compiled on single lane roundabouts. Multi-lane roundabouts are unknown to most motorists. Though anecdotal, many drivers feel frustrated with the multi-lane roundabout concept, being confused with how the intersection operates and how to interact with other drivers. It appears even with extensive community education and the construction of single lane roundabouts, this problem persists.

While single lane roundabouts are successful, and this is leading to the construction of more single lane roundabouts, this does not appear to be true with multi-lane roundabouts. In many communities where the multi-lanes are built, it has become even more difficult to propose another multi-lane. In two separate instances, two separate dual lane roundabouts have been reconfigured with striping and temporary traffic control devices to unbalanced roundabouts in Minnesota. Officials need to be cautious proceeding with multi-lane roundabouts, and set realistic expectations with the public about the performance that can be expected once constructed. If this is not done properly, and expectations do not match reality, officials from the local to the state level could experience a public blowback. This may cause multi-lane roundabouts becoming completely unacceptable to the public (whether through public opinion or legislation). Though multi-lanes are suffering several operational difficulties, the option should never be removed.

Driver Confusion

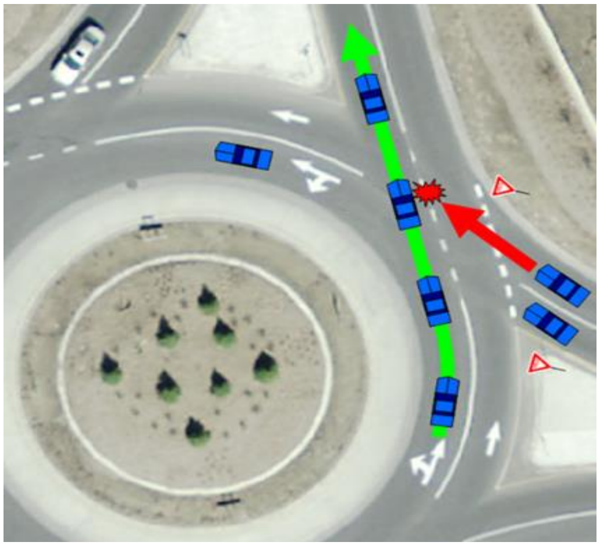

Figure 4: *Crash resulting from failure to yield*

Fully built multi-lanes across the country are showing that drivers are confused about lane choice as they approach a multi-lane roundabout, and how to correctly navigate the roundabout. Crashes at multi-lane roundabouts have consisted of two major crash types. The first is with yielding to the traffic within the roundabout (Figure 4). Crash reports and other studies find that this is about one third of the crashes at a multi-lane roundabout. This is perplexing to many engineers as single lane roundabouts typically do not have this issue, and not nearly to the degree that multi-lane roundabouts do.

The second crash issue is when drivers change lanes within the multi-lane, as a result of getting in the wrong lane on approach and proceeding through the multi-lane in an incorrect (even illegal) manner. This can be making a right turn from the left lane or making a left turn or U-turn from the right lane. As the driver intent can become unclear or unknown to other drivers within the roundabout, this maneuver causes about one-third of the total crashes. The last third comes from an assortment of rear ends, run off the road, wrong way, pedestrian/bicycle crashes, and hitting items in the center island and signing.

Correct Lane upon approach/ Signing Issues

The need to get drivers into the correct lane as they approach the intersection appears to be extremely important. In the configurations displayed in the Minnesota Manual of Uniform Traffic Control Devices (MnMUTCD), the driver that wishes to turn left should be in the left lane. Drivers wishing to go straight can be in either lane, and drivers wishing to go right should be in the right lane. Many engineers have expressed frustration when watching multi-lanes operate, as it should be intuitive that drivers wishing to turn left should be in the left hand approach lane.

This is how nearly every other at-grade intersection operates. Engineers at MnDOT responsible for traffic control devices and engineering design believe there may be a preconceived idea to drivers that as one approaches the roundabout, they feel they will exit the roundabout on the outside lane[11]. Since drivers expect to exit the roundabout on the outside lane, they will enter on the outside lane.

Many different signing and striping configurations have been attempted to alleviate this problem and to get drivers into the correct approach lane.

The three signs that have been the most used in Minnesota are the standard signing with a dot to represent the center-island, and "fish-hooks" with or without the dot. Based on interviews with engineers at the Minnesota Department of Transportation, the standard signing with the dot is appearing to be the most effective[12].

In October 2007, the Federal Highway Administration (FHWA) released a study regarding signing and lane choice for multi-lane roundabouts[13]. The FHWA operates a large driving simulator that can realistically create driving conditions and then test drivers with different scenarios and see how they react. The simulator can also create multiple signing and striping packages with the same geometric conditions and then see how changing certain variables can change behavior of the test drivers.

The results showed that all 5 signing packages had a compliance rate between 88.6% and 90.7%. No one signing package significantly outperformed any of the others, and none failed (85% was the performance measure to pass). The researchers found that drivers were more consistent in choosing the right lane correctly (94.8%) versus the left lane correctly (82.3%). However, it appears that drivers do not understand the idea of either lane being an option. When either entry lane was the correct choice, the driver responded correctly only about 44% of the time[13].

The report suggests that any signing scheme works about the same. The report concludes with the following:

> *"In summary, all five of the entry lane restriction signing and marking schemes performed equally in terms of driver compliance, with no meaningful differences among them. Furthermore, under no scheme did any participant attempt to drive around the circulatory roadway in the wrong direction. However, the research participants did not comprehend very well the concept of "either lane" being available as a roundabout entry choice."*[13]

There has been considerable discussion within MnDOT that the most effective, and possibly the only option, to get the most drivers into the correct lanes before the intersection may be overhead signing. Existing experience, and the FHWA study, are indicating that ground mounted signs are not visible enough for drivers to choose the correct lane with enough time to select a lane. Overhead signing would tell drivers the exact lane they need to be positioned within before the roundabout approach lanes. Getting drivers into the correct lanes will then greatly reduce crashes within the circulatory roadway since drivers will no longer need to switch lanes.

However, overhead signs would bring significant additional costs to the roundabout. A planning level estimate for cantilever type signs is typically $50,000 to $75,000 dollars. For full overhead signs that bridge the roadway with supports at both ends, current costs range from $125,000 to $150,000 per approach. With more rigorous safety standards, full bridges are likely to be used in the future. If fully bridged signs on all four approaches are required, this could increase the cost of a multi-lane roundabout by up to $600,000. Further study will be needed to see if such signing can be justified based on the benefits (crash reductions) versus the costs.

Circulatory Striping Configurations

In 2009, the Federal Manual of Uniform Traffic Control Devices (Federal MUTCD)[14] released striping configurations for multi-lane roundabouts for the first time. As with many items in the MUTCD, they are typically added with little data, but significant discussion of the manual's committees and experts. Only after many years of wide deployment of an item, and studying a specific issue, can items be changed, clarified, or removed. The striping packages included in the MUTCD are a collective of current best practices. The MnMUTCD states that multi-lane roundabouts shall have lane line markings on the approach, but only states that they should have lane line markings within the circulatory roadway[15]. The Federal MUTCD states the same language. In the MUTCD, the word "shall" is a must comply condition, while the word "should" is a recommendation.

There has been considerable debate about the markings within the circulatory roundabout. Some engineers have suggested that the MUTCD recommended markings with pavement message arrows and significant striping will achieve the best results. Others have argued that minimal to no markings within the circulating roadway may be the most appropriate.

With many multi-lanes throughout the United States, this could be studied more rigorously. Each state is developing different standards for striping configurations, giving many different sample types to compare. Currently, Colorado and Kansas are not striping the circulatory roadway. Other states are following the MUTCD guidance.

With different types of schemes, and no clear correlation between crash performance and marking schemes, markings within the circulatory may or may not play a role in the crash performance of the intersection.

Pedestrian, Bicycle, and ADA Considerations

Pedestrian and Bicycle groups have expressed frustration with roundabouts. The largest concern comes from vehicles that are exiting the roundabout. As vehicles exit a roundabout, they are typically accelerating in speed. This comes from the drivers believing they have navigated the roundabout, and the geometric conditions of the super-elevation within the intersection has switched from being uncomfortable for the driver (this is done intentionally) to a normal super-elevation allowing the driver to feel comfortable again. As the driver becomes comfortable, they speed up from less than 15 miles per hour (mph) to a much higher speed. For various reasons, drivers are not looking for pedestrians or bicyclists.

There are conflicting research reports and studies stating whether roundabouts are positive or negative for bike and pedestrian safety. Several studies indicate that single lane roundabouts offer a greater level of safety, especially versus signalized and non-signalized intersections. Other groups, mostly pedestrian and bicycle advocacy groups, express concern and have conducted limited studies showing roundabouts as being a hazard.

The United States Access Board published the Public Right-of-Way Access Guidelines (PROWAG) in 2011[19]. PROWAG is a set of published guidelines written to help elected officials, government agencies, engineers, and policymakers deal with issues regarding the Americans with Disabilities Act (ADA). Regulations and court rulings from ADA have decisively shown that all Americans, regardless of physical abilities, have an inherent right to use public right-of-way to achieve mobility, and to do so with a minimal level of risk. The Minnesota Department of Transportation has adopted nearly all of PROWAG as a standard for dealing with ADA issues on the State Right-of-Way. The notable exception not adopted is the section on roundabouts.

However, NCHRP Report 674[8] is an in-depth study regarding pedestrians with low visual abilities (visually disabled or blind). The report closely observed visually disabled persons crossing different types of “free” turning movements. The report looked at channelized turn lanes (CTL), single lane roundabouts, and multi-lane roundabouts. Though the sample site size is small (2, 3, and 2 respectively), the researchers had visually impaired individuals cross each site over 100 times to gain a more rigorous sample size.

The report used three main performance measures to indicate how much ease, and risk, there is with each crossing type. The first was overall delay; defined as the amount of time it took a person to wait before they felt comfortable crossing.

The report found that the free turning CTL’s (think of a channelized, free right turn lane at a signalized intersection) had the longest delay for the pedestrian crossing. It is theorized that the pedestrian had to gain knowledge of when opportunities were available, and then decide to go on the next similar opportunity. Due to frequent turns and high speeds in the CTL, delay grows. Though similar, roundabout pedestrian delay is about 9-10 seconds shorter than the CTL’s.

Single Lane and Multi-Lane Roundabouts had nearly the same level of overall delay (16 seconds versus 17 seconds, respectively).

The report concluded that multi-lane roundabouts present *an unacceptable level of risk* to visually disabled pedestrians (page 84, NCHRP 674). The research team recommended that multilane roundabouts be installed with pedestrian HAWK signals and/or raised pedestrian walkways.

The report does not mention the cost of a HAWK system. Current planning level guidance suggests $100,000 to $150,000 per device. If this recommendation becomes standard, this could build an additional $400,000 to $600,000 (four approaches with a HAWK on each approach) per multi-lane roundabout.

In Michigan, a group of disabled and blind citizens brought suit against the Michigan Department of Transportation (MDOT) and the Road Commission for Oakland County (RCOC) after the installation of a two lane and a three lane roundabout in 2007. The suit alleged that the roundabouts were inhibiting on the civil rights of the disabled and blind to conduct their daily commerce. The lawsuit claimed the roundabouts directly violated the ADA and several sections of Federal Law.

In December of 2011, the Plaintiffs and County settled out of court with an agreement[10]. The county would install Pedestrian Activated Beacons (HAWK's) or Rectangular Rapid-Flashing Beacons (RRFB) at the roundabouts to increase the safety for those with disabilities and visual impairments. MDOT and RCOC also agreed to study the results after the installation[10]. The RCOC placed an RRFB at the intersection of Maple Road and Farmington Road (ADT = 41,700), and a HAWK at the intersection of Maple and Drake (ADT = 41,500).

Researchers went to the sites with both blind and sighted pedestrians to conduct the experiment, both before and after the installation of HAWKs or the Rectangular Rapid-Flashing Beacon (RRFB). The results for both intersections and installations showed that after the installation of the countermeasure, O&M interventions decreased for blind pedestrians (sighted did not need O&M specialists), average delay decreased, and driver yielding compliance increased.

Though this is not federally mandated, signalizing roundabouts may make their effectiveness diminish, and is counterproductive to the original intent of the roundabout.

Safety and Crash Analysis

Examining 144 roundabouts within the state of Minnesota that had crash data, a comparative analysis of the roundabout crash performance was completed. The Definition of terms used, and how they are calculated, is shown in the List of Acronyms and Terms.

The crash data in Table 1 shows the number of crashes based on the type of roundabout. These numbers are, when adjusted for rates, appear consistent with other studies and research reports around the country in showing the performance in crashes after the installation of various roundabouts.

Description	Number of Sites	Site Years	Entering Volume	K Crashes	A Crashes	B Crashes	C Crashes	PDO Crashes	Total Crashes
Single Lane	104	571	1,604.8 MEV	1	4	35	87	391	518
Unbalanced	34	98	661.0 MEV	0	1	21	73	411	506
Dual Lane	6	31	226.8 MEV	0	0	15	52	396	463

Table 1: *Aggregated Crash Data, by Injury, from Minnesota Roundabouts (2006-2015)*

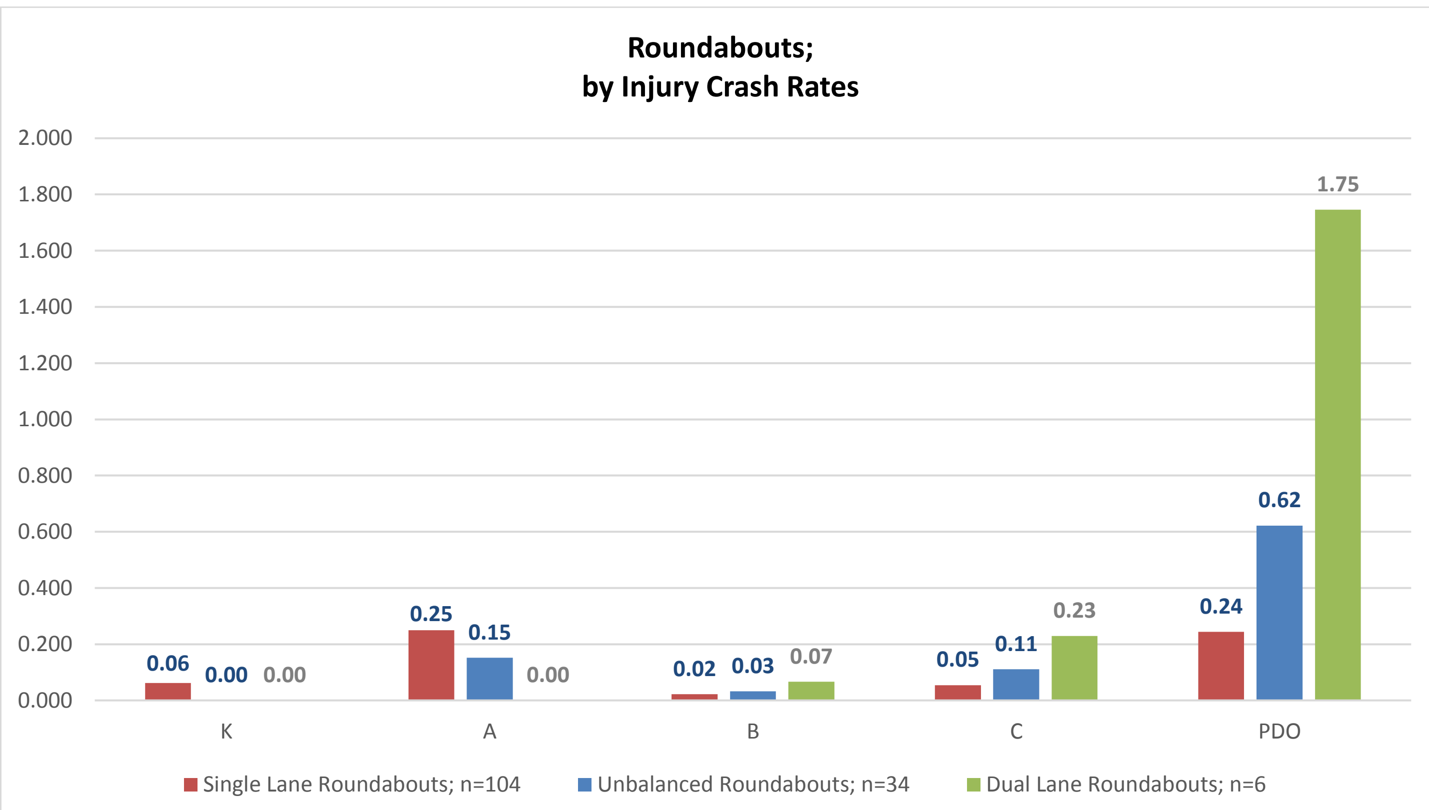

Figure 5: *Comparing roundabout types by injury rates*

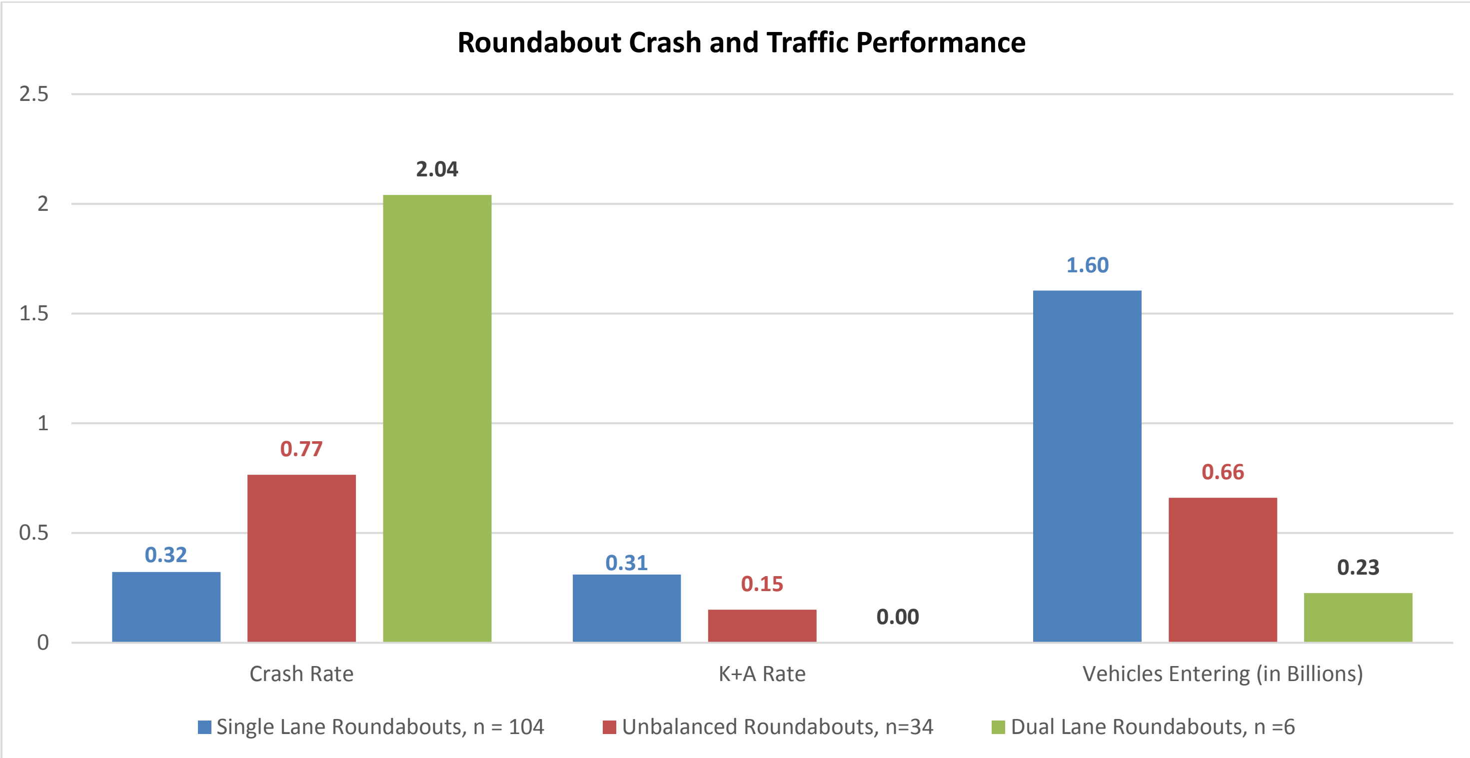

Figure 6: *Roundabouts Crash and Traffic Performance, by Type*

Though single lanes are showing great success, multi-lanes are not having the same success. This is especially true in the all crashes performance. All roundabouts seem to be performing well when looking at severe (K+A) crashes.

The unbalanced and dual lane roundabout crash rate is also 240% and 630% greater, respectively, than the single lane roundabouts in Minnesota.

Description	Number of Sites	Rear-End Cashes	Sideswipe – Same Direction	Left Turning	Run-off-Road	Right Angle	Multi-Vehicle	Ped Crash	Bike Crash
Single Lane	104	132	42	11	100	89	313	10	3
Unbalanced	33	114	164	5	59	80	403	3	0
Dual Lane	6	63	204	19	19	102	427	5	2

Table 2: *Aggregated Crash Data, by selected types, from Minnesota Roundabouts (2006-2015)*

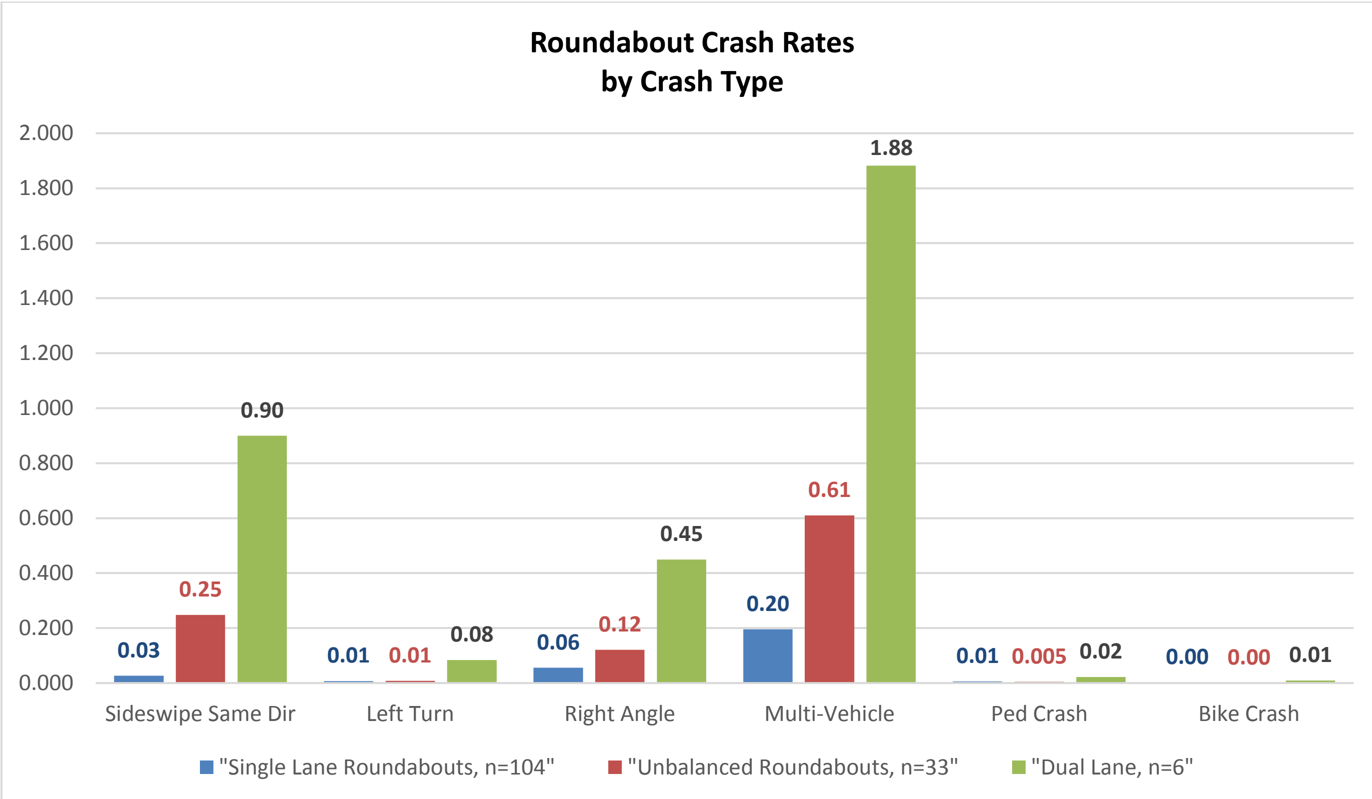

Figure 7: *Roundabout Crashes, selected types (2006-2015)*

Conclusion of Current Issues

Multi-lane roundabouts are showing several problems that require complex solutions. These solutions could add significant costs for a multi-lane roundabout to function correctly. With overhead signing, pedestrian activated signals (HAWKS), and continuous experimentation with signing and striping, these add to the final cost. Overhead signing and HAWK's alone could add $1.2 Million per intersection.

The safety performance of multi-lane roundabouts is not definitive; it appears they have a similar safety performance to high volume, low speed signalized intersections; defined by MnDOT as a traffic volume greater than 15,000 ADT, and the posted speed is less than 45 mph. This is similar to the operations of a multi-lane roundabout.

Multi-lane roundabouts could be built as a capacity solution to highly congested areas, not as solely safety solutions. MnDOT constructs other devices for safety that increase crash rates as a whole, but will reduce severe crashes.

Conclusions

Single-lane roundabouts have achieved great success in Minnesota. Single-lane roundabouts have reduced severe and injury crashes across the state. They have also gained positive feedback and acceptance once constructed. With this success, transportation officials have tried to duplicate this success with multi-lane roundabouts. In Minnesota, and nationally, multi-lane roundabouts have been having operational challenges with driver perceptions, driver confusion, lane choice decisions, striping and signing issues, bicycle and pedestrian concerns, ADA (Americans with Disabilities Act) compliance, and traffic safety/crash concerns.

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