Effect of Roundabouts on Accident Rate and Severity in Arizona

by

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ABSTRACT

This study examines the outcomes of roundabouts in the State of Arizona. Two types of roundabouts are introduced in this study, single-lane roundabouts and double-lane roundabouts. A total of 17 roundabouts across Arizona were chosen upon several selection criteria and according to the availability of data for roundabouts in Arizona. Government officials and local cities' personnel were involved in this work in order to achieve the most accurate results possible. This thesis focused mainly on the impact of roundabouts on the accident rates, accident severities, and any specific trends that could have been found. Scottsdale, Sedona, Phoenix, Prescott, and Cottonwood are the cities that were involved in this study. As an overall result, both types of roundabouts showed improvements in decreasing the severity of accidents. Single-lane roundabouts had the advantage of largely reducing the overall rate of accidents by 18%, while double-lane roundabouts increased the accident rate by 62%. Although the number of fatalities was very small, both types of roundabouts were able to stop all fatalities during the analysis periods used in this study. Damage rates increased by 2% and 60% for single-lane and double-lane roundabouts, respectively. All levels of injury severities dropped by 44% and 16% for single-lane and double-lane roundabouts, respectively. Education and awareness levels of the public still need to be improved in order for people to be able to drive within the roundabouts safely.

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1 INTRODUCTION

BACKGROUND

Modern roundabouts are the newest traffic control system and differ from their successors as traffic circles and rotaries in three major topics (Baranowski, 2015):

1. Modern roundabouts give vehicles within the roundabout the right-of-way.
2. Modern roundabouts are smaller, ranging from 70-160 ft., than the older editions of rotaries, which used to range from 300-400 ft. Currently, space is a very important demand within the transportation department and that is why modern roundabouts solved the issue of consuming large areas to construct a rotary.
3. Modern roundabouts have raised splitters and islands, which help reducing entry speeds while driving inside the roundabout, which are one of the major benefits of modern roundabouts.

Figure 1 shows a typical simple modern roundabout design, whereas Figure 2 shows a small modern roundabout vs. a large traditional rotary or traffic circle (Oregon DOT, 2000).

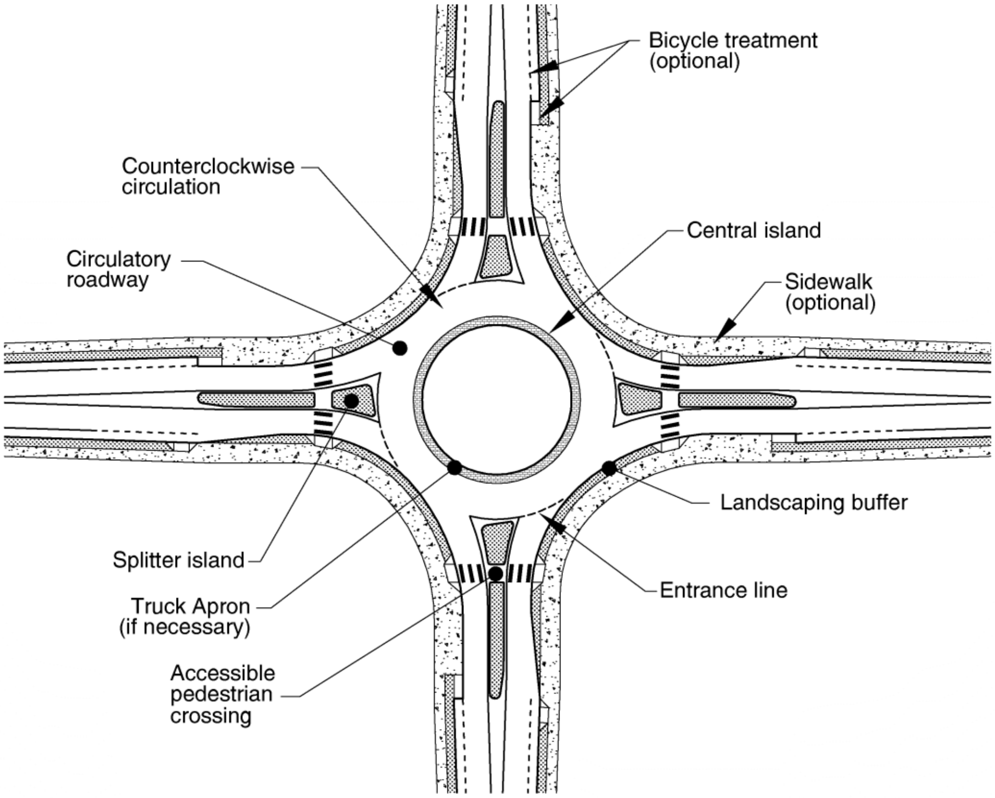

Figure 1: Typical modern roundabout design.

Figure 2: Small modern roundabout vs. large traditional rotary or traffic circle.

According to the Arizona Department of Transportation, modern roundabouts are designed in a way that would reduce crashes and improve traffic flow (ADOT, 2015a). Through learning and understanding how a roundabout works and how to drive through it, the optimum results can be achieved.

The more and the bigger the data set used for a study, the more confident results could be drawn out of it. For that sake, in this study five cities from Arizona were chosen. The following are the cities that include the evaluated roundabouts:

1. City of Scottsdale
2. City of Sedona
3. City of Phoenix
4. City of Cottonwood
5. City of Prescott

The City of Scottsdale is considered one of the lead locations in Arizona that began using the roundabout's idea. The idea of roundabouts was implemented for the first time in Scottsdale during the 1980s (City of Scottsdale, 2016), when the city was going through a traffic-calming project. Scottsdale started implementing roundabouts even before the public heard about them or official designs were published.

Roundabouts were used in Scottsdale as a safer right-of-way control device in place of stop signs or traffic signals. Nationwide studies have shown the significant reductions roundabouts can achieve for collision rates, injury rates, and fatality rates.

This study focuses on showing the benefits of converting conventional intersections into roundabouts. Both advantages and disadvantages of roundabouts are discussed besides stating some recommendations for future implementations of roundabouts.

OBJECTIVES OF THE STUDY

The main objective of this study is shedding some light on the safety of roundabouts in the State of Arizona. A total of five cities used in this study with different designs and characteristics. Some of the roundabouts are single-lane and some are double-lane. The previous type of traffic control of those intersections were either stop signs or traffic lights.

This study intends to show any trends in accident rates and severities and compares those numbers before and after the construction of roundabouts. Within this study, there is discussion about possible improvements for future roundabouts. Data analysis is implemented to show any possible trends among the analyzed locations.

This study has the intention to support government cooperation for reaching better understanding of roundabouts implementation.

Another objective of this study is to show the differences between single-lane roundabouts and double-lane roundabouts. Both of these types of roundabouts have been implemented among the five chosen cities. Additionally, single-lane roundabouts and double-lane roundabouts have their own advantages and disadvantages, and this study helps identifying them.

2 LITERATURE REVIEW

It has been noticeably recognized that cities around the United States, or even around the world, have been requesting changes and solutions for their traffic congestion and delay. Standing at a traffic light for a long time, not only wastes people's time on a daily basis, but also increases greenhouse gas emission, which is a big environmental concern nowadays. With the increase in number of vehicles in our streets, congestion becomes a bigger concern as well as accidents. For that reason, roundabouts have been used in an effort to provide a solution for that concern by yielding instead of completely stopping for some time at a traffic light or a stop sign.

Roundabouts are used comprehensively all over Europe and the U.S., and in many other places around the world, to reduce accidents, traffic delay, fuel consumption, air pollution, and construction costs, while increasing capacity and enhancing intersection beauty. The Michigan Department of Transpiration (DOT) stated that roundabouts have been successfully used to control traffic speeds in residential neighborhoods and are accepted as one of the safest types of intersection design. According to the Michigan DOT, modern roundabouts started as regular traffic circles, but they comprise some differences (Waddell, Sept. 2009).

I. Yield at entry: At roundabouts, the entering traffic yields the right-of-way to the circulating traffic. This yield-at-entry rule prevents traffic from locking-up and allows for free flow movement.

II. Deflection: The entry and center island of a roundabout deflect entering traffic to slow traffic and reinforce the yielding process.

III. Flare: The entry to a roundabout often flares out from one or two lanes to two or three lanes at the yield line to provide increased capacity.

Since mid-nineties, studies on the safety of roundabouts emerged from the United Kingdom. In 1977, crash data were collected from 114 roundabouts built before 1972. Crash analysis showed that roundabouts reduced injury crashes by 46% at sites formerly under priority control, and by 62% at formerly signalized sites. However, Washtenaw Country Road Commission in Michigan observed that sites previously controlled by large-island roundabouts showed noticeably increased crash rates because the larger diameter required higher entry and exit speeds, which reduced the safety levels (Waddell, Sept. 2009).

Waddell added that the first proposal of a modern roundabout in the United States was made in the City of Ojai, California, in 1988. According to the California Department of Transportation, the actual proposal was a simple three-leg design. Although many other countries tested roundabouts for a number of years and documented their safety data, the city backed out from the idea, due to their limited knowledge of the proposed idea.

The first official roundabout project in the U.S. was constructed in Summerlin (north of Las Vegas), Nevada, in 1990 (Baranowski, 2015). Until early nineties, there was still a mix of ideas and impressions about roundabouts within the U.S. In 1994, California converted a traffic circle into a roundabout, which boosted the level of service for that intersection from F to A, while maintaining the same traffic volume of 5,000 vehicles per hour, and reducing crashes by 44%. On the other hand, other states like Michigan were completely unaware of what a roundabout is or what it does, and along with Wisconsin DOT they kept building the 1940's rotary designs (Waddell, Sept. 2009).

A large number of research studies have been conducted recently on the safety of roundabouts (Rodegerdts et al., 2007 and 2010). During the year 1996, a study was conducted on six roundabouts, which were previously regulated by some other traffic control, and the results were dramatic. The converted roundabouts, reportedly, reduced crashes from an average of about 4 crashes per year to 1 crash per year, a total reduction in crashes by 73%. To provide a solid analysis, statistical analyses were conducted and the results were statistically significant with a 99% confidence limit (Vanderbilt, 2008).

According to the Federal Highway Admiration (FHWA), roundabouts are generally safer than other intersection controls by reducing crashes for both low and medium traffic capacity conditions (FHWA, 2000). The statistical analysis study done in this guide used a total of 11 roundabouts consisting of:

1. 8 signal-lane roundabouts
2. 3 multilane roundabouts

Table 1 shows the accident rates and reduction levels in both types of roundabouts. Single-lane roundabouts reduced crashes by 51%, while double-lane roundabouts reduced them by 29%. From an injury prospective, single-lane roundabout reduced the injury levels by 73%, which is twice the reduction occurred by double-lane roundabouts (FHWA, 2000).

As a total, Table 1 shows that roundabouts, in a general sense, decrease accident rates and injury levels. While this table shows the positive side of roundabouts, this study will try to show both of the good side and the bad side as not always roundabouts bring better results in all cases.

Table 1: Average annual crash frequencies at 11 U.S. intersections converted to roundabouts (FHWA, 2000).

Type of roundabout	Number of Sites	Before Roundabout			After Roundabout			Percent Change		
		Total	Injury	Property Damage	Total	Injury	Property Damage	Total	Injury	Property Damage
Single-Lane	8	4.8	2.0	2.4	2.4	0.5	1.6	-51	-73	-32
Multilane	3	21.5	5.8	15.7	15.3	4.0	11.3	-29	-31	-10
Total	11	9.3	3.0	6.0	5.9	1.5	4.2	-37	-51	-29

Single lane roundabouts and multilane roundabouts differ from each other from a safety prospective. Single-lane roundabouts are the simplest form of roundabouts, and the more lanes are added the more complicated the design characteristics become.

Figure 3 presents the idea of when speeds are reduced, the chances of pedestrian death rates also decrease (FHWA, 2000). The Federal Highway Administration presented the benefit of speed reduction through this figure. It can be seen that when speeds are reduced by half (from 40 mph to 20 mph) death rates are reduced by 5.7 times. Although these results are not obtained at roundabout locations, they show that if roundabouts decrease vehicle speed, the pedestrian fatality rate could generally decrease.

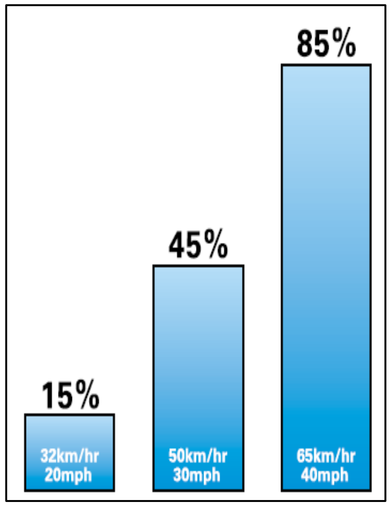

Figure 3: Pedestrian rates of death corresponding to three speed categories.

The literature shows that the U.S. has hardly given roundabouts a chance. There are approximately 4 million miles of paved road in the U.S., compared to France's 612,000, and the U.K.'s 245,000. However, in the U.S. there are about 10 times less than the percentage of roundabouts in other countries. As an average, the United States preserve only 90 roundabouts per 100,000 miles of paved road, while France has 4,900, and the U.K. has a massive 10,200 roundabouts per 100,000 miles (Crockett, Sept., 2015).

Fully neglecting the benefits of roundabouts, the American public are still refusing to submit for nationally spreading the construction of roundabouts. According to collected data from the International Road Traffic Accident Database, about six million traffic accidents occur each year in the U.S., of these 40% happen at intersections. Both 4-way and T-shaped intersections are “deadly places,” according to Crockett (Sept., 2015). Within the period of 1998 and 2007, 21.5% of all traffic-related deaths, and 44.8% of all traffic-related injuries occur at intersections. As a result, an average of 9,000 people die and about 767,000 get injured in intersection collisions every year in the U.S.

Vanderbilt (2008) explains why traditional intersections are more dangerous to drive at than roundabouts. Roundabouts are typically built using what is called ”negative superelevation,” meaning that water flows away from the center and also that the road slopes against the direction of a driver's turn. As a result, any crashes in a roundabout take place at lower speeds and are, thus, less likely to be fatal. They also eliminate the left turn against oncoming traffic, which is one of the main reasons for intersection danger, as well as the prospect of vehicles running a red light or speeding up as they approach an intersection to ‘beat the light.”

Roundabouts by their nature and geometric design, reduce the conflict points tremendously. Figures 4 and 5 show how conflict points are reduced by going from traditional intersections into roundabouts. Figure 4 shows the decrease of the number of conflict points when a traditional T-shaped intersection becomes a T-shaped roundabout. The reduction of the number of conflict points simply means reducing the chances of two or more vehicles getting into an accident. When a conflicting point changes angle from a 90 degrees (crossing) into a curved one (merging) is also considered a less potential harmful collision (Crockett, Sept., 2015). Additionally, roundabouts fully remove any crossing conflicts between vehicles, which in many cases can create a collision opportunity. Similarly, Figure 5 shows the decrease of the number of conflict points when a traditional 4-way intersection is converted to a 4-way roundabout. The figure shows that there are 32 conflict points within a 4-way traditional intersection, while in the most complicated form or a roundabout, a maximum of 8 conflict points are possible to exist.

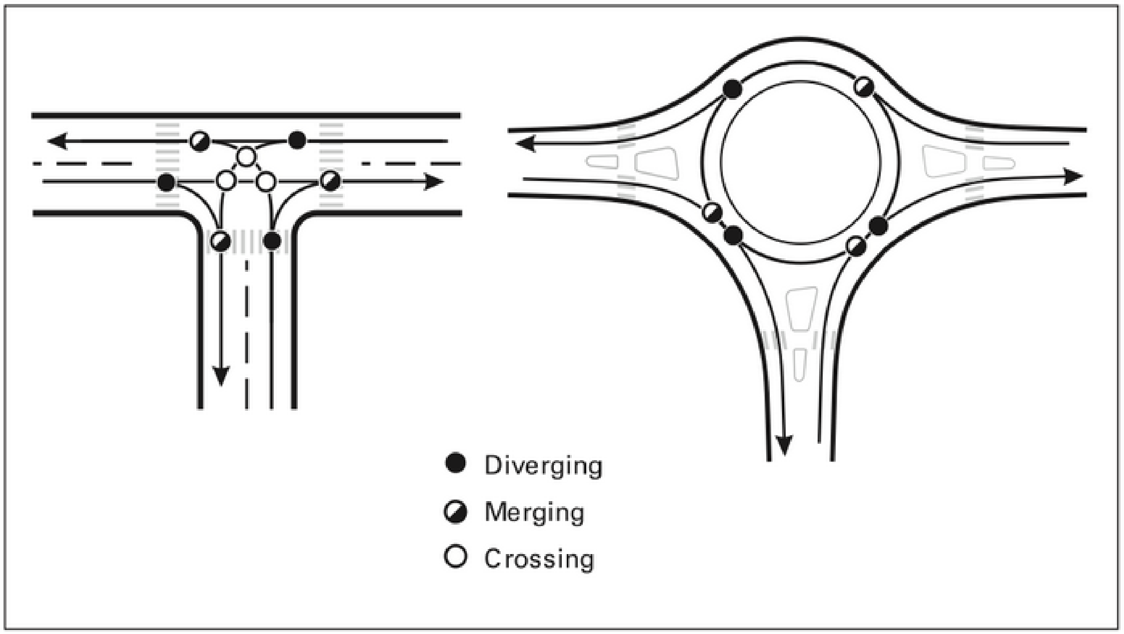

Figure 4: Conflict points comparison between T-shaped intersection and a roundabout.

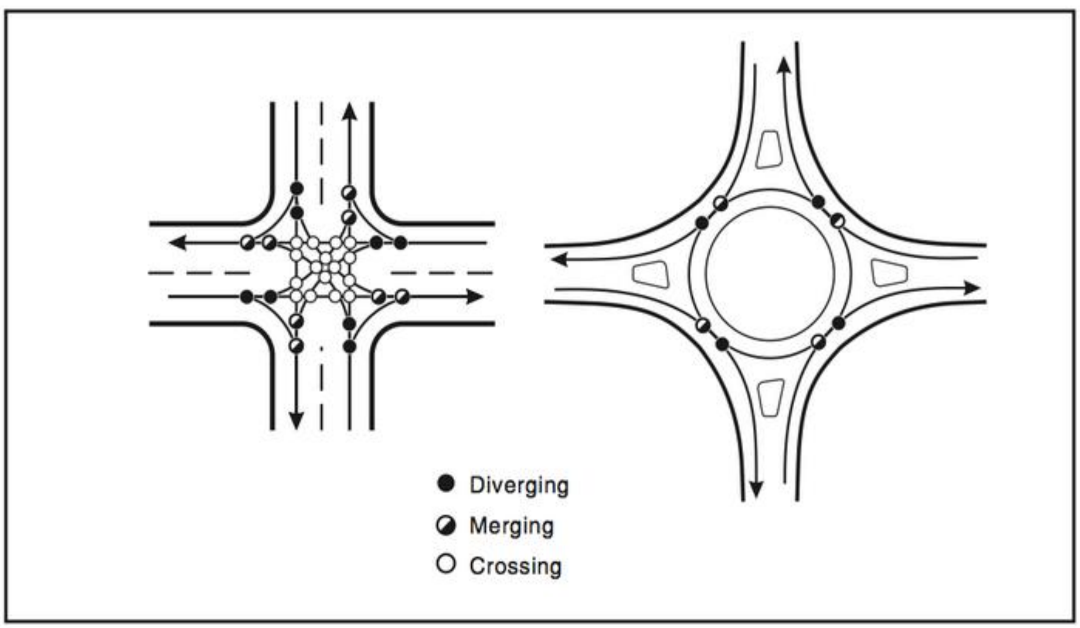

Figure 5: Conflict points comparison between 4-way intersection and a roundabout.

Driving through a roundabout could be frustrating experience if a person does not know how to navigate through it. Therefore, what most of the public do not understand is they lack the knowledge of driving through the roundabouts. The concept of reducing the number of conflict points is the basis for the safety of roundabouts.

Retting et al. (2001) studied 24 traditional intersections converted into roundabouts in 8 different states. Crash Analysis were conducted on these sets of data, and in most cases, the time period (in months) was the same in the before and after periods (See Table 2). In some of the cases when the time interval was not the same, Bayes method was used for normalization (Retting, R.A., April 2001).

Table 2: Details of the sample roundabouts conversions and the corresponding crash counts

Jurisdiction	Year Opened	Control Before Conversion[a]	Single or Multilane	Annual Average Daily Traffic		Months		Crash Count			
								Before		After	
				Before	After	Before	After	All	Injury	All	Injury
Anne Arundel County, Md	1995	1	Single	15345	17220	56	38	34	9	14	2
Avon, Colo	1997	2	Multilane	18942	30418	22	19	12	0	3	0
Avon, Colo	1997	2	Multilane	13272	26691	22	19	11	0	17	1
Avon, Colo	1997	5	Multilane	22030	31525	22	19	44	4	44	1
Avon, Colo	1997	5	Multilane	18475	27525	22	19	25	2	13	0
Avon, Colo	1997	5	Multilane	18795	31476	22	19	48	4	18	0
Bradenton Beach, Fla	1992	1	Single	17000	17000	36	63	5	0	1	0
Carroll County, Md	1996	1	Single	12627	15990	56	28	30	8	4	1
Cecil County, Md	1995	1	Single	7654	9293	56	40	20	12	10	1
Fort Walton Beach, Fla	1994	2	Single	15153	17825	21	24	14	2	4	0
Gainesville, Fla	1993	5	Single	5322	5322	48	60	4	1	11	3
Gorham, Me	1997	1	Single	11934	12205	40	15	20	2	4	0
Hilton Head, SC	1996	1	Single	13300	16900	36	46	48	15	9	0
Howard County, Md	1993	1	Single	7650	8500	56	68	40	10	14	1
Manchester, Vt	1997	1	Single	13972	15500	66	31	2	0	1	1
Manhattan, Kan	1997	1	Single	4600	4600	36	26	9	4	0	0
Montpelier, Vt	1995	2	Single	12627	11010	29	40	3	1	1	1
Santa Barbara, Calif	1992	3	Single	15600	18450	55	79	11	0	17	2
Vail, Colo	1995	1	Multilane	15300	17000	36	47	16	...	14	2
Vail, Colo	1995	4	Multilane	27000	30000	36	47	42	...	61	0
Vail, Colo	1997	4	Multilane	18000	20000	36	21	18	...	8	0
Vail, Colo	1997	4	Multilane	15300	17000	36	21	23	...	15	0
Washington County, Md	1996	1	Single	7185	9840	56	35	18	6	2	0
West Boca Raton, Fla	1994	1	Single	13469	13469	31	49	4	1	7	0

Note. Ellipses (...) indicate that data are not available.
[a] 1 = 4-legged, 1 street stopped; 2 = 3-legged, 1 street stopped; 3 = all-way stop; 4 = other unsignalized; 5 = signal.

The majority of people and researchers discuss roundabouts from the prospective of a passenger car. However, the other angle that should be given more consideration is trucks and buses. According to the American Public Transportation Association, trucks make up about 10% of total highway miles traveled in the U.S. Although some buses use alternative fuels, many buses and trucks use traditional fuel substances, which emit tremendous amounts of emissions (APTA, March 2014). Since roundabouts may reduce the accident severity and travel delay, roundabouts may improve the safety of buses and trucks as well as decreasing hazardous emissions.

Ourston (1996) compared crash records of signalized crossroads, T intersections, and roundabouts. Through comparison of California, British, Australian, and Norwegian data, the study estimated that roundabout construction should result in 50% fewer crashes than a signalized cross intersection.

Slabosky (1997) reviewed the literature to estimate likely roundabout crash reductions for specific intersection conditions. The findings suggested the safety improvement from roundabout installation was probably superior to improving an existing signal, installation of a warranted signal, or installation of an unwarranted signal. The only comparable safety treatment was installation of median crossovers and indirect turns.

Another type of roundabouts that has been known for some time now is the Turbo-roundabout (Transoft Solutions, 2015). Turbo roundabouts are rather a new type of roundabouts, which provides an amplified flow of traffic, requiring drivers to choose their direction before entering the roundabout. Fortuijn first introduced that type of roundabouts in the late 1990's as a safer and more efficient alternative to the standard multi-lane roundabouts (Transoft Solutions, 2015).

During the 1990, Netherlands had the privilege to install the first turbo roundabout and soon became so popular that the Dutch government developed its own design guidelines. In 2015, there were about 300 turbo roundabouts in the Netherlands. Eastern Europe, Germany, and some parts of North America shared the spread of turbo roundabouts as well within the last decade. Some of these regions and countries used the Dutch edition of those roundabouts, while some took on the experimental way and designed their own version according to their specified geometrics. Most recent counts estimate about 390 turbo roundabouts currently in-place around the world (Transoft Solutions, 2015).

One of the down side of single lane roundabouts, they do not function well when they are implanted in high capacity sites. Once the traffic accumulates congestion develops. Multi-lane roundabouts may solve the traffic congestion issue in high-volume areas, but they compromise the safety aspect of a roundabout. Turbo roundabouts may help with both issues, through the following solutions they offer (Transoft Solutions, 2015):

1) Because turbo roundabouts force drivers to choose their travelling direction a little before entering the roundabout through the raised lane dividers between the directions. Turbo roundabouts limit weaving maneuvers, which ultimately reduce crashes related to changing lanes. Research and experiments show that traffic accidents are reduced by 72% on turbo-roundabouts compared to multi-lane roundabouts.

2) Through maintaining all roundabout guidelines and specifications, turbo roundabouts maintain the same volumes as multi-lane roundabouts.

3) The equine design of turbo roundabouts clearly reduces the number of conflict points, as can be seen in Figure 6, which also helps significantly in reducing crashes inside the roundabout. Turbo roundabouts force the drivers to choose their entry direction according to their exit direction because of the raised lane dividers, which do not allow the driver to change lanes once they get inside the specific lane.

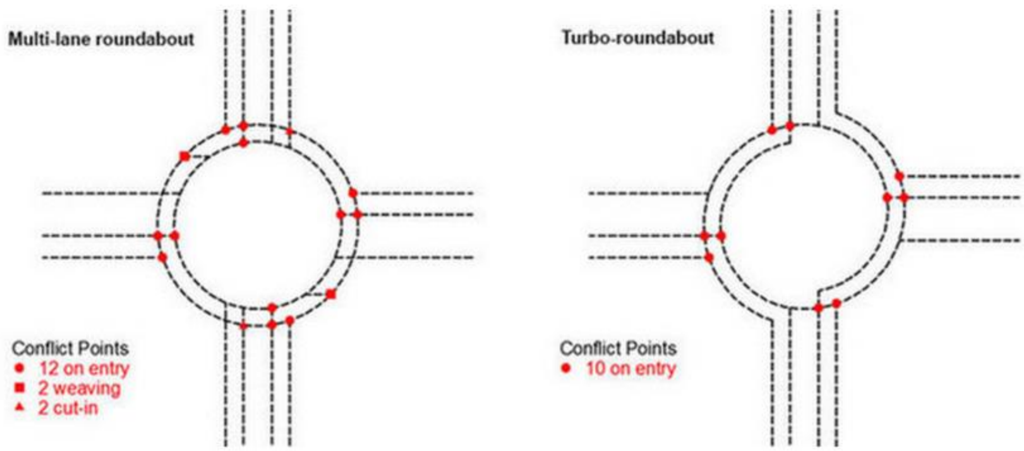

Figure 6: Conflict points comparison between a multi-lane roundabout and a turbo-roundabout.

4) Turbo roundabouts are considered as safe as a single lane roundabout, while still maintaining the high traffic capacity as the multi-lane roundabouts due to a number of special characteristics such as the raised lane islands and pavement markings. These characteristics help maintain low vehicle's speed and safer environment.

As a downside, turbo roundabouts increase the levels of driver's frustration, and that by itself might cause accidents. When a driver have to choose the specific lane to enter the roundabout way before the actual roundabout, which in many cases the drivers do not know where those lanes would lead them to, this will create anger and frustration. Therefore, drivers might act unpredictability and unsafely under those frustrations.

The Manual on Uniform Traffic Control Devices (MUTCD) describes the guidelines of pavement markings for roundabouts. Chapter 3C of the MUTCD shows detailed process for the different segments of a roundabout and how they differ from a pavement marking point of view. The chapter includes many figures to help the engineers throughout the procedure of making all the AutoCAD drawings with the markings. Additionally, Chapters 2B and 2D describes the signing process of a roundabout and the designated signs specifically used at a roundabout structure. (MUTCD, 2009).

The National Cooperative Highway Research Program (NCHRP) published in the years 2007 and 2010 two reports about roundabouts in the United States, and an informational guide about roundabouts, respectively. The NCHRP 572 Report (Rodegerdts, 2007) focused on the safety aspect of roundabouts, the operational impacts, and some design criteria as a guide for all the geometric designers and traffic engineers who have interest in roundabouts. The NCHRP 672 Report (Rodegerdts, 2010) presented a full scale guide addressing the planning, design and construction, and the maintenance procedures of roundabouts. Given that both reports are three years apart, the 2010 report is much comprehensive with richer information and deeper guidelines presenting a three years' worth of advancement in knowledge.

When studying roundabout safety, the accident severity needs to be considered due to the large difference among different severity levels on the impact on the cost and the health and wellbeing of humans. The Arizona Department of Transportation publishes a Motor Vehicle Crash Facts report on an annual base. The 2014 edition of that report, which is the most recent, shows the economic loss due to all levels of accident's severities. The average economic cost per of a fatality crash is $1,530,000, an incapacitating injury is $76,398, a non-incapacitating injury is $24,480, a possible injury is $13,872, and a property damage only is $9,486. (ADOT, 2015b).

In summary, many studies have been conducted to evaluate the effect of converting traditional intersections to roundabouts on safety. Most of these studies showed safety improvements due to converting traditional intersections to roundabouts with different degrees of success. However, accurate information on rates of accidents, damages, injuries and fatalities in Arizona is not known for single- and multi-lane roundabouts. Also, the effect of roundabout conversion on accident severity at different conditions is not well known.

3 DATA COLLECTION

As previously mentioned, this study includes data from five cities in Arizona, which are:

1. City of Scottsdale
2. City of Sedona
3. City of Phoenix
4. City of Cottonwood
5. City of Prescott

In Table 3, roundabouts are classified according to the number of lanes since this study is targeting the performance differences between single-lane roundabouts and double-lane roundabouts. A total of 17 roundabouts were analyzed.

Table 3: Summary of roundabouts used in this study

City	Intersection	Type
Scottsdale	94 & Union Hills	Single-Lane
Scottsdale	96 & Cholla	Single-Lane
Scottsdale	96 & Sweetwater	Single-Lane
Scottsdale	100 & Cactus	Single-Lane
Scottsdale	104 & Cactus	Single-Lane
Scottsdale	108 & Cactus	Single-Lane
Sedona	AZ 179/Arrow Dr./Morgan Rd.	Single-Lane
Sedona	AZ 179/Back O'Beyond Rd.	Single-Lane
Sedona	AZ 179/Canyon Dr.	Single-Lane
Sedona	AZ 179/Chapel Rd.	Single-Lane
Sedona	AZ 179/Schnebly Hill Rd.	Single-Lane
Sedona	AZ 89A/AZ 179	Double-Lane
Sedona	AZ 89A/Brewer Rd	Double-Lane
Phoenix	99th Ave. & Lower Buckeye Rd	Double-Lane
Cottonwood	AZ 89A/Verde Heights Dr.	Double-Lane
Scottsdale	Hayden & Northsight	Double-Lane
Prescott	SR 89 & Willow Lake Rd	Double-Lane

Data on roundabouts were collected from Arizona DOT websites, where 80 roundabouts are scattered in several cities around the state (Arizona DOT, 2015). In order to have valid analysis on the effect of roundabouts on accident rates, data had to be screened. The selection criteria that were used are:

1. Availability of roundabout historical and geometrical data, such as location, date of roundabout conversion, number of lanes, previous traffic control, etc.

2. Availability of accident data for several years before and after roundabout conversion, broken down by damage, different levels of injury, and fatality.

3. Availability of traffic data, especially the average annual daily traffic (AADT) in the major street and the growth rate.

Following these selection criteria, the following data were collected at each of the 17 roundabouts:

1. Most current average annual daily traffic (AADT).
2. Accident data were obtained either from the Arizona ADOT database or city records. The accident data and location were broken down by route, milepost, and year. The number of years before and after roundabout conversion was selected to be equal for rational comparison.
3. The type of traffic control device used prior to the construction of the roundabouts.
4. The roundabout conversion year.
5. Accidents data collected, according to the following severity classifications:

Level 1. Damage without injury

Level 2. Minor injury

Level 3. Non-incapacitating injury

Level 4. Incapacitating injury

Level 5. Fatality

Table 4 shows the years of roundabout conversions, analysis period and average AADT before and after the conversion of all the intersections used in this study.

Table 4: Years of roundabout conversion, analysis period and average AADT before and after conversion

Intersection	Year of Conversion	Analysis Period Before or After Conversion (Years)	Average AADT Before Conversion	Average AADT After Conversion
94 St. & Union Hills	2006	9	2454	2806
96 St. & Cholla	2006	9	7688	8791
96 St. & Sweetwater	2006	9	4744	5424
100 St. & Cactus	2008	7	8467	9397
104 St. & Cactus	2008	7	5901	6550
108 St. & Cactus	2008	7	5559	6170
AZ 179/Arrow Dr./Morgan Rd.	2008	6	7347	8033
AZ 179/Back O'Beyond Rd.	2008	6	7172	7842
AZ 179/Canyon Dr.	2008	6	8571	9372
AZ 179/Chapel Rd.	2008	6	9183	10041
AZ 179/Schnebly Hill Rd.	2008	6	8396	9181
AZ 89A/AZ 179	2008	6	10058	10998
AZ 89A/Brewer Rd.	2008	6	8527	9324
99th Ave. & Lower Buckeye Rd	2009	5	4293	4625
AZ 89A/Verde Heights Dr.	2009	5	19676	21196
Hayden Rd. & Northsight	2013	2	35384	36453
SR 89 & Willow Lake Rd.	2009	5	9069	9770

4 ANALYSIS OF RESULTS

After all the required data were collected, the analysis part took place. As previously mentioned, the main objective of this study is to show both of the safety advantages and disadvantages for the single and double lane roundabouts.

The data analysis was done in two main parts: accident rate and accident severity.

For the accident rates analysis, the following categories of comparisons were generated for single-lane and double-lane roundabouts:

1. Total number of accidents per year before and after the construction of roundabouts.
2. Total number of accidents per million vehicles before and after the construction of roundabouts.
3. Total number of damages per year before and after the construction of roundabouts.
4. Total number of damages per million vehicles before and after the construction of roundabouts.
5. Total number of injuries (combined severity levels of 2-4) per year before and after the construction of roundabouts.
6. Total number of injuries (combined severity levels of 2-4) per million vehicles before and after the construction of roundabouts.
7. Total number of fatalities per year before and after the construction of roundabouts.

8. Total number of fatalities per million vehicles before and after the construction of roundabouts.

For the severity analysis, the trends of the 5 levels severity were compared before and after the roundabout conversion for single-lane and double-lane roundabouts.

SINGLE-LANE ROUNDABOUTS

Accident Rates

Table 5 and Figures 7 and 8 show the accident rates at the studied single-lane roundabouts. It can be noticed that the roundabout conversion increased the accident rates per year at 4 locations and decreased them at 6 locations, while one roundabout maintained the same accident rate before and after conversion. The 100th St. and Cactus Rd. intersection showed the most negative outcome from converting the intersection into a roundabout, where the accident rate increased from 0.1 to 1.9 per year. On the other hand, Arizona Route 179 and Morgan Rd. showed the best desirable outcome out of all the analyzed single-lane roundabouts, where the accident rate decreased from 1.5 to zero per year.

Table 5: Single-lane roundabout accident rates

Intersection	Total Number of Accidents		Accident Rate per Year		Accident Rate per Million Vehicles	
	Before	After	Before	After	Before	After
94 & Union Hills	0	2	0.0	0.2	0.0	0.2
96 & Cholla	4	7	0.4	0.8	0.2	0.2
96 & Sweetwater	3	7	0.3	0.8	0.2	0.4
100 & Cactus	1	13	0.1	1.9	0.0	0.5
104 & Cactus	7	7	1.0	1.0	0.5	0.4
108 & Cactus	6	2	0.9	0.3	0.4	0.1
AZ 179/Arrow Dr./Morgan Rd.	9	0	1.5	0.0	0.6	0.0
AZ 179/Back O'Beyond Rd.	2	1	0.3	0.2	0.1	0.1
AZ 179/Canyon Dr.	7	3	1.2	0.5	0.4	0.1
AZ 179/Chapel Rd.	6	2	1.0	0.3	0.3	0.1
AZ 179/Schnebly Hill Rd.	6	3	1.0	0.5	0.3	0.1

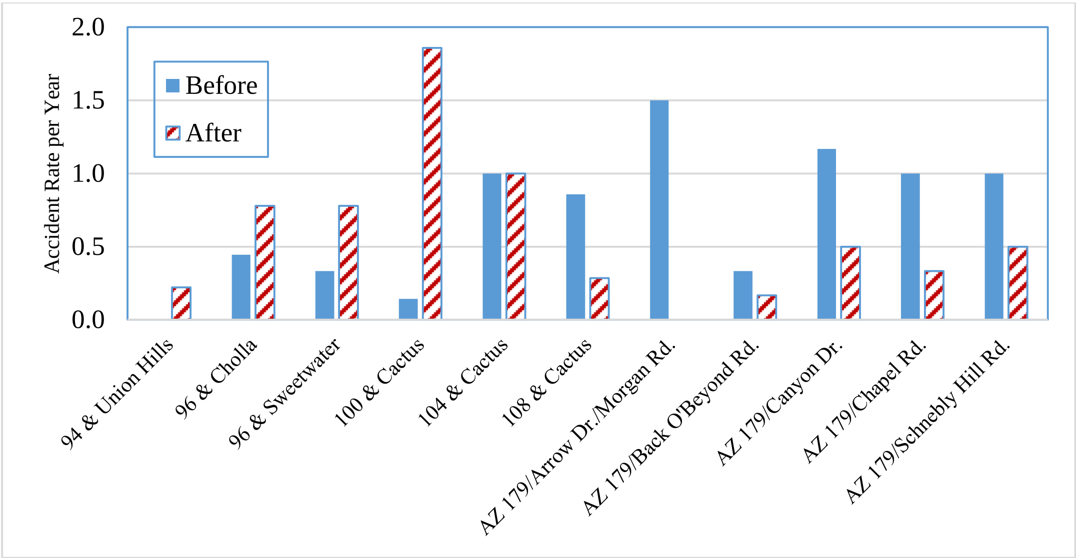

Figure 7: Accident rates per year before and after single-lane roundabouts.

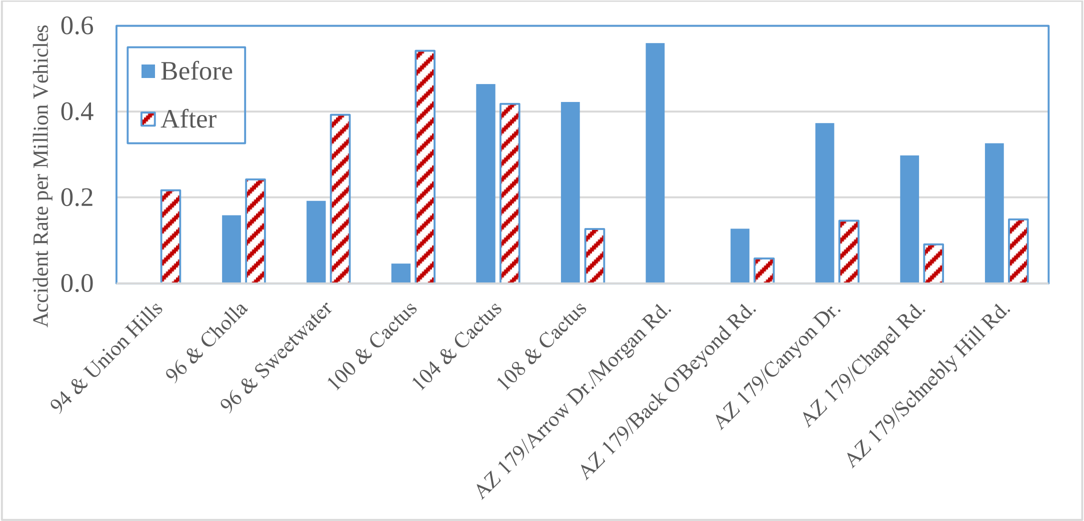

Figure 8: Accident rates per million vehicles before and after single-lane roundabouts.

Table 6 and Figures 9 and 10 represent the damage rates for single-lane roundabouts. Out of the 11 locations, 7 single-lane roundabouts decreased the damage rate per year, 3 increased the damage rate, and one maintained the same damage rate. As previously mentioned about the total accident rates, the 100th St. and Cactus Rd. intersection showed the most undesirable results due to roundabout conversion with an increase from one single damage before the roundabout to 16 damages after the roundabout. The 96th St. and Sweetwater Rd. intersection showed no effect when comparing damages before and after the roundabout. Additionally, the results indicate that the AZ 179 Route and Morgan Rd. intersection showed the best improvements among all single-lane roundabouts with a decrease from 5 damage cases to zero damages after installing the roundabout.

Table 6: Single-lane roundabout damage rates

Intersection	Total Number of Damages		Damage Rate per Year		Damage Rate per Million Vehicles	
	Before	After	Before	After	Before	After
94 & Union Hills	0	3	0.0	0.3	0.0	0.3
96 & Cholla	2	9	0.2	1.0	0.1	0.3
96 & Sweetwater	6	6	0.7	0.7	0.4	0.3
100 & Cactus	1	16	0.1	2.3	0.0	0.7
104 & Cactus	8	6	1.1	0.9	0.5	0.4
108 & Cactus	8	2	1.1	0.3	0.6	0.1
AZ 179/Arrow Dr./Morgan Rd.	5	0	0.8	0.0	0.3	0.0
AZ 179/Back O'Beyond Rd.	1	0	0.2	0.0	0.1	0.0
AZ 179/Canyon Dr.	4	1	0.7	0.2	0.2	0.0
AZ 179/Chapel Rd.	3	1	0.5	0.2	0.1	0.0
AZ 179/Schnebly Hill Rd.	4	3	0.7	0.5	0.2	0.1

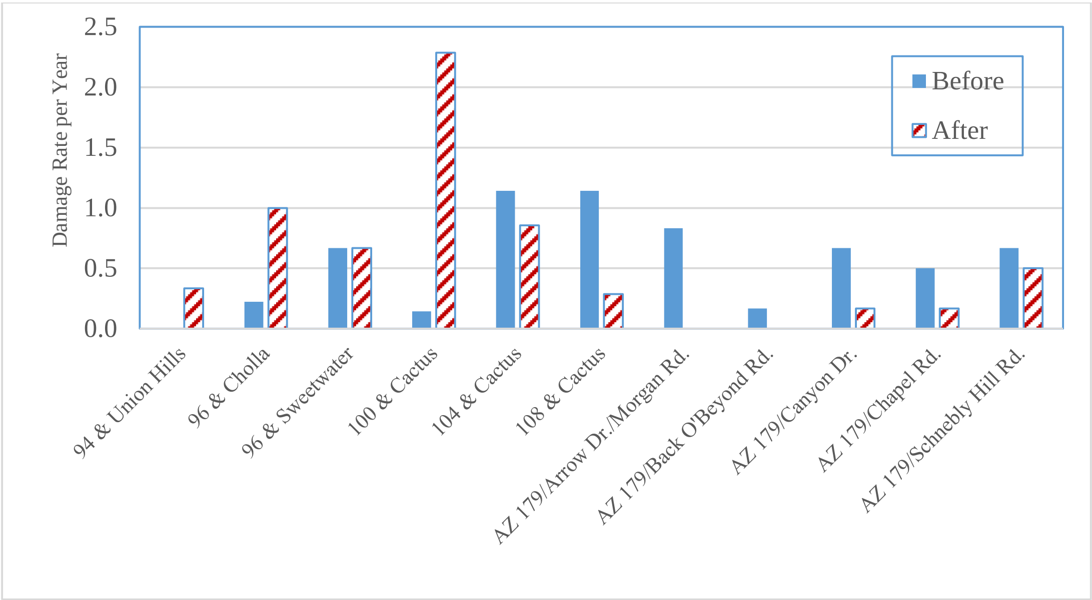

Figure 9: Damage rates per year before and after single-lane roundabouts.

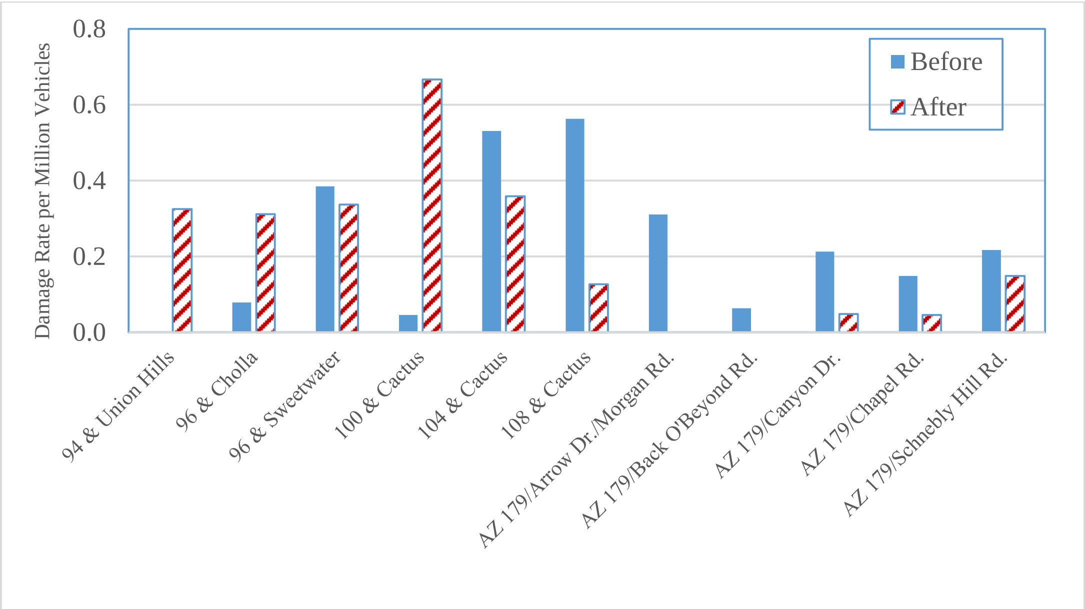

Figure 10: Damage rates per million vehicles before and after single-lane roundabouts.

Table 7 and Figures 11 and 12 show the injury rates before and after single-lane roundabout conversions. Eight roundabouts helped decrease the injury rates per year, while only 3 of them had an increase in the injury rates. The 100th St. and Cactus Rd. intersection along with 96th St. and Cactus Rd. intersection showed the worst outcome regarding injury rates. Both of these intersections had an increase in injuries from one to four injuries and a zero to three injuries before and after roundabouts conversion, respectively.

Table 7: Single-lane roundabout injury rates

Intersection	Total Number of Injuries		Injury Rate per Year		Injury Rate per Million Vehicles	
	Before	After	Before	After	Before	After
94 & Union Hills	0	1	0.0	0.1	0.0	0.1
96 & Cholla	4	1	0.4	0.1	0.1	0.0
96 & Sweetwater	0	3	0.0	0.3	0.0	0.2
100 & Cactus	1	3	0.1	0.4	0.0	0.1
104 & Cactus	3	2	0.4	0.3	0.2	0.1
108 & Cactus	2	1	0.3	0.1	0.1	0.1
AZ 179/Arrow Dr./Morgan Rd.	4	0	0.7	0.0	0.2	0.0
AZ 179/Back O'Beyond Rd.	3	1	0.5	0.2	0.2	0.1
AZ 179/Canyon Dr.	3	2	0.5	0.3	0.2	0.1
AZ 179/Chapel Rd.	4	2	0.7	0.3	0.2	0.1
AZ 179/Schnebly Hill Rd.	2	0	0.3	0.0	0.1	0.0

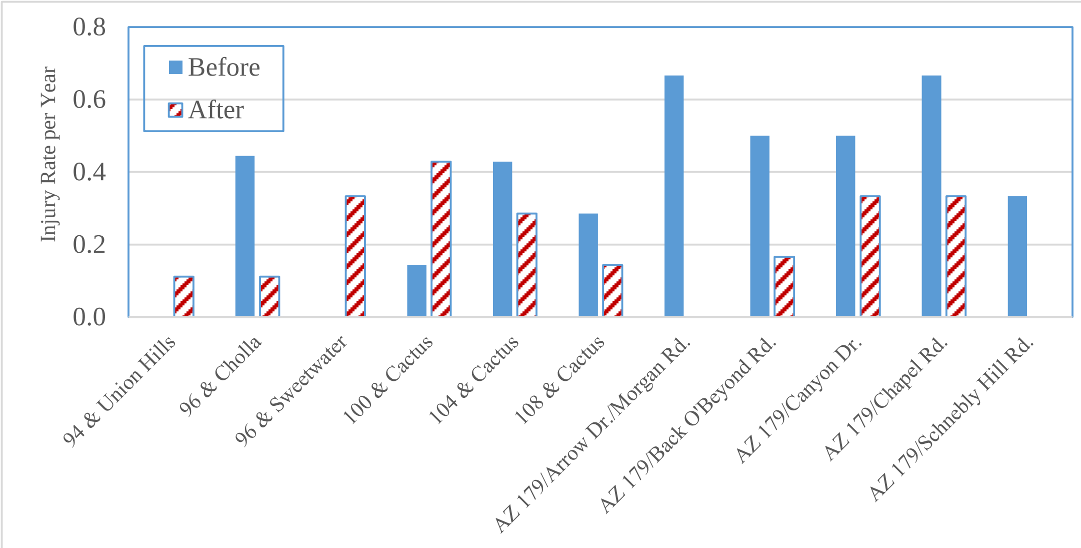

Figure 11: Injury rates per year before and after single-lane roundabouts

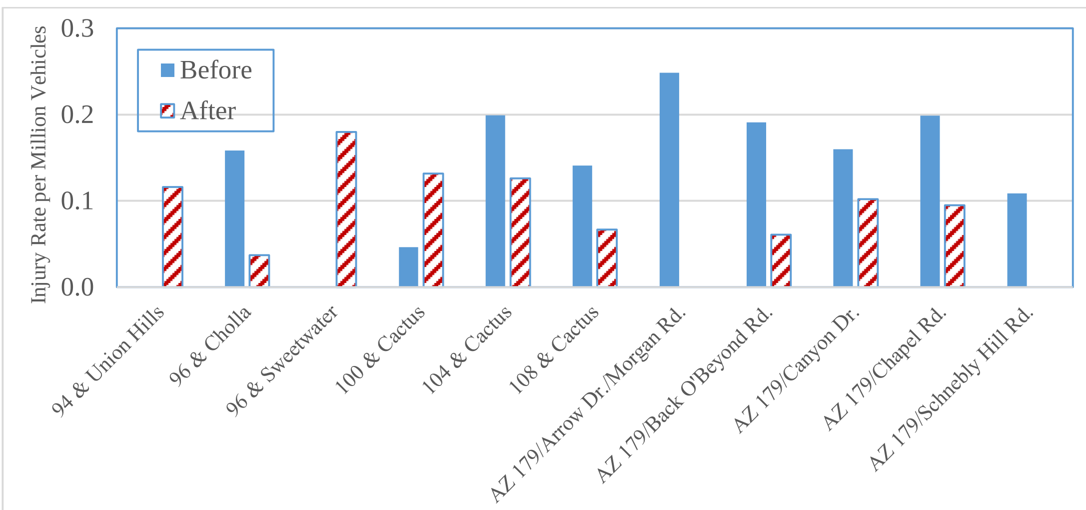

Figure 12: Injury rates per million vehicles before and after single-lane roundabouts

Although the total number of fatalities in all cases were small when compared to the number of accidents, some attention need to be given to fatality rates. From Table 8 and Figures 13 and 14, the rate of fatalities dropped to zero after roundabout conversion. Given the limited number of total roundabouts analyzed in this study, this drop in the fatality rate is considered a significant outcome. The only intersection that had a previous history with fatalities before roundabout conversion was AZ 179 Route and Schnebly Hill Rd.

Table 8: Single-lane roundabout fatality rates

Intersection	Total Number of Fatalities		Fatality Rate per Year		Fatality Rate per Million Vehicles	
	Before	After	Before	After	Before	After
94 & Union Hills	0	0	0.0	0.0	0.0	0.0
96 & Cholla	0	0	0.0	0.0	0.0	0.0
96 & Sweetwater	0	0	0.0	0.0	0.0	0.0
100 & Cactus	0	0	0.0	0.0	0.0	0.0
104 & Cactus	0	0	0.0	0.0	0.0	0.0
108 & Cactus	0	0	0.0	0.0	0.0	0.0
AZ 179/Arrow Dr./Morgan Rd.	0	0	0.0	0.0	0.0	0.0
AZ 179/Back O'Beyond Rd.	0	0	0.0	0.0	0.0	0.0
AZ 179/Canyon Dr.	0	0	0.0	0.0	0.0	0.0
AZ 179/Chapel Rd.	0	0	0.0	0.0	0.0	0.0
AZ 179/Schnebly Hill Rd.	1	0	0.2	0.0	0.1	0.0

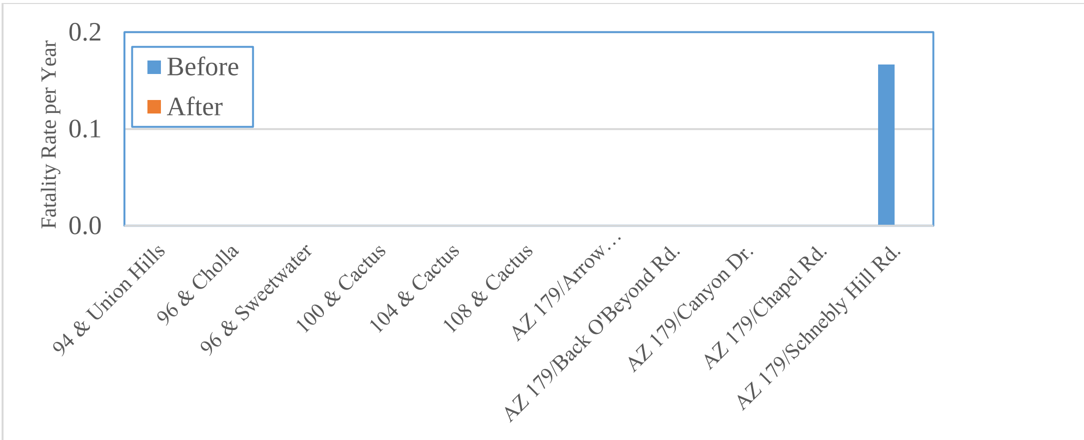

Figure 13: Fatality rates per year before and after single-lane roundabouts.

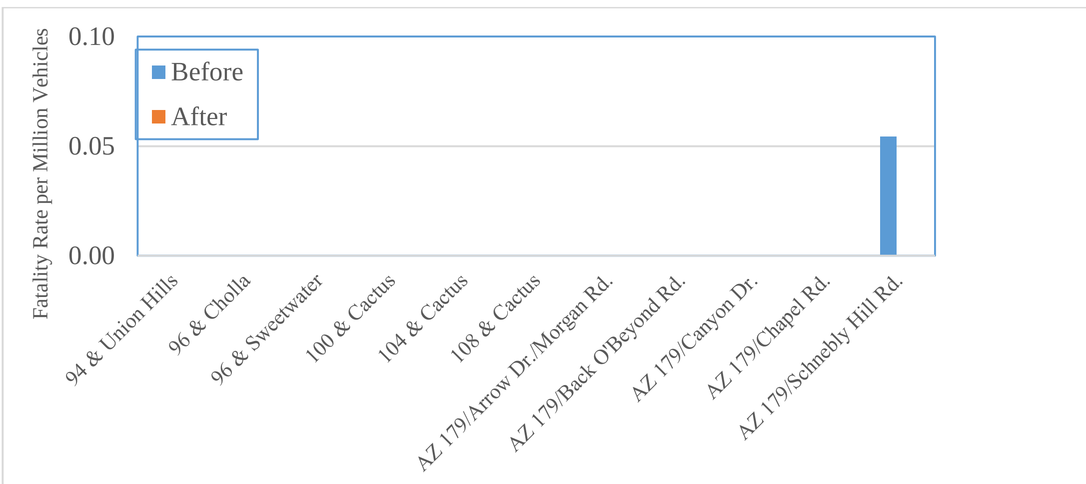

Figure 14: Fatality rates per million vehicles before and after single-lane roundabouts.

Accident Severities

The accident severity analysis used the following five levels:

1. Damage without Injury.
2. Minor Injury.
3. Non-Incapacitating Injury.
4. Incapacitating Injury.
5. Fatality.

The accident data were normalized by dividing the sum of each severity level by the total of all accidents before and after roundabout conversion. Normalizing the data provides a rational estimate of the different severity levels relative to the sum of all accidents. For example, 5 accidents at a certain severity level out of a total of 20 accidents is less severe than 5 accidents at the same severity level out of a total of 10 accidents. Table 9 lists all single-lane roundabout accidents with their different severity levels and the normalized results.

Table 9: Single-lane roundabout accident severity analysis

Intersection	No. of Accidents		Number of Injuries for Different Severities									
			Before					After				
	Before	After	1	2	3	4	5	1	2	3	4	5
94 & Union Hills	0	2	0	0	0	0	0	3	0	1	0	0
96 & Cholla	4	7	2	1	2	1	0	9	1	0	0	0
96 & Sweetwater	3	7	6	0	0	0	0	6	2	1	0	0
100 & Cactus	1	13	1	1	0	0	0	16	2	1	0	0
104 & Cactus	7	7	8	2	1	0	0	6	0	2	0	0
108 & Cactus	6	2	8	2	0	0	0	2	1	0	0	0
AZ 179/Arrow Dr./Morgan Rd.	9	0	5	3	1	0	0	0	0	0	0	0
AZ 179/Back O'Beyond Rd.	2	1	1	0	3	0	0	0	0	0	1	0
AZ 179/Canyon Dr.	7	3	4	0	2	1	0	1	1	1	0	0
AZ 179/Chapel Rd.	6	2	3	4	0	0	0	1	2	0	0	0
AZ 179/Schnebly Hill Rd.	6	3	4	1	1	0	1	3	0	0	0	0
	Normalized Severities		0.82	0.27	0.20	0.04	0.02	1.00	0.19	0.13	0.02	0.00

Figure 15 shows the relation between the different levels of severity and the normalized severity rates. Generally, it can be seen that all severity levels were decreased after roundabout conversion, except the damage only level. Since severity level 1 is less severe than other levels, the results indicate that the single-lane roundabout conversion reduced the severity of accidents.

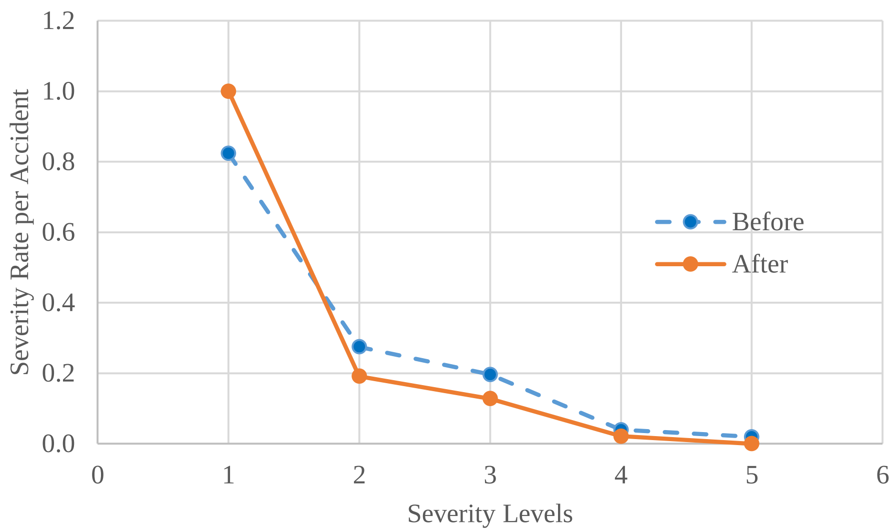

Figure 15: Normalized vs. actual accident severity rates before and after single-lane roundabouts.

DOUBLE-LANE ROUNDABOUTS

Accident Rates

Table 10 and Figures 16 and 17 show the accident rates at the studied double-lane roundabouts. It is obvious to conclude that all of the 7 double-lane roundabouts showed an increase in the overall accident rate, except one roundabout that showed a decrease in accident rate. Table 10, shows that the worst individual performance of a double-lane roundabout was the 89 Alternate Route and 179 Route intersection in Sedona with a large increase from 7.5 accidents per year to 24.8 accidents per year. On the other hand, Hayden Rd. and Northsight Blvd intersection showed a much more desirable outcome by decreasing the yearly rate of accidents from 11.5 to 10.5. While having in mind that this decrease is not an important one, it is the only positive outcome among all the analyzed double-lane roundabouts.

Table 10: Double-lane roundabouts accident rates

Intersection	Total Number of Accidents		Accident Rate per Year		Accident Rate per million Vehicles	
	Before	After	Before	After	Before	After
AZ 89A/AZ 179	45	149	7.5	24.8	2.0	6.2
AZ 89A/Brewer Rd	15	21	2.5	3.5	0.8	1.0
99th Ave. & Lower Buckeye Rd	38	50	7.6	10.0	4.9	5.9
AZ 89A/Verde Heights Dr.	7	11	1.4	2.2	0.2	0.3
Hayden & Northsight	23	21	11.5	10.5	0.9	0.8
SR 89 & Willow Lake Rd	27	35	5.4	7.0	1.6	2.0

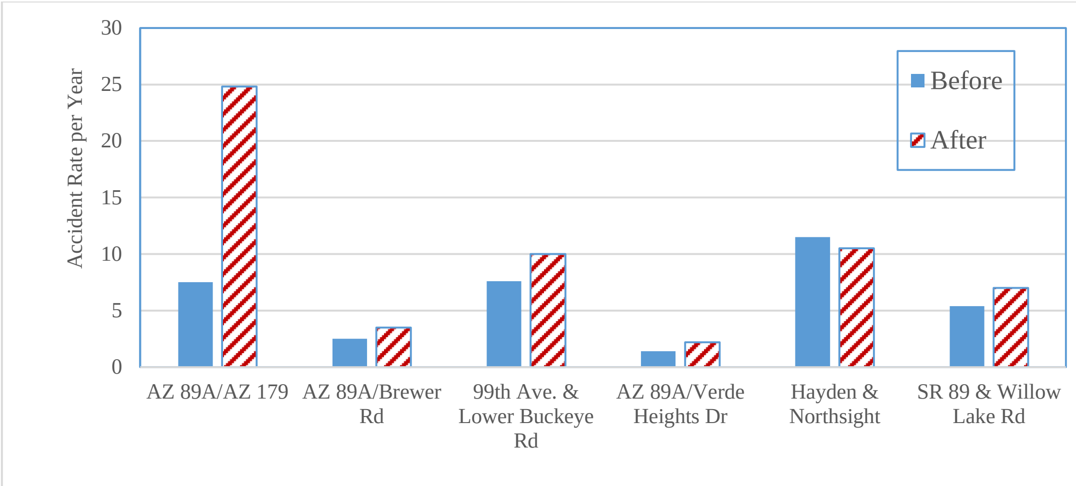

Figure 16: Accident rates per year before and after double-lane roundabouts.

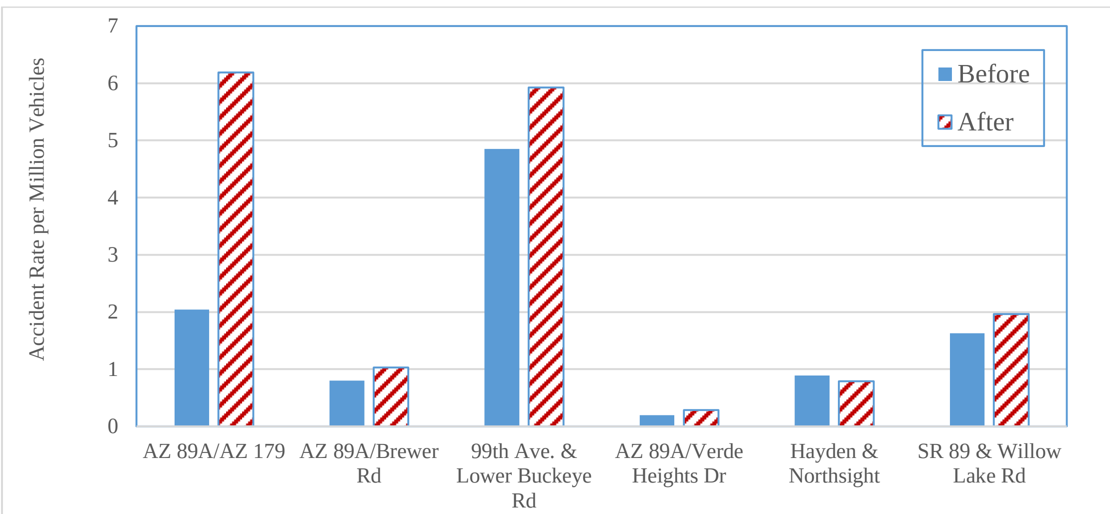

Figure 17: Accident rates per million vehicles before and after double-lane roundabouts

The results from Table 11 and Figures 18 and 19 indicate that the overall damage rate for all of the double-lane roundabouts is not desirable. All double-lane roundabouts showed increase in the damage rates per year except the State Route 89 and Willow Lake Rd. intersection with a very minor decrease from 4.4 to 4.2 damages per year. The most unfavorable individual performance of all intersections was the Route 89 Alternate and Route 179 intersection with an increase from 6.7 to 22.8 damages per year. These unexpected outcomes may be related to the geometrical nature of the double-lane roundabouts and the unfamiliarity of the public about driving through them. Double-lane roundabouts could be confusing if the condition of signage or the pavement marking is poor.

Table 11: Double-lane roundabout damage rates

Intersection	Total Number of Damages		Damage Rate per Year		Damage Rate per Million Vehicles	
	Before	After	Before	After	Before	After
AZ 89A/AZ 179	40	137	6.7	22.8	1.8	5.7
AZ 89A/Brewer Rd	11	17	1.8	2.8	0.6	0.8
99th Ave. & Lower Buckeye Rd	29	47	5.8	9.4	3.7	5.6
AZ 89A/Verde Heights Dr.	4	7	0.8	1.4	0.1	0.2
Hayden & Northsight	35	37	17.5	18.5	1.4	1.4
SR 89 & Willow Lake Rd	22	21	4.4	4.2	1.3	1.2

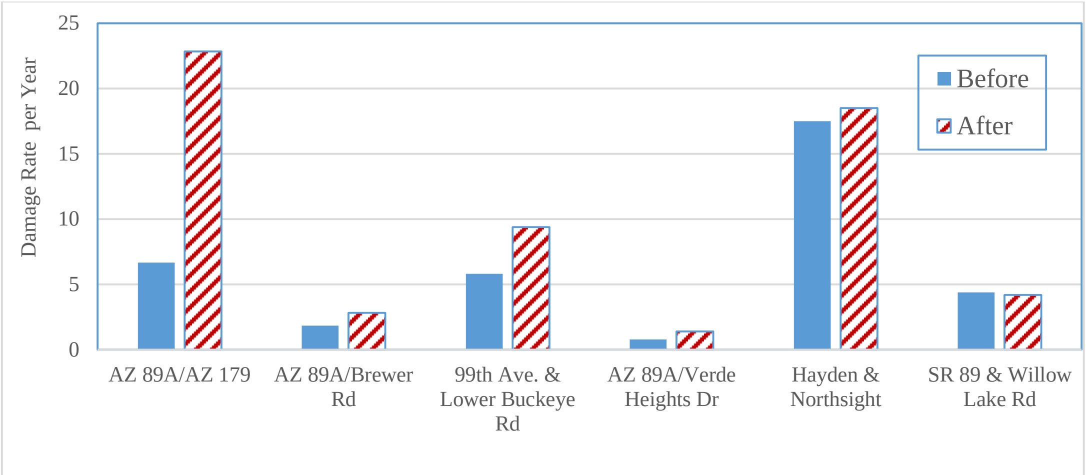

Figure 18: Damage rates per year before and after double-lane roundabouts.

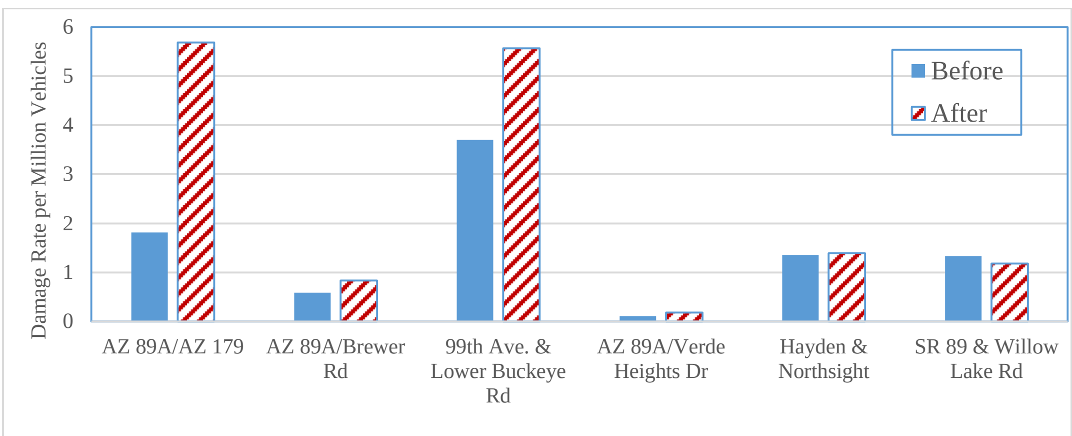

Figure 19: Damage rates per million vehicles before and after double-lane roundabouts.

Table 12 and Figures 20 and 21 present the injury rates for the double-lane roundabout intersections. Three of the intersections showed a decrease of injury rate due to double-lane roundabout conversion, while the other 3 showed an increase. The Route 89 Alternate and Route 179 intersection in Sedona had an increase from 1.2 to 3.0 injury rate per year as well as the State Route 89 and Willow Lake Rd. intersection in Prescott from 1.2 to 3.6. Scottsdale presented the good side of using double-lane roundabouts by a decrease from 5.0 to 0.5 injuries per year at the Hayden Rd. and Northsight Blvd roundabout.

Table 12: Double-lane roundabout injury rates

Intersection	Total Number of Injuries		Injury Rate per Year		Injury Rate per Million Vehicles	
	Before	After	Before	After	Before	After
AZ 89A/AZ 179	7	18	1.2	3.0	0.3	0.7
AZ 89A/Brewer Rd	5	4	0.8	0.7	0.3	0.2
99th Ave. & Lower Buckeye Rd	13	4	2.6	0.8	1.7	0.5
AZ 89A/Verde Heights Dr.	3	5	0.6	1.0	0.1	0.1
Hayden & Northsight	10	1	5.0	0.5	0.4	0.04
SR 89 & Willow Lake Rd	6	18	1.2	3.6	0.4	1.0

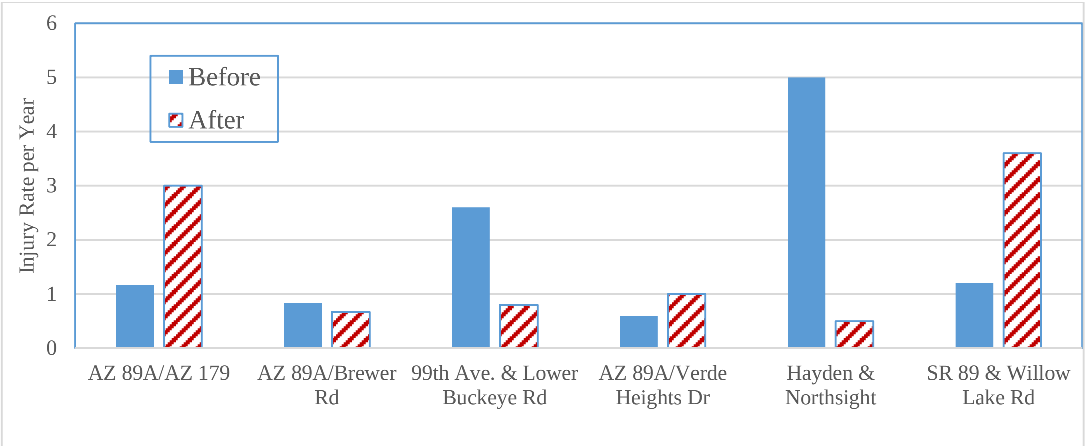

Figure 20: Injury rates per year before and after double-lane roundabouts.

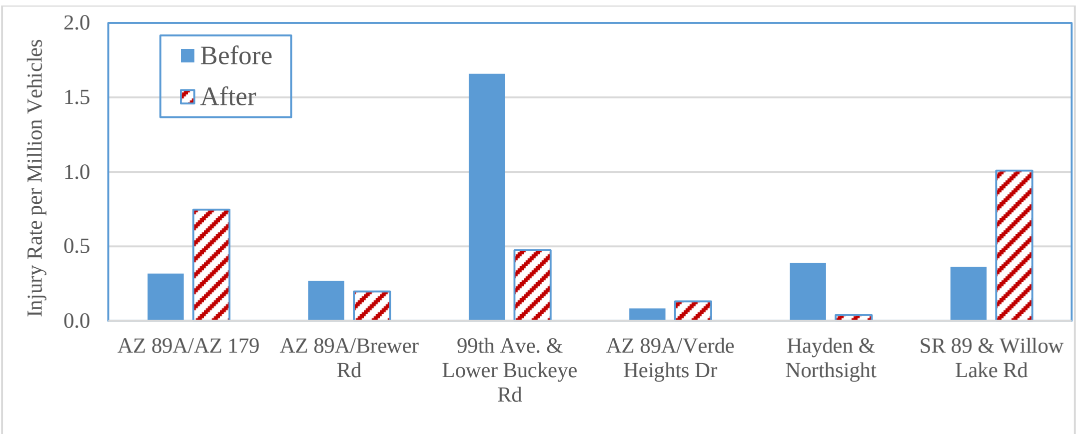

Figure 21: Injury rates per million vehicles before and after double-lane roundabouts.

Table 13 shows the fatality rates for the analyzed double-lane roundabouts. The table shows that the only intersection that had a previous history of fatalities was the Route 89 Alternate and Verde Heights Dr. intersection in Cottonwood. Even though there was one death case at that intersection before roundabout conversion, it changed to zero after the roundabout installment. Similarly, from both Figures 22 and 23 the rate of fatalities dropped to zero at this intersection.

Table 13: Double-lane roundabout fatality rates

Intersection	Total Number of Fatalities		Fatality Rate per Year		Fatality Rate per million Vehicles	
	Before	After	Before	After	Before	After
AZ 89A/AZ 179	0	0	0.0	0.0	0.0	0.0
AZ 89A/Brewer Rd	0	0	0.0	0.0	0.0	0.0
99th Ave. & Lower Buckeye Rd	0	0	0.0	0.0	0.0	0.0
AZ 89A/Verde Heights Dr.	1	0	0.2	0.0	0.0	0.0
Hayden & Northsight	0	0	0.0	0.0	0.0	0.0
SR 89 & Willow Lake Rd	0	0	0.0	0.0	0.0	0.0

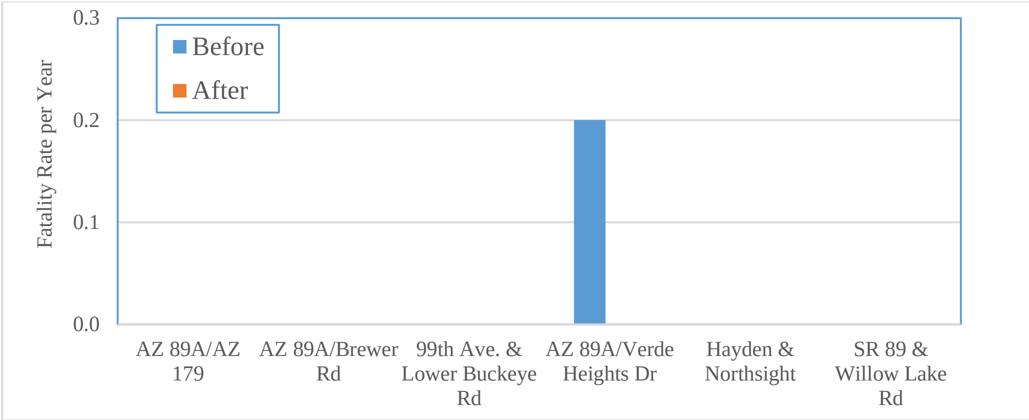

Figure 22: Fatality rates per year before and after double-lane roundabouts.

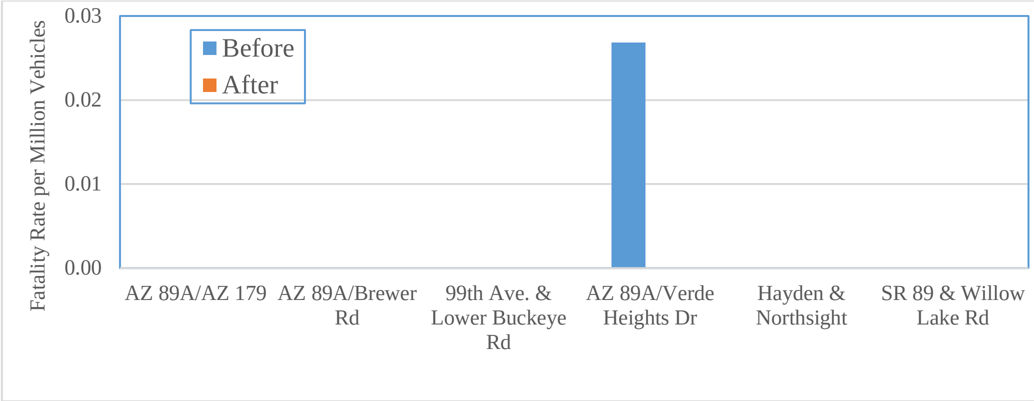

Figure 23: Fatality rates per million vehicles before and after double-lane roundabouts.

Accident Severities

As previously mentioned in the case of single-lane roundabouts, the accident data were normalized by dividing the sum of accidents of each severity level by the total number of accidents. Table 14 and Figure 24 show the severities of accidents for the analyzed double-lane roundabouts and the normalized results.

Table 14: Double-lane roundabouts accident severity analysis

Intersection	No. of Accidents		Number of Injuries for Different Severities									
			Before					After				
	Before	After	1	2	3	4	5	1	2	3	4	5
AZ 89A/AZ 179	45	149	40	2	3	2	0	137	9	9	0	0
AZ 89A/Brewer Rd.	15	21	11	3	2	0	0	17	2	1	1	0
99th Ave. & Lower Buckeye Rd.	38	50	29	6	7	0	0	47	3	1	0	0
AZ 89A/Verde Heights Dr.	7	11	4	0	3	0	1	7	2	3	0	0
Hayden & Northsight	23	21	35	5	4	1	0	37	0	1	0	0
SR 89 & Willow Lake Rd	27	35	22	2	4	0	0	21	14	4	0	0
	Normalized Severities		0.91	0.12	0.15	0.02	0.01	0.93	0.10	0.07	0.00	0.00

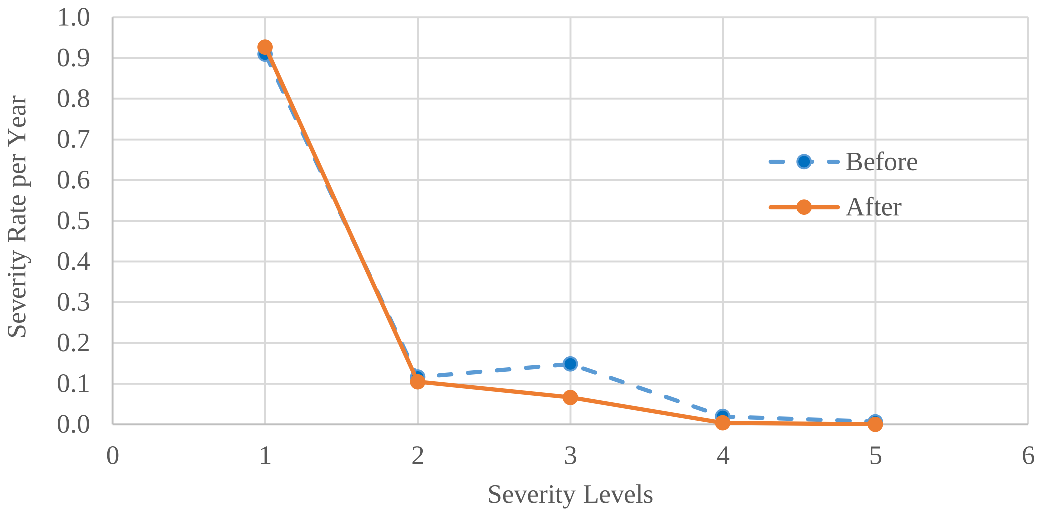

Figure 24: Normalized vs. actual accident severity rates before and after double-lane roundabouts.

Similar to Single-lane roundabouts, the results show the relation between the different levels of severities and the normalized severity rates for the double-lane roundabouts. Generally, it can be seen that the only category of the severities increased after using the double-lane roundabout was the damage only, which is the least severe category. Most importantly, it can be noticed that all of the injury categories have decreased after constructing the double-lane roundabouts. The Hayden Rd. and Northsight Blvd. intersection had the overall best individual performance of all of the analyzed double-lane roundabout, where 5 injuries from severity level two were eliminated, 4 injuries from severity level three decreased to a single case, and a single case of the severity level four dropped to zero after the conversion into the double-lane roundabout.

5 DISCUSSION

As indicated in Chapter 3, roundabouts were selected according to the availability of the following data:

1. Geometric design data
2. Crash data
3. Intersection related information

Figures 25-32 show comparisons between the average rates of total accidents, damages, injuries, and fatalities before and after roundabout conversions for all single-lane roundabouts. For each category, the rates were presented per year and per million vehicles.

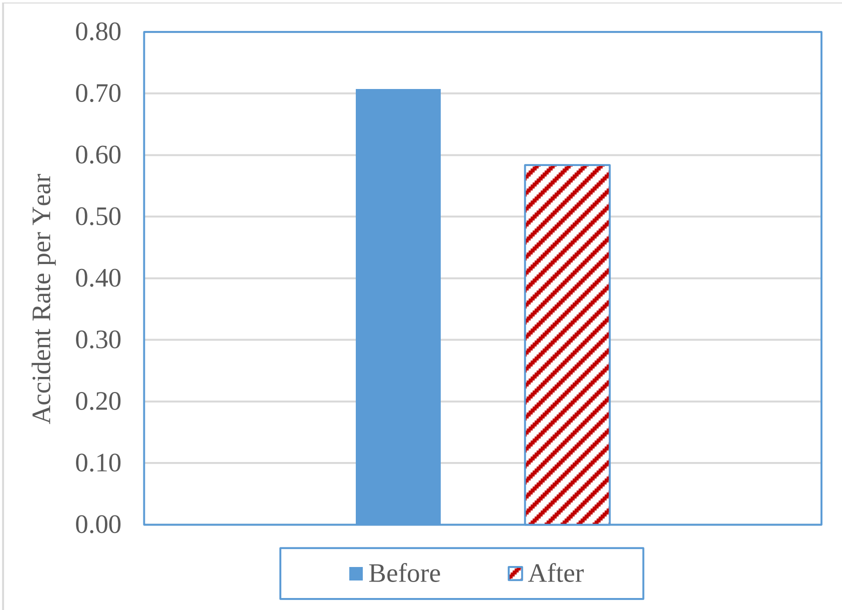

Figure 25: Average accident rate per year before and after single-lane roundabouts.

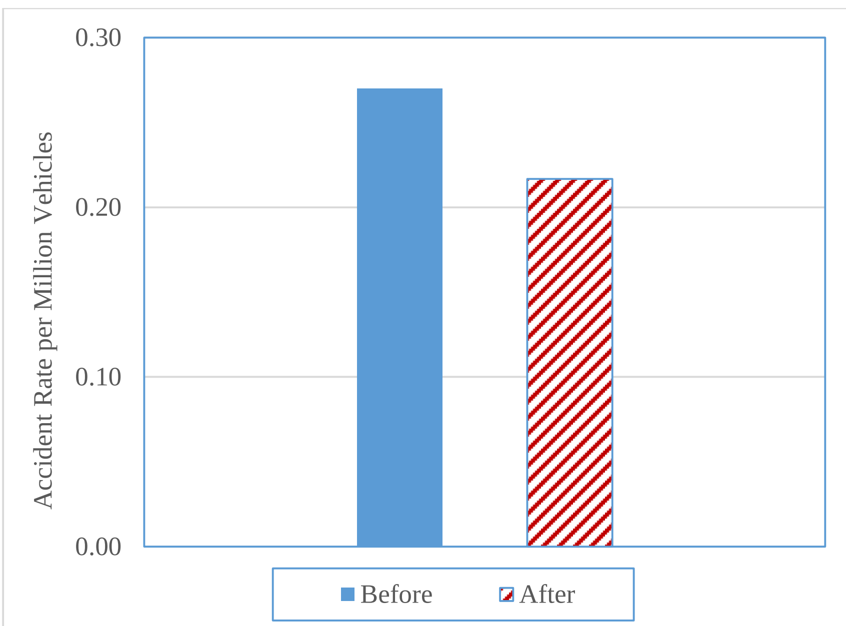

Figure 26: Average accident rate per million vehicles before and after single-lane roundabouts.

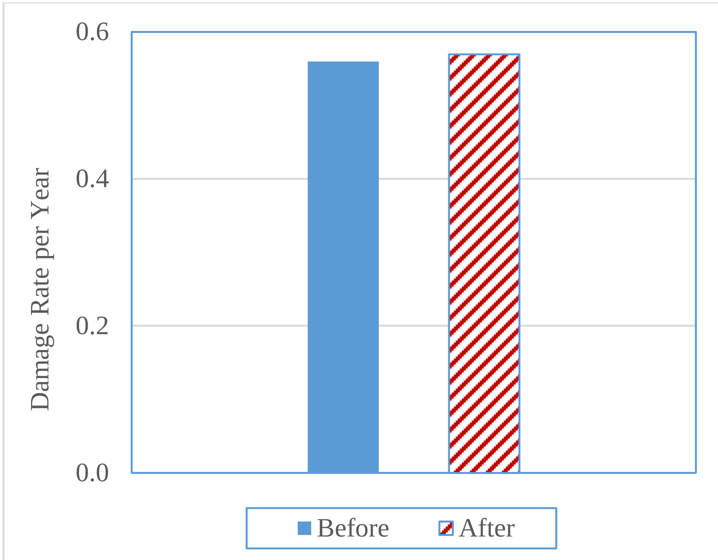

Figure 27: Average damage rate per year before and after single-lane roundabouts.

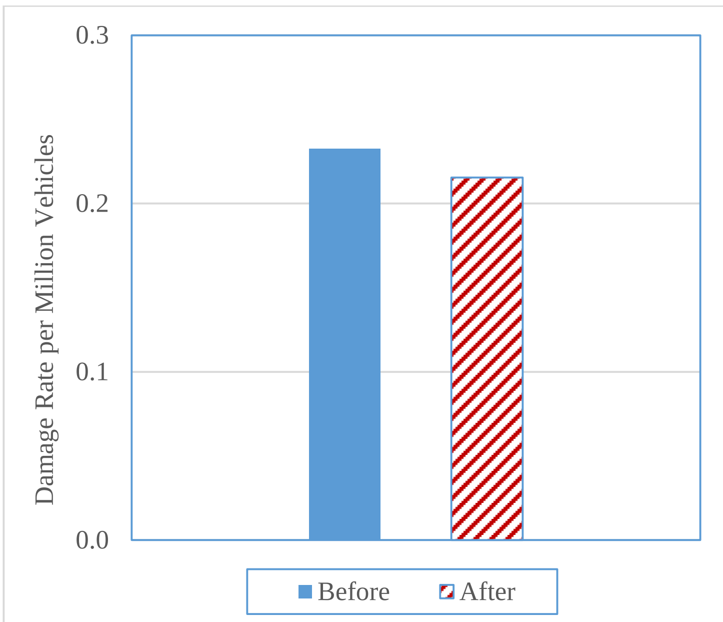

Figure 28: Average damage rate per million vehicles before and after single-lane roundabouts.

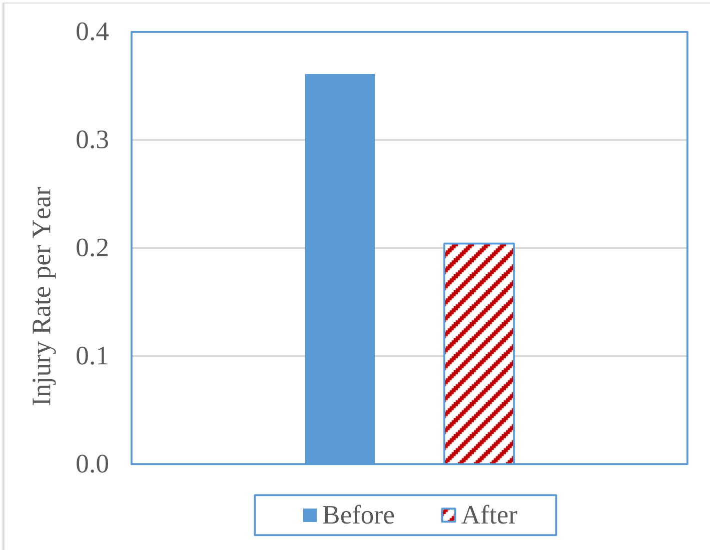

Figure 29: Average injury rate per year before and after single-lane roundabouts.

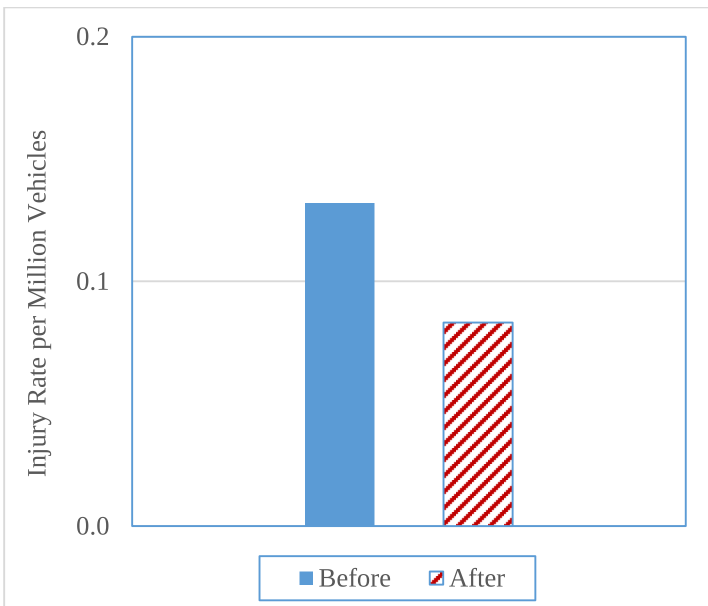

Figure 30: Average injury rate per million vehicles before and after single-lane roundabouts.

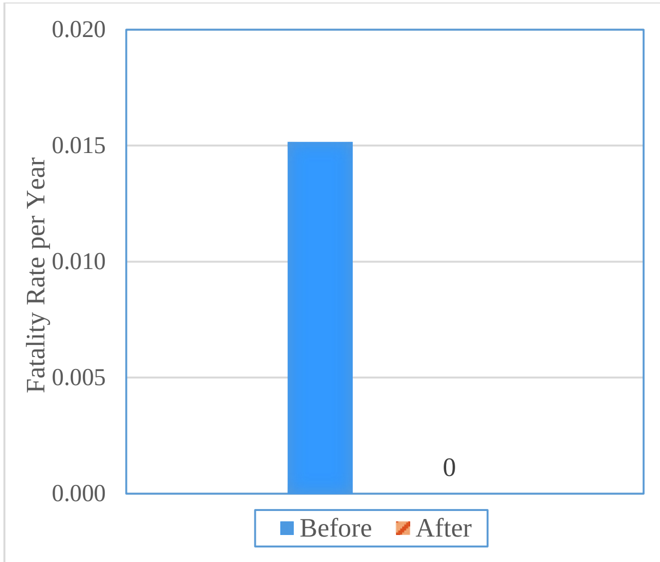

Figure 31: Average fatality rate per year before and after single-lane roundabouts.

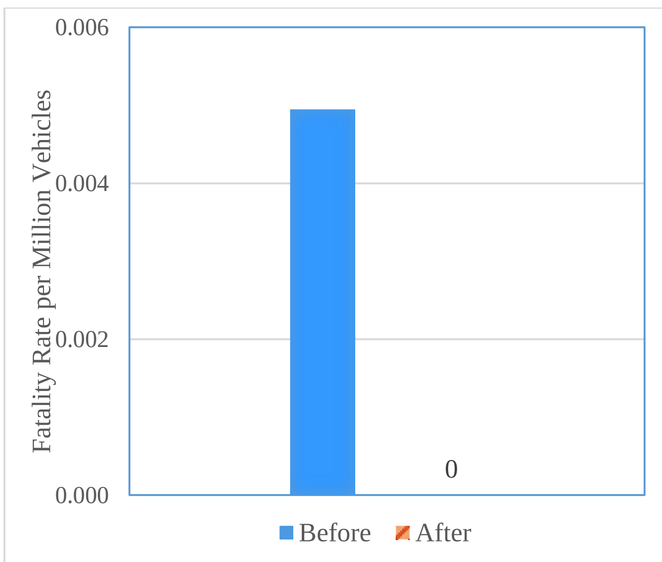

Figure 32: Average fatality rate per million vehicles before and after single-lane roundabouts.

The results in Figures 25-32 indicate that in all cases the roundabouts helped reduce the rates, except a very small increase in the rate of damage. Therefore, the overall performance of single-lane roundabouts is very good, specifically from the injury severity reduction point of view. Table 15 shows the average rate change per year and per million vehicles for all accidents, damages, injuries, and fatalities for single-lane roundabouts due to roundabout conversion.

Table 15: Average rate changes for all accidents, damage, injuries, and fatalities for single-lane roundabouts due to the roundabout conversion

Accident Rate	Percent Change per Year	Percent Change per Million Vehicles
All accidents	-18	-19
Damage	+2	-4
Injury	-44	-38
Fatality	-100	-100

Similar to the single-lane roundabouts, Figures 33-40 show comparisons between the average rates of total accidents, damages, injuries, and fatalities before and after roundabout conversions for all single-lane roundabouts. As a first impression, it can be noticed that double-lane roundabouts did not have a positive impact as what have been seen previously from the single-lane roundabouts. Actually, the overall accident rate and the damage rate increased after converting those intersections into double-lane roundabouts. However, the injury rates decreased, which might be considered the more desired outcome. Also, fatalities vanished after roundabout conversion. Table 16 shows the average rate change per year for all accidents, damages, injuries, and fatalities for all double-lane roundabouts due to roundabout conversion

Table 16: Average rate changes for all accidents, damage, injuries, and fatalities for double-lane roundabouts due to the roundabout conversion.

Accident Rate	Percent Change per Year	Percent Change per Million Vehicles
All accidents	+62	+55
Damage	+60	+67
Injury	-16	-16
Fatality	-100	-100

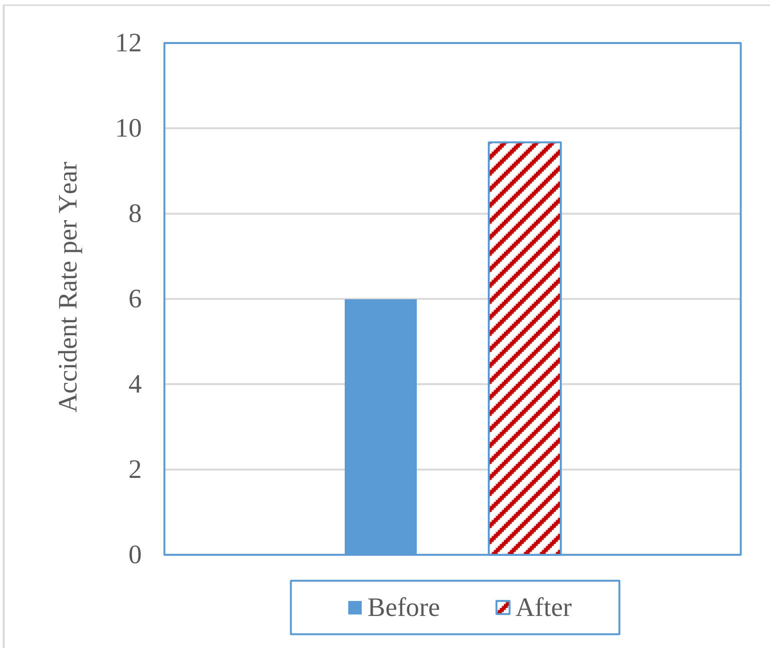

Figure 33: Average accident rate per year before and after double-lane roundabouts.

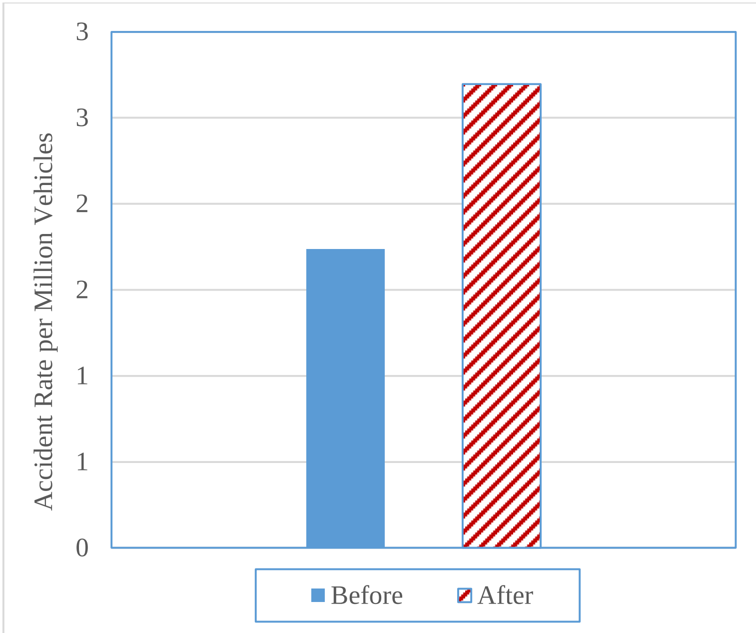

Figure 34: Average accident rate per million vehicles before and after single-lane roundabouts.

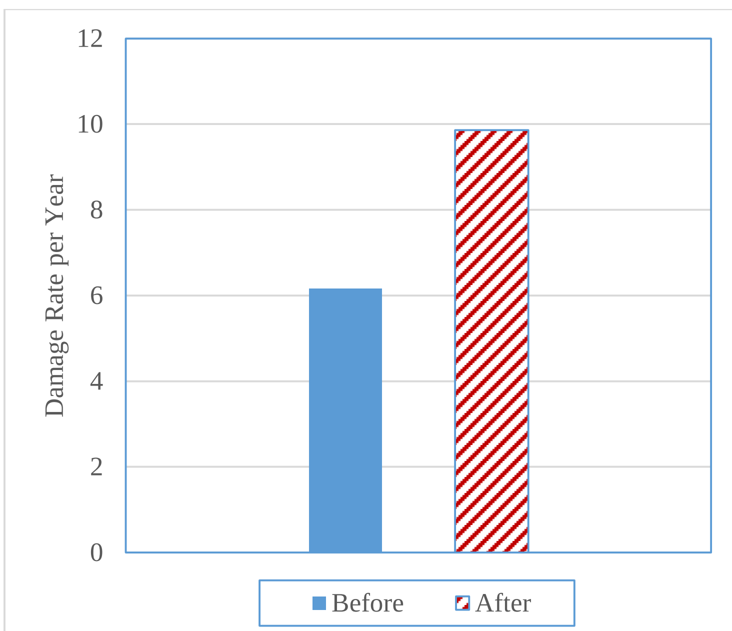

Figure 35: Average damage rate per year before and after double-lane roundabouts.

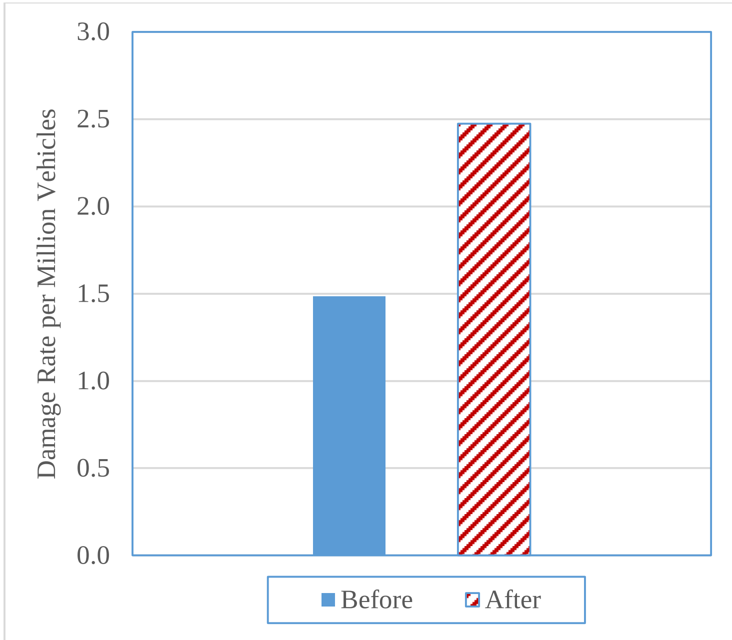

Figure 36: Average damage rate per million vehicles before and after double-lane roundabouts.

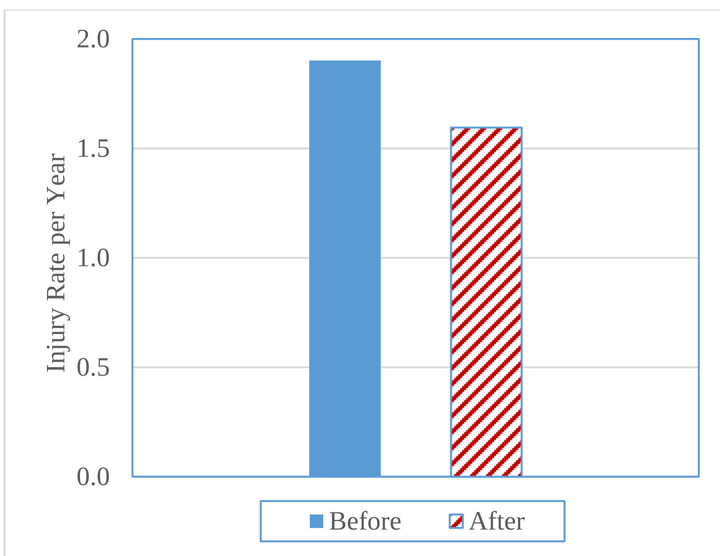

Figure 37: Average injury rate per year before and after double-lane roundabouts.

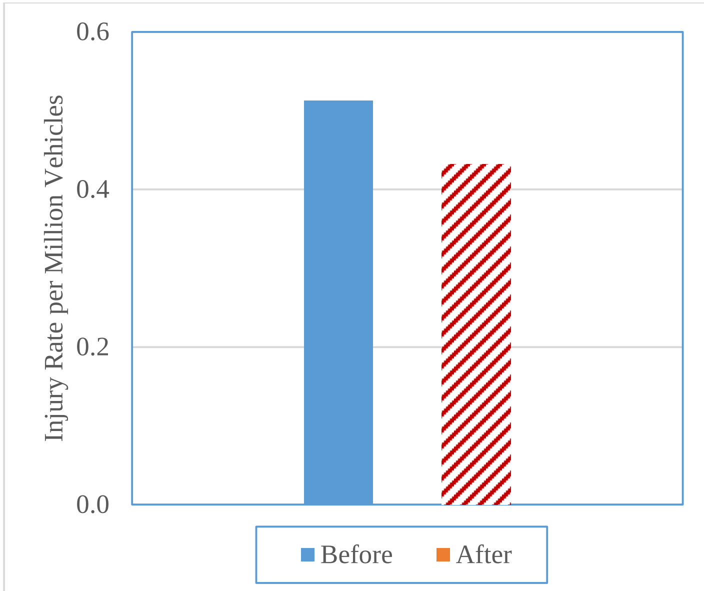

Figure 38: Average injury rate per million vehicles before and after double-lane roundabouts.

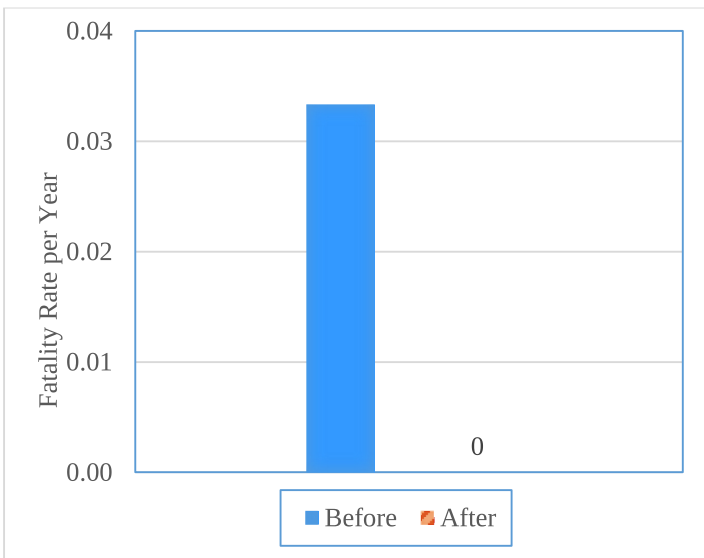

Figure 39: Average fatality rate per year before and after double-lane roundabouts.

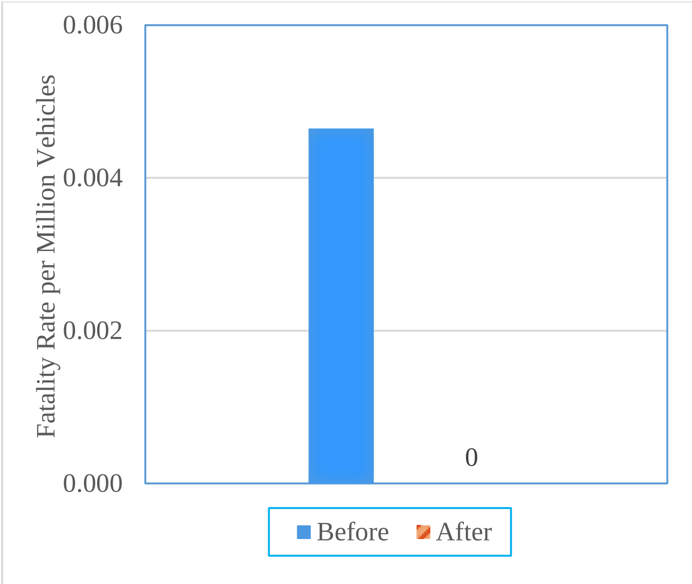

Figure 40: Average fatality rate per million vehicles before and after double-lane roundabouts.

It can be argued that double-lane roundabouts did not have an effective outcome as what have been seen in the single-lane roundabout case. There are many possible reasons behind the lake of good outcome from the double-lane roundabouts, such as:

- Lack of planning: Not fully sure when and where to put double-lane roundabouts.
- Small amount of knowledge about roundabout performance, which may lead to poor judgment.
- Poor public knowledge about roundabouts: The more the public get to be introduced to roundabouts, the easier they would be able to drive through them.
- The lack of full set of specifications and warrants to ensure that roundabout conversion and the number of lanes in the roundabout are used at the appropriate

ranges of traffic volume. If the traffic volume exceeds a certain value, a roundabout may not be the safest traffic control system.

6 SUMMARY AND CONCLUSIONS

Seventeen roundabouts in 5 cities in Arizona were used to study the effect of roundabout conversion on intersection safety, out of which 11 single-lane roundabouts and 16 double-lane roundabouts. Most of the locations of single-lane roundabouts were controlled by 2-way stop signs before conversion, while most of the locations of double-lane roundabouts were controlled by signals. Accident data were collected and broken down into 5 categories: damage without injury, minor injury, non-incapacitating injury, incapacitating injury, and fatality. Equal number of years were used before and after the roundabout conversion at each location. The most recent AADT value at each location was used to backcalculate the average AADT values in the periods before and after roundabout conversion. The average rate of accidents, damages, injuries and fatalities per year and per million vehicles were evaluated. Also, the effect of roundabout conversion on the severity of accidents was evaluated.

The following observations were derived:

1. For single-lane roundabouts, an average of 18% decrease in the rate of accidents per year and an average of 19% decrease in the rate of accidents per million vehicles after roundabout conversion were observed.

2. For single-lane roundabouts, the average rate of damage did not largely change after roundabout conversion.

3. For single-lane roundabouts, an average of 44% decrease in the rate of injuries per year and an average of 38% decrease in the rate of injuries per million vehicles after roundabout conversion were observed.

4. For double-lane roundabouts, a large increase of 62% in the average rate of accidents per year and a large increase of 55% in the average rate of accidents per million vehicles after roundabout conversion were observed.

5. For double-lane roundabouts, a large increase of 60% in the average rate of damages per year and a large increase of 67% in the average rate of damages per million vehicles after roundabout conversion were observed.

6. For double-lane roundabouts, a 16% decrease in the average rate of injuries per year and per million vehicles after roundabout conversion were observed.

7. One fatality incident occurred before roundabout conversion for each of the single and double lane roundabouts before roundabout conversion. No fatalities occurred after roundabout conversion

8. For all roundabouts, the normalized accident rate for severity level 1 either increased or remained approximately the same after roundabout conversion, while the rates for severity levels 2-5 decreased.

In evaluating "safety" one cannot only look at crash rate without looking at severity. An accurate judgment on crash impact can be obtained when all factors are considered, especially if the crash involves health and wellbeing of humans. The human element and the pain and suffering that crashes cause to individuals involved and their families have to be a primary consideration within the full context of all crashes. For example, one injury or one fatal crash is much more severe than a property damage only crash. Unlike people, cars can be easily repaired or replaced. With this in mind, single-lane roundabouts did not largely affect the rate of damage without injury, but double-lane roundabouts increased it. However, both types of roundabout decreased the rates of injury and fatality. This can be viewed as a road safety success.

7 RECOMMENDATIONS FOR FUTURE RESERACH

The following are a number of recommendations for future studies of roundabouts in Arizona, which can also be studied at the national level:

1) Aside from the roundabout's definitions, pavement marking, and signing guidelines mentioned in the Manual on Uniform Traffic Control Devices (MUTCD), there is a need for developing warrants and design guidelines for an engineering sound implementation of roundabouts with specific limits of roadway capacity limits for roundabouts.
2) More educational and awareness materials for the public for better driving at roundabouts. Visual demonstrations of how to approach, drive, and navigate through roundabouts would be highly recommended.
3) More in-depth planning before converting regular intersections into roundabouts. Examining the feasibility of constructing the roundabout and how would it improve that location is a step that must be done before going into the construction phase.
4) More research to be done in the roundabouts field of study under different traffic conditions.
5) Including roundabouts history and design features within the educational textbooks for future generations to learn more about it.

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