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EFFECT OF TRAFFIC ROUNDABOUTS ON SAFETY IN ARIZONA

Final Report

by

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DISCLAIMER

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EXECUTIVE SUMMARY

Seventeen roundabouts in 5 cities in Arizona were used in the study, out of which 11 single-lane and 16 double-lane. Most of the locations of single-lane roundabouts were controlled by 2-way stop signs before the roundabout installation, while most of the locations of double-lane roundabouts were controlled by signals. Accidents data were collected and broken down into 3 levels: damage, 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 AADT value at the time of roundabout conversion, which is the midpoint of the analysis period. The average rates of accidents, damages, and injuries per year and per year per million vehicles were evaluated. It was found that single-lane roundabouts reduced the accident rate of intersections. However, double-lane roundabouts increased the accident rate of intersections. A decision needs to be made as to either remove double-lane roundabouts or find solutions on how to make these roundabouts safe, such as making geometric improvements or educating the public on how to use them. The results also showed that both single- and double-lane roundabout conversions reduced the severity levels of accidents. Considering both accident rate and severity level, warrants needs to be developed for roundabout conversion for both single- and multi-lane roundabout conversion.

1.0 INTRODUCTION

Although roundabouts have gained popularity recently in many urban areas in the United States, they are still relatively unknown among most of the American public. Because of this, many misconceptions exist about roundabouts, as they are often confused with older style traffic circles and rotaries. Figure 1 shows a typical simple modern roundabout design.

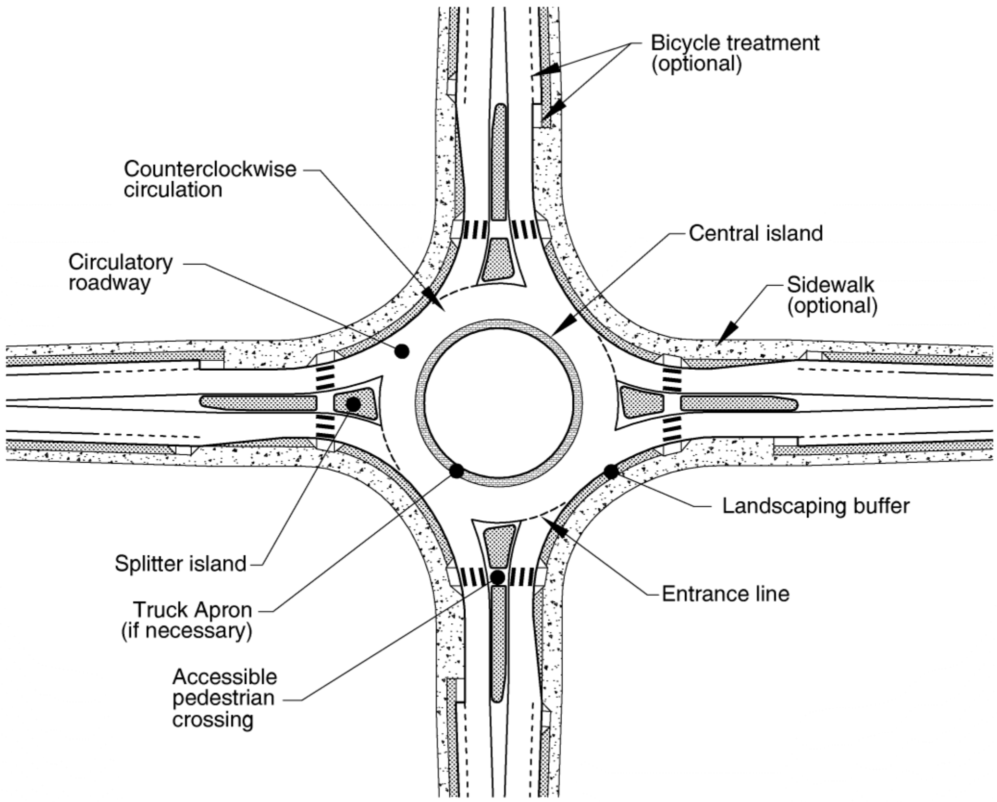

Figure 1: Typical modern roundabout design (1).

It has been noticeably recognized that cities around the United States, or even around the world, requesting changes and solution for their traffic congestions and delays. Standing at a traffic light for a long time, not only wastes people's time on a daily basis, but also increases greenhouse gas emissions, which is a big environmental concern nowadays. Safety in our streets became a big concern due to the increase in number of accidents. Researches have been conducted to find solutions for these issues. Roundabouts are used comprehensively all over Europe and the U.S., and in many other places around the world, to reduce accidents, traffic delays, fuel consumption, air pollution, and construction costs, while increasing capacity and enhancing intersection appearance. Roundabouts, successfully used to control traffic speeds in residential neighborhoods, are accepted as one of the safest types of intersection design (2).

The main objective of roundabouts is to provide a safer right-of-way control device in place of stop signs or traffic signals. Nationwide studies have shown the significant reduction roundabouts achieved for collision rates, injury rates, and fatality rates.

Modern roundabouts started as regular traffic circles and gradually replaced them. Modern roundabouts are considered the newest traffic control system, which differ from their successors as traffic circles and rotaries in several major issues (2, 3):

1. Modern roundabouts give vehicles within the roundabout the right-of-way, which prevents traffic from locking-up and allows free flow movement.
2. The entry and center island of a roundabout deflects entering traffic to slow traffic and reinforce the yielding process.
3. 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.
4. Modern roundabouts are smaller (ranging from 70-160 ft) than the older editions of rotaries, which used to range between 300-400 ft (Figure 2). Currently, space is a very important demand within city limits, where modern roundabouts may partially solve the issue of consuming large areas.
5. Modern roundabouts have raised splitters and islands, which help reduce entry speeds while driving inside the roundabout.

Figure 2: Small modern roundabout vs. large traditional rotary or traffic circle (1).

Modern roundabouts are designed to reduce crashes and improve traffic flow. Optimum results can be achieved through learning and understanding how roundabouts work and how to drive through them (4).

Many state and local agencies throughout the U.S. have been hesitant to install roundabouts due to lack of objective nationwide guidelines on planning, performance, safety, and design. The public's opinion is split between supporters and opposed.

Roundabouts have been used by some cities in Arizona for about a decade (4-7). In the last decade, 80 modern roundabouts were built in several cities within Arizona. Although one of the benefits of using roundabouts is to improve safety, no studies have been conducted to evaluate the effect of these roundabouts on safety at these intersections. If these roundabouts prove to be safer than traditional intersections as claimed, transportation agencies need to keep them and increase their use. On the other hand, if these roundabouts are actually less safe than traditional intersections, a decision needs to be made as to either remove them or find solutions on how to make them safe, such as making geometric improvements or educating the public on how to use them. In addition, no guidelines are available to the common driver to show the proper use of these roundabouts at different locations in Arizona. In many cases, drivers are confused on who has the right of way, which lane to use in case of multi-lane roundabouts, or changing lanes inside the roundabout.

1.1 OBJECTIVES

The main objective of this study is to evaluate the effect of using roundabouts on crash rate and severity in cities in Arizona. The effect on rate of accidents, damages, injuries, and fatalities of both single-lane and double-lane roundabouts are evaluated.

1.2 LITERATURE REVIEW

According to FHWA (8), roundabouts have fewer vehicular accidents than other intersection forms on average. The reason for this reduction is that roundabouts have fewer conflict points than traditional intersections as shown in Figure 3. A conflict point is defined as a location where the paths of two motor vehicles, or a vehicle and a bicycle or pedestrian queue, diverge, merge, or cross each other. Three types of conflicts are available: merge, diverge, and crossing. Crossing conflicts are often the most severe in terms of vehicular injuries and fatalities. At a traditional intersection these accidents most often occur when a driver fails to adhere to a stoplight or stop sign. By eliminating crossing conflicts, roundabouts can, by their design, largely lower the incidents of injuries and fatalities associated with conflict points. In addition to the reduction of conflict points, roundabouts require lower operating speeds for both the driver entering the roundabout and the driver driving in the circle.

Rodegerdts et al. (10) reported a 35% reduction in crashes at 55 sites where traditional intersections were converted to roundabouts, from 1,122 to 726 per year. Moreover, a 76% reduction in severe injury crashes was observed, from 296 to 72. They found no reduction in overall accidents at signalized intersections in urban areas after roundabout conversion, but a 60% reduction in severe injury crashes. At suburban signalized intersections, however, a dramatic 67% reduction in overall crashes occurred after roundabout conversion (from 292 to 98). There was not a significant amount of data on severe injury crashes for these locations. At rural intersections, researchers found a 87% reduction in severe injury crashes after the installation of a roundabout.

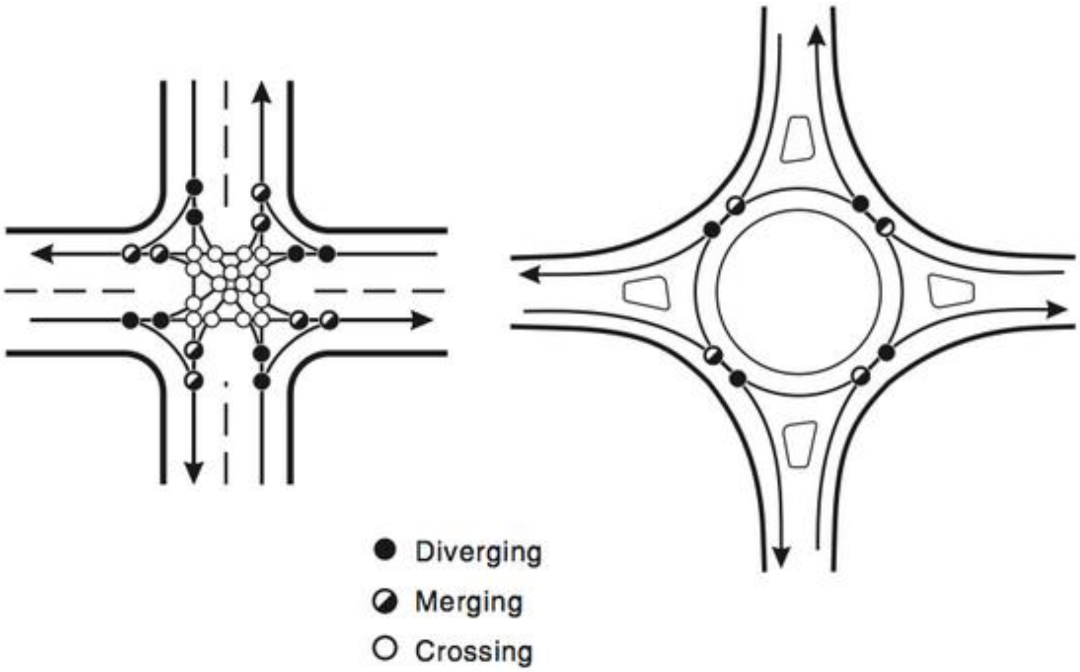

Figure 3: Comparison of traffic conflict points between a traditional intersection and roundabout (9).

Since mid-1990s, studies about the safety of roundabouts emerged from the United Kingdom. In 1977, crash data were collected from 114 roundabouts built before 1972 (11). Analysis showed that roundabouts reduced injury crashes by 46% at sites formerly under priority control, and by 62% at formerly signalized sites. However, sites previously controlled by large-island roundabouts showed noticeably increased crash rates when they reduced the size of the central island.

The first unofficial roundabout in the United States was constructed in the City of Ojai, California, in 1988. The California Department of Transportation stated that "Caltrans was going to "test" the concept in Ojai (11). 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 roundabouts in the U.S. were constructed in Summerlin (north of Las Vegas), Nevada, in 1990. The project involved two roundabouts that were designed for a low traffic volume of 6,000 and 3,000 vehicles per hour.

Large amounts of research studies conducted recently on the safety of roundabouts (11-16). Flannery and Datta (12) analyzed crash records from six U.S. roundabouts converted from another form of control. The study showed that roundabout conversion reduced crashes from an average of 3.75 per year to an average of one per year, a crash reduction of 73%. The reduction was statistically significant at a 99% level of confidence. Ourston (13) 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 (14) 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.

A new type of multi-lane roundabouts that has been introduced recently is the Turbo-roundabout (17). Turbo roundabouts provide an amplified flow of traffic, requiring drivers to choose their direction before entering the roundabout. Fortuijn (17) first introduced that type of roundabouts in the late 1990s as a safer and more efficient alternative to the standard multi-lane roundabouts. In 1990, the Netherlands installed the first turbo roundabout and soon became so popular that the Dutch government developed its own design guidelines. Currently, there are 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 according to their specified geometrics. Most recent counts estimate about 390 turbo roundabouts currently in-place around the world. Turbo roundabouts limit weaving maneuvers, which ultimately reduces any crashes related to changing lanes. Also, turbo roundabouts reduce the number of conflicting points, which also help in reducing crashes inside the roundabout.

In summary, many studies have been conduction 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 results. Currently, no studies are available to show such effect in Arizona.

2.0 DATA COLLECTION

There are 80 roundabouts in Arizona scattered in several cities around the state (4). 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 roundabout conversion, broken down by damage, injury, and fatality.
3. Availability of traffic data, especially the average annual daily traffic (AADT) in the major street.

Following these selection criteria, 17 roundabouts in 5 cities, which are Scottsdale, Sedona, Phoenix, Cottonwood, and Prescott, were used in the analysis. The roundabout historical and geometrical data were obtained and separated into two categories: single-lane (11 roundabouts) and double-lane (6 roundabouts) (4). Table 1 shows the roundabouts used in this study. Most of the roundabouts were built in 2006-2008. The locations of all single-lane roundabouts were controlled by 2-way stop signs before roundabout conversion, except at one location which was controlled by a 4-way stop sign. Also, the locations of all double-lane roundabouts were controlled by traffic signals, except at one location that was controlled by a 2-way stop sign.

Accident data were obtained either from the Arizona Department of Transportation (ADOT) database or city records. The ADOT accident data were broken down by route, milepost, and year. Therefore, a search was made to match the roundabout location with the milepost.

Accidents were reported at 5 levels of severity:

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

Table 1: Roundabouts used in the analysis and their features.

Intersection	City	Roundabout Type	Traffic Control Before Conversion	Year of Conversion
94 St. & Union Hills	Scottsdale	Single-Lane	2-way stop	2006
96 St. & Cholla	Scottsdale	Single-Lane	2-way stop	2006
96 St. & Sweetwater	Scottsdale	Single-Lane	4-way stop	2006
100 St. & Cactus	Scottsdale	Single-Lane	2-way stop	2008
104 St. & Cactus	Scottsdale	Single-Lane	2-way stop	2008
108 St. & Cactus	Scottsdale	Single-Lane	2-way stop	2008
AZ 179/Arrow Dr./Morgan Rd.	Sedona	Single-Lane	2-way stop	2008
AZ 179/Back O'Beyond Rd.	Sedona	Single-Lane	2-way stop	2008
AZ 179/Canyon Dr.	Sedona	Single-Lane	2-way stop	2008
AZ 179/Chapel Rd.	Sedona	Single-Lane	2-way stop	2008
AZ 179/Schnebly Hill Rd.	Sedona	Single-Lane	2-way stop	2008
AZ 89A/AZ 179	Sedona	Double-Lane	Signal	2008
AZ 89A/Brewer Rd.	Sedona	Double-Lane	Signal	2008
99th Ave. & Lower Buckeye Rd	Phoenix	Double-Lane	2-way stop	2009
AZ 89A/Verde Heights Dr.	Cottonwood	Double-Lane	Signal	2009
Hayden & Northsight	Scottsdale	Double-Lane	Signal	2013
SR 89 & Willow Lake Rd	Prescott	Double-Lane	Signal	2009

In this study, three accident levels were used: damage, injury (levels 2-4 combined), and fatality. The AADT value in the major street at each roundabout was obtained for the year 2014 or 2015 either from the ADOT website (18) or city records.

Table 2 shows the number accidents, damages without injuries, injuries, and fatalities. Note that the total number of accidents does not match the number of damages, injuries, or fatalities. The reason is that an accident could have more than one damage, injury or fatality.

The table shows that only one fatality occurred at the AZ 179/Schnebly Hill Road intersection before the single-lane roundabout conversion. No fatalities occurred after any single-lane roundabout conversion. Also, only one fatality occurred at the AZ 89A/Verde Heights Dr.

intersection before the double-lane roundabout conversion. Similarly, no fatalities occurred after any double-lane roundabout conversion.

Table 2: Number of accidents before and after roundabouts conversion and traffic data.

Intersection	Before				After				Most Recent AADT
	Total	Damage	Injury	Fatality	Total	Damage	Injury	Fatality	
94 St. & Union Hills	0	0	0	0	2	3	1	0	3,000
96 St. & Cholla	4	2	4	0	7	9	1	0	9,400
96 St. & Sweetwater	3	6	0	0	7	6	3	0	5,800
100 St. & Cactus	1	1	1	0	13	16	3	0	9,900
104 St. & Cactus	7	8	3	0	7	6	2	0	6,900
108 St. & Cactus	6	8	2	0	2	2	1	0	6,500
AZ 179/Arrow Dr./Morgan Rd.	9	5	4	0	0	0	0	0	8,400
AZ 179/Back O'Beyond Rd.	2	1	3	0	1	0	1	0	8,200
AZ 179/Canyon Dr.	7	4	3	0	3	1	2	0	9,800
AZ 179/Chapel Rd.	6	3	4	0	2	1	2	0	10,500
AZ 179/Schnebly Hill Rd.	6	4	2	1	3	3	0	0	9,600
Single-Lane Roundabout Average	4.6	3.8	2.4	0.1	4.3	4.3	1.5	0	8,000
AZ 89A/AZ 179	45	40	7	0	149	137	18	0	11,500
AZ 89A/Brewer Rd.	15	11	5	0	21	17	4	0	9,750
99th Ave. & Lower Buckeye Rd	38	29	13	0	50	47	4	0	4,800
AZ 89A/Verde Heights Dr.	7	4	3	1	11	7	5	0	22,000
Hayden & Northsight	23	35	10	0	21	37	1	0	37,000
SR 89 & Willow Lake Rd	27	22	6	0	35	21	18	0	10,140
Double-Lane Roundabout Average	25.8	23.5	7.3	0.2	47.8	44.3	8.3	0	15,865

3.0 ANALYSIS OF RESULTS

In order to study the effect of roundabout conversion on accident rate, equal number of years were used before and after the roundabout construction at each location. Since the accident data are available up to 2014 or 2015, the number of years after construction was calculated at each location and a similar number of years before construction was used for comparison.

The latest available AADT data was obtained for either 2014 or 2015, depending on the available sources. In order to provide a fair comparison of accident rates before and after roundabout conversion, an average AADT value had to be used. An average traffic growth rate of 1.5 percent was assumed during the analysis period, which was obtained from the ADOT database (18). Therefore, the most recent AADT value at each location was used to backcalculate the AADT value at the time of construction, which is the midpoint of the analysis period. Table 3 shows the analysis period before and after construction and the backcalulated AADT value at the time of construction at each location.

Table 3: Analysis period and traffic data at each location.

Intersection	Analysis Period Before and After Construction (Years)	AADT at Year of Construction
94 St. & Union Hills	9	2,624
96 St. & Cholla	9	8,221
96 St. & Sweetwater	9	5,073
100 St. & Cactus	7	8,920
104 St. & Cactus	7	6,217
108 St. & Cactus	7	5,857
AZ 179/Arrow Dr./Morgan Rd.	6	7,682
AZ 179/Back O'Beyond Rd.	6	7,499
AZ 179/Canyon Dr.	6	8,963
AZ 179/Chapel Rd.	6	9,603
AZ 179/Schnebly Hill Rd.	6	8,780
Single-Lane Roundabout Average		7,222
AZ 89A/AZ 179	6	10,517
AZ 89A/Brewer Rd.	6	8,917
99th Ave. & Lower Buckeye Rd	5	4,456
AZ 89A/Verde Heights Dr.	5	20,422
Hayden & Northsight	2	35,914
SR 89 & Willow Lake Rd	5	9,413
Double-Lane Roundabout Average		14,940

Several approaches were used to analyze accident data:

1. Average rate of accidents per year
2. Average rate of accidents per year per million vehicles
3. Average rate of damages per year
4. Average rate of damages per year per million vehicles
5. Average rate of injuries per year
6. Average rate of injuries per year per million vehicles
7. Number of fatalities

Table 4 shows the rates per year of total accidents, damages and injuries at each location, whereas Table 5 shows the rates per year per million vehicles of total accidents, damages and injuries at each location.

Table 4: Accident Rates per year before and after roundabout conversion.

Intersection	Before			After		
	Total	Damage	Injury	Total	Damage	Injury
94 St. & Union Hills	0.0	0.0	0.0	0.2	0.3	0.1
96 St. & Cholla	0.4	0.2	0.4	0.8	1.0	0.1
96 St. & Sweetwater	0.3	0.7	0.0	0.8	0.7	0.3
100 St. & Cactus	0.1	0.1	0.1	1.9	2.3	0.4
104 St. & Cactus	1.0	1.1	0.4	1.0	0.9	0.3
108 St. & Cactus	0.9	1.1	0.3	0.3	0.3	0.1
AZ 179/Arrow Dr./Morgan Rd	1.5	0.8	0.7	0.0	0.0	0.0
AZ 179/Back O'Beyond Rd.	0.3	0.2	0.5	0.2	0.0	0.2
AZ 179/Canyon Dr.	1.2	0.7	0.5	0.5	0.2	0.3
AZ 179/Chapel Rd	1.0	0.5	0.7	0.3	0.2	0.3
AZ 179/Schnebly Hill Rd	1.0	0.7	0.3	0.5	0.5	0.0
Single-Lane Roundabout Average	0.71	0.56	0.36	0.58	0.57	0.20
AZ 89A/AZ 179	7.5	6.7	1.2	24.8	22.8	3.0
AZ 89A/Brewer Rd.	2.5	1.8	0.8	3.5	2.8	0.7
99th Ave. & Lower Buckeye Rd.	7.6	5.8	2.6	10.0	9.4	0.8
AZ 89A/Verde Heights Dr.	1.4	0.8	0.6	2.2	1.4	1.0
Hayden & Northsight	11.5	17.5	5.0	10.5	18.5	0.5
SR 89 & Willow Lake Rd	5.4	4.4	1.2	7.0	4.2	3.6
Double-Lane Roundabout Average	5.98	6.17	1.90	9.67	9.86	1.59

Table 5: Accident Rates per year per million vehicles before and after roundabout conversion.

Intersection	Before			After		
	Total	Damage	Injury	Total	Damage	Injury
94 St. & Union Hills	0.0	0.0	0.0	0.2	0.3	0.1
96 St. & Cholla	0.1	0.1	0.1	0.3	0.3	0.0
96 St. & Sweetwater	0.2	0.4	0.0	0.4	0.4	0.2
100 St. & Cactus	0.0	0.0	0.0	0.6	0.7	0.1
104 St. & Cactus	0.4	0.5	0.2	0.4	0.4	0.1
108 St. & Cactus	0.4	0.5	0.1	0.1	0.1	0.1
AZ 179/Arrow Dr./Morgan Rd.	0.5	0.3	0.2	0.0	0.0	0.0
AZ 179/Back O'Beyond Rd.	0.1	0.1	0.2	0.1	0.0	0.1
AZ 179/Canyon Dr.	0.4	0.2	0.2	0.2	0.1	0.1
AZ 179/Chapel Rd.	0.3	0.1	0.2	0.1	0.0	0.1
AZ 179/Schnebly Hill Rd	0.3	0.2	0.1	0.2	0.2	0.0
Single-Lane Roundabout Average	0.26	0.22	0.13	0.23	0.23	0.08
AZ 89A/AZ 179	2.0	1.7	0.3	6.5	5.9	0.8
AZ 89A/Brewer Rd.	0.8	0.6	0.3	1.1	0.9	0.2
99th Ave. & Lower Buckeye Rd.	4.7	3.6	1.6	6.1	5.8	0.5
AZ 89A/Verde Heights Dr.	0.2	0.1	0.1	0.3	0.2	0.1
Hayden & Northsight	0.9	1.3	0.4	0.8	1.4	0.0
SR 89 & Willow Lake Rd.	1.6	1.3	0.3	2.0	1.2	1.0
Double-Lane Roundabout Average	1.67	1.43	0.49	2.80	2.57	0.45

3.1 Single-Lane Roundabouts

3.1.1 Accident Rate

Figures 4-5 show the accident rate per year and accident rate per year per million vehicles, respectively. Figures 6-7 show the damage rate per year and damage rate per year per million vehicles, respectively. Figures 8-9 show the injury rate per year and injury rate per year per million vehicles, respectively.

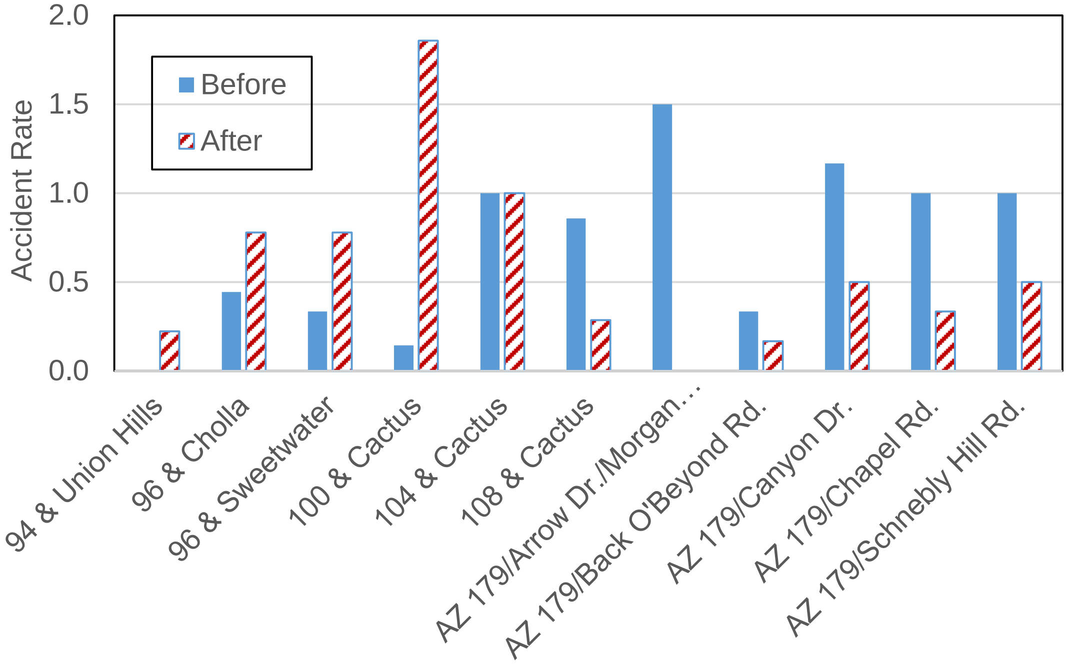

Figure 4: Accident rate per year for single-lane roundabouts before and after roundabout conversion at different locations.

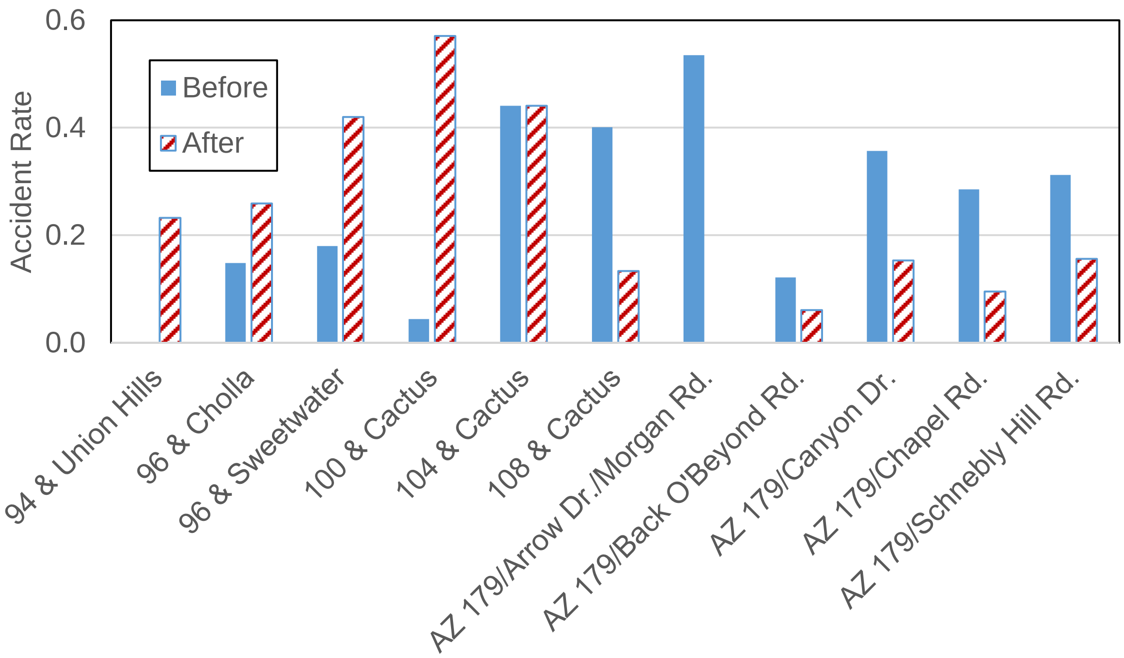

Figure 5: Accident rate per year per million vehicles for single-lane roundabouts before and after roundabout conversion at different locations.

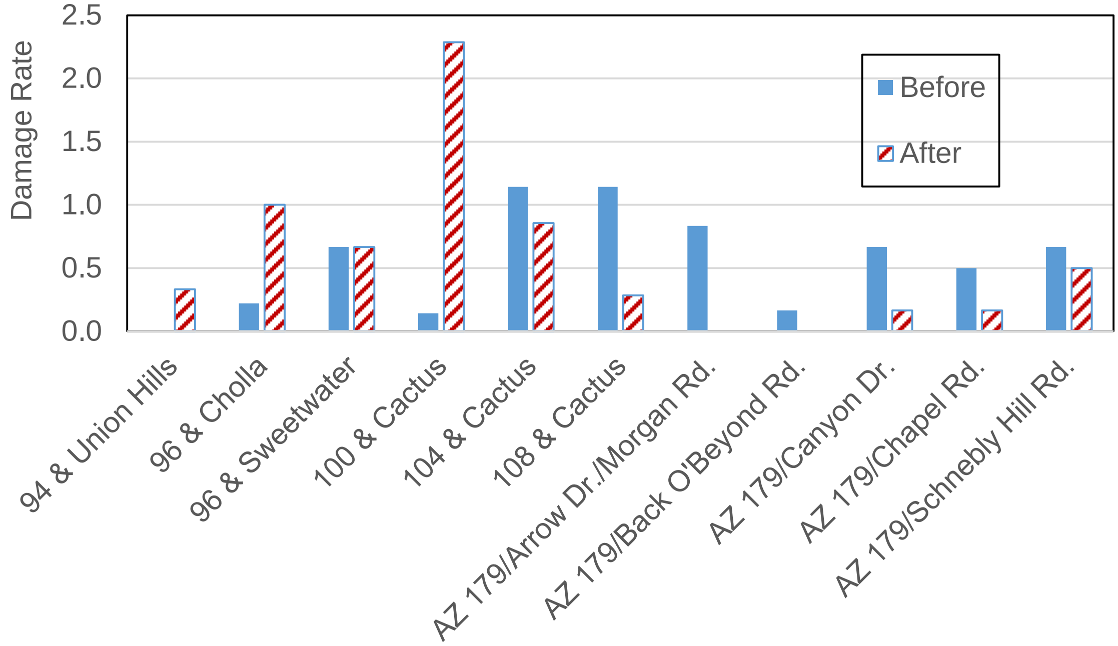

Figure 6: Damage rate per year for single-lane roundabouts before and after roundabout conversion at different locations.

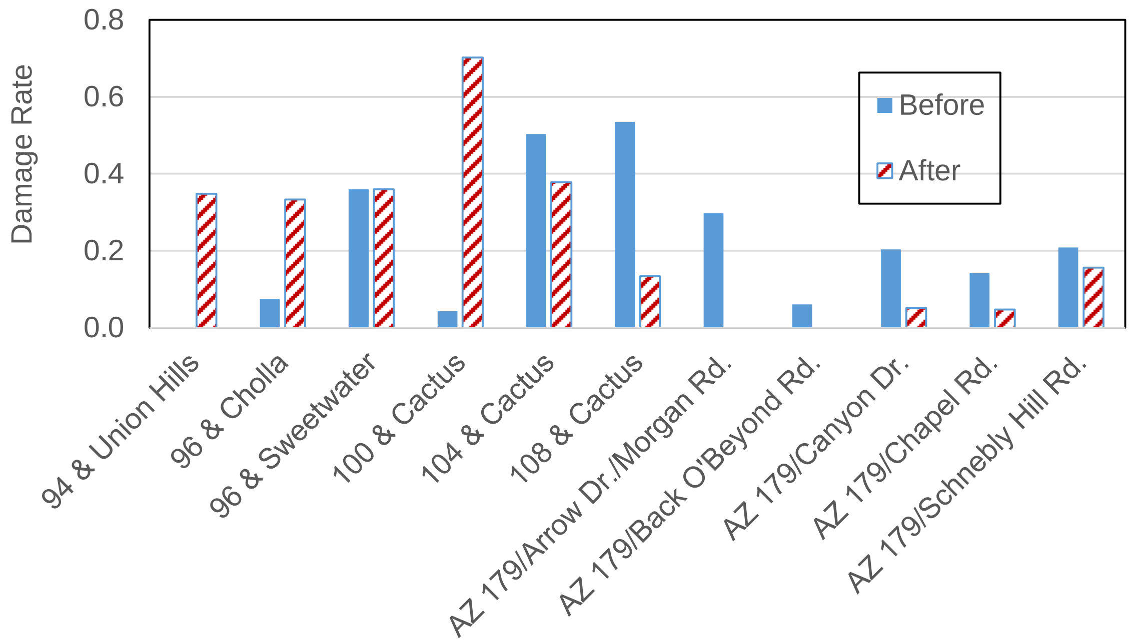

Figure 7: Damage rate per year per million vehicles for single-lane roundabouts before and after roundabout conversion at different locations.

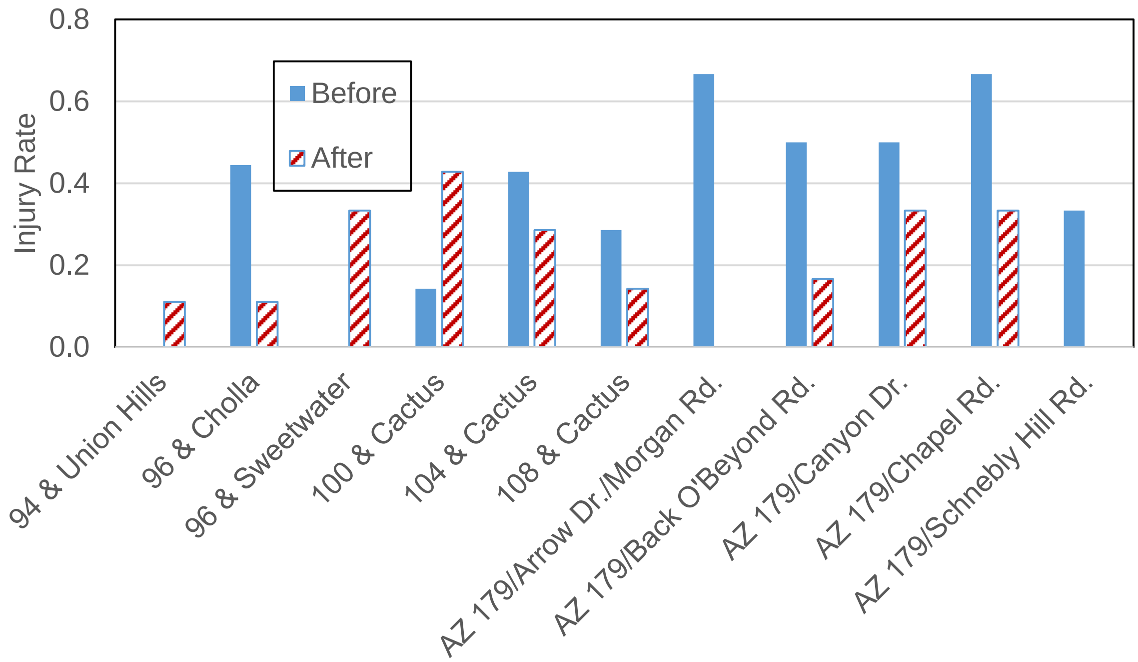

Figure 8: Injury rate per year for single-lane roundabouts before and after roundabout conversion at different locations.

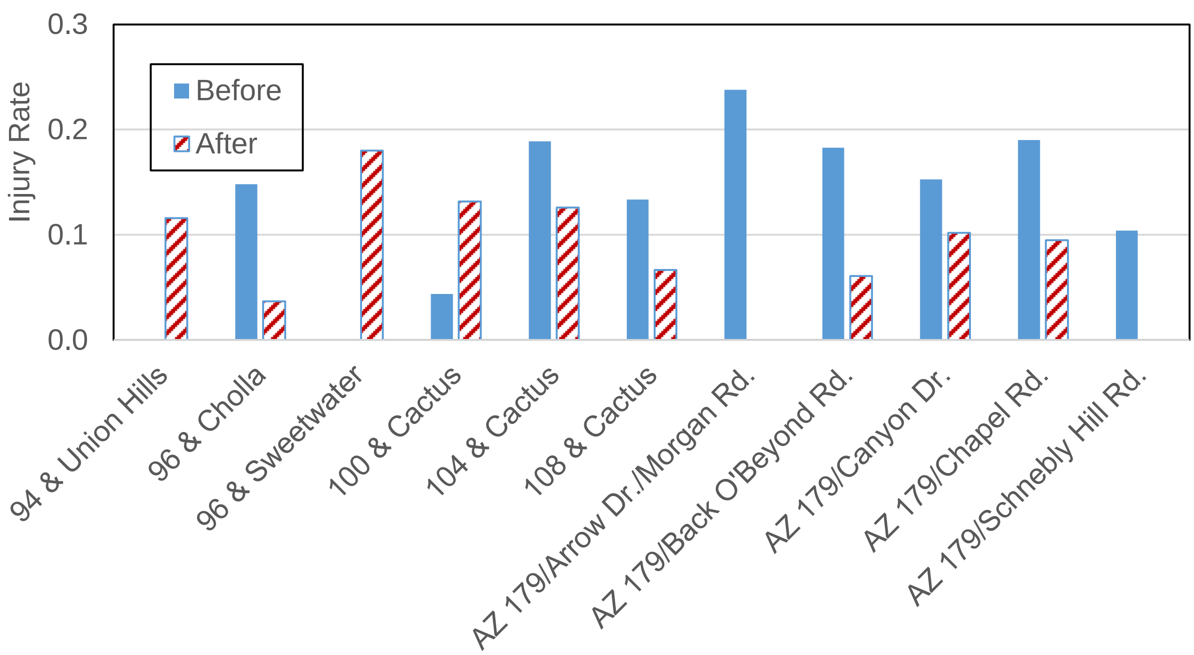

Figure 9: Injury rate per year per million vehicles for single-lane roundabouts before and after roundabout conversion at different locations.

3.1.2 Accident Severity

In order to evaluate the effect of roundabout conversion on the accident severity, the total number of accidents with different severities were normalized by dividing the total number of accidents for each severity level by the total number of accidents before and after roundabout conversion. Table 6 and Figure 10 show the normalized accident rates for different severity levels before and after roundabout conversion. It can be seen that the normalized accident rate for severity level 1 increased after roundabout conversion, while the rates of severity levels 2-5 decreased. Since severity level 1 is less severe than other levels, it indicates that the single-lane roundabout conversion reduced the severity of accidents.

Table 6: Normalized accident rates for different severity levels before and after single-lane roundabout conversion.

	Total Accidents Before Roundabout					Total Accidents After Roundabout				
Severity Level	1	2	3	4	5	1	2	3	4	5
Total Accidents	42	14	10	2	1	47	9	6	1	0
Normalized Accidents	0.82	0.27	0.20	0.04	0.02	1.00	0.19	0.13	0.02	0.00

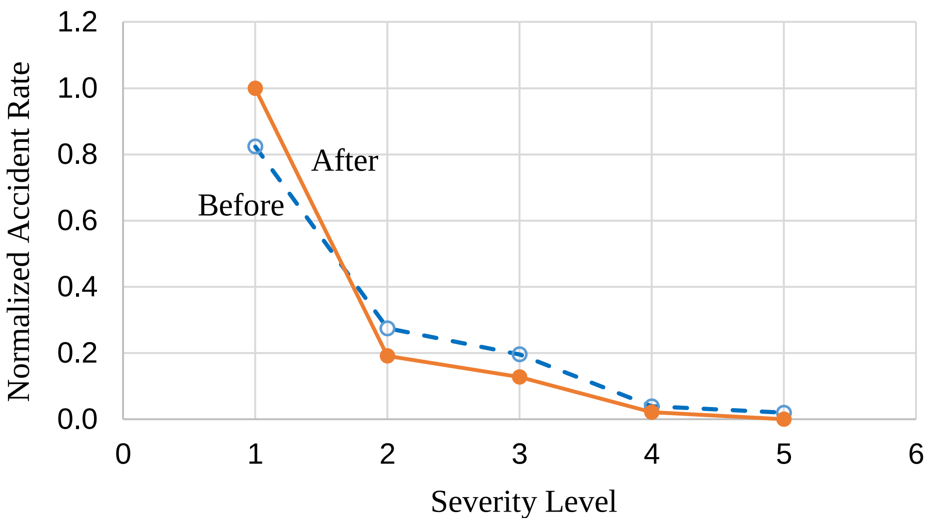

Figure 10: Normalized accident rates for different severity levels before and after single-lane roundabout conversion.

3.2 Double-Lane Roundabouts

3.2.1 Accident Rate

Figures 11-12 show the accident rate per year and accident rate per year per million vehicles, respectively. Figures 13-14 show the damage rate per year and damage rate per year per million vehicles, respectively. Figures 15-16 show the injury rate per year and injury rate per year per million vehicles, respectively.

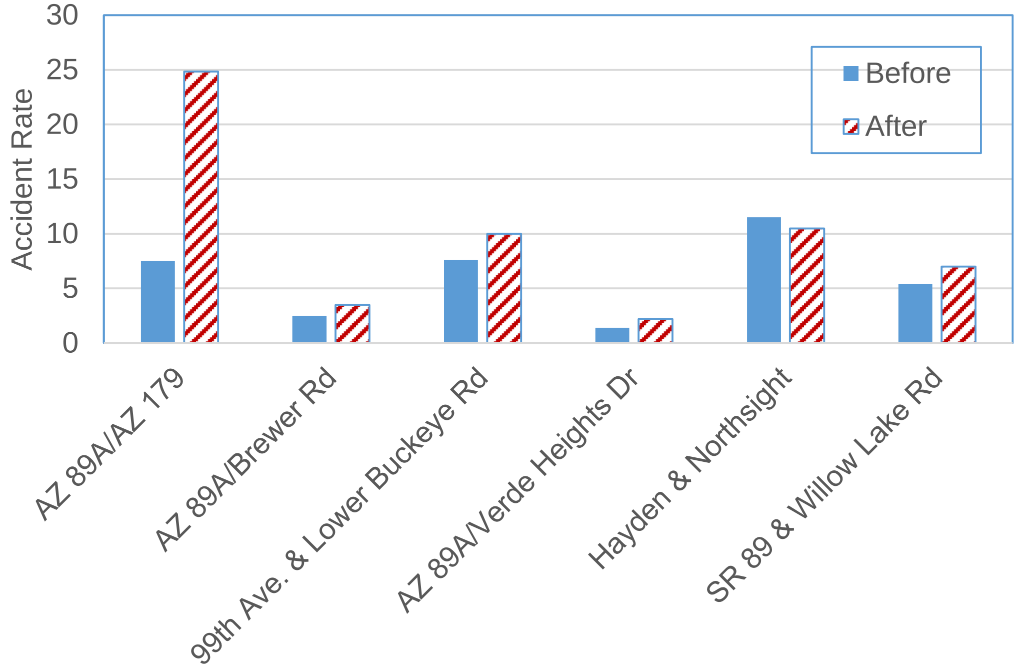

Figure 11: Accident rate per year for double-lane roundabouts before and after roundabout conversion at different locations.

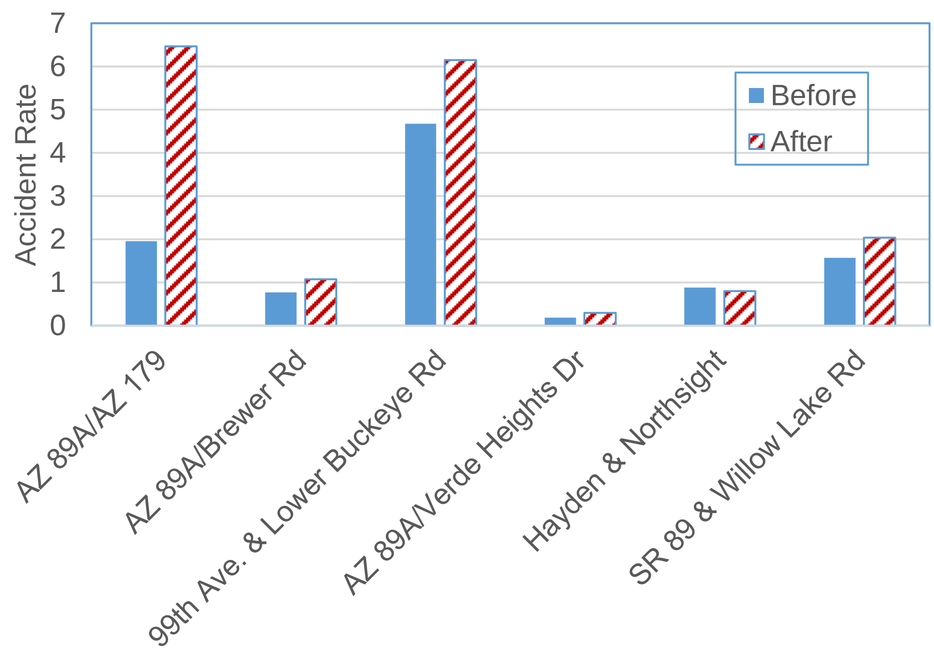

Figure 12: Accident rate per year per million vehicles for double-lane roundabouts before and after roundabout conversion at different locations.

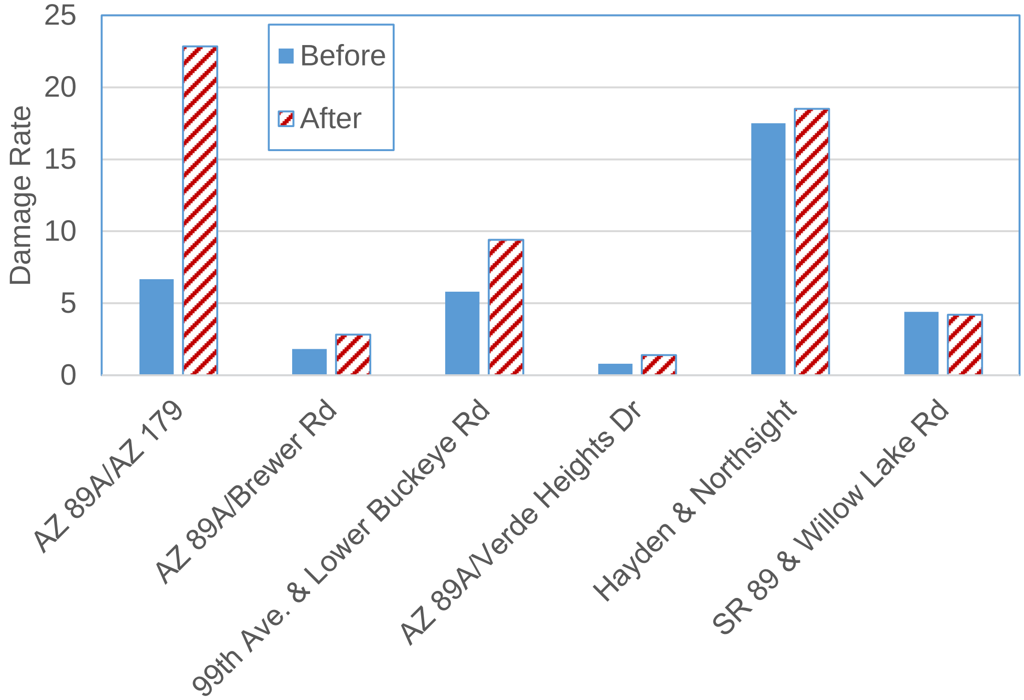

Figure 13: Damage rate per year for double-lane roundabouts before and after roundabout conversion at different locations.

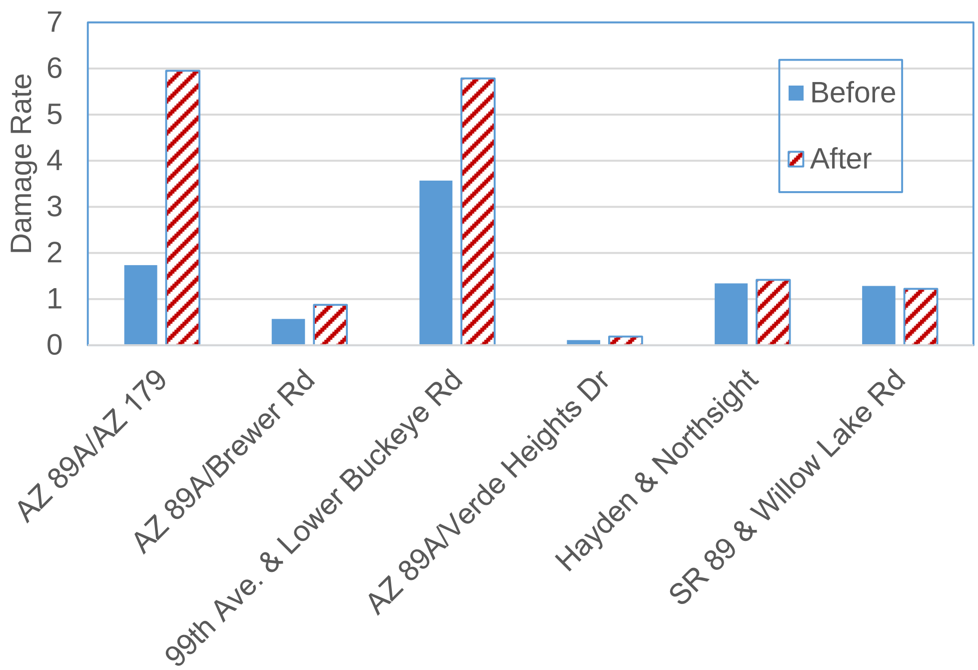

Figure 14: Damage rate per year per million vehicles for double-lane roundabouts before and after roundabout conversion at different locations.

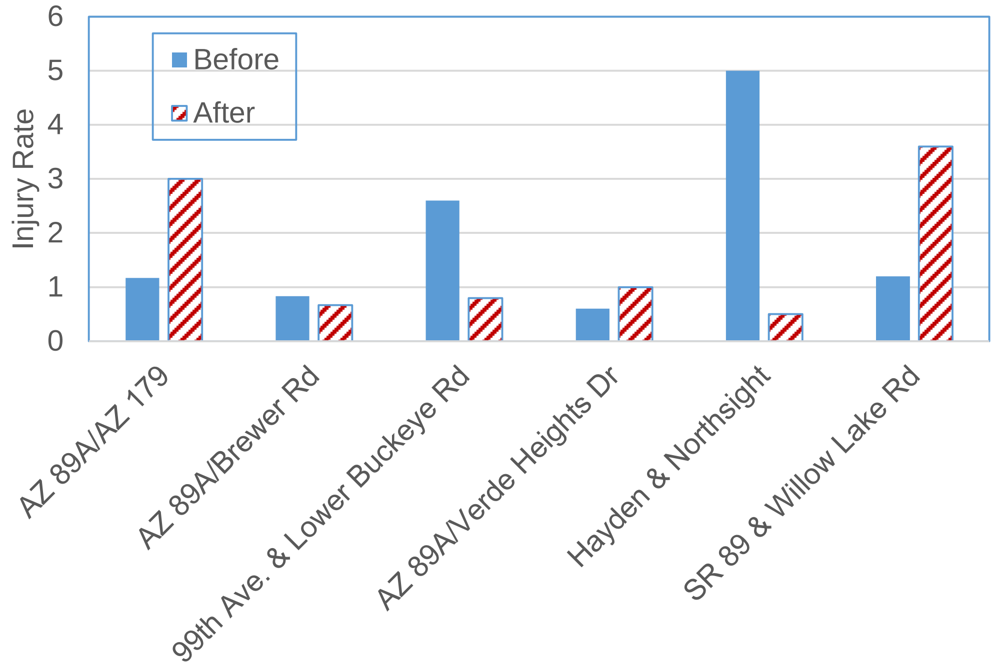

Figure 15: Injury rate per year for double-lane roundabouts before and after roundabout conversion at different locations.

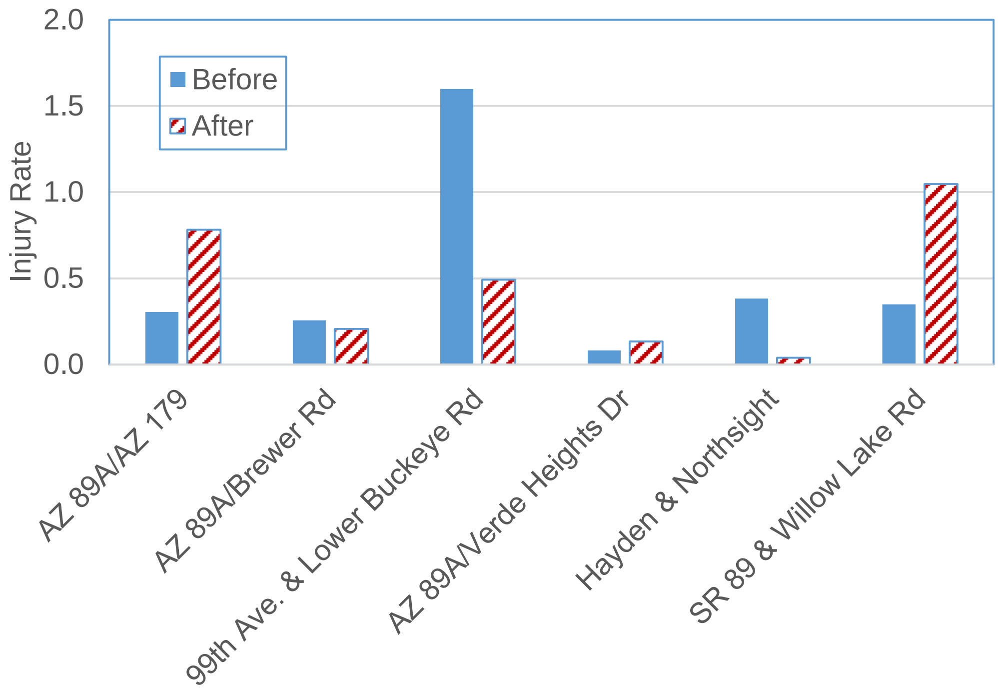

Figure 16: Injury rate per year per million vehicles for double-lane roundabouts before and after roundabout conversion at different locations.

3.2.2 Accident Severity

Similar to the case of single-lane roundabouts, the total number of accidents with different severities were normalized by dividing the total number of accidents for each severity level by the total number of accidents before and after roundabout conversion. Table 7 and Figure 17 show the normalized accident rates for different severity levels before and after roundabout conversion. It can be seen that the normalized accident rate for severity level 1 remained approximately the same after roundabout conversion, while the rates of severity levels 2-5 decreased. This indicates that the double-lane roundabout conversion reduced the severity of accidents in general.

Table 7: Normalized accident rates for different severity levels before and after roundabout conversion.

	Total Accidents Before Roundabout					Total Accidents After Roundabout				
Severity Level	1	2	3	4	5	1	2	3	4	5
Total Accidents	141	18	23	3	1	266	30	19	1	0
Normalized Accidents	0.91	0.12	0.15	0.02	0.01	0.93	0.10	0.07	0.00	0.00

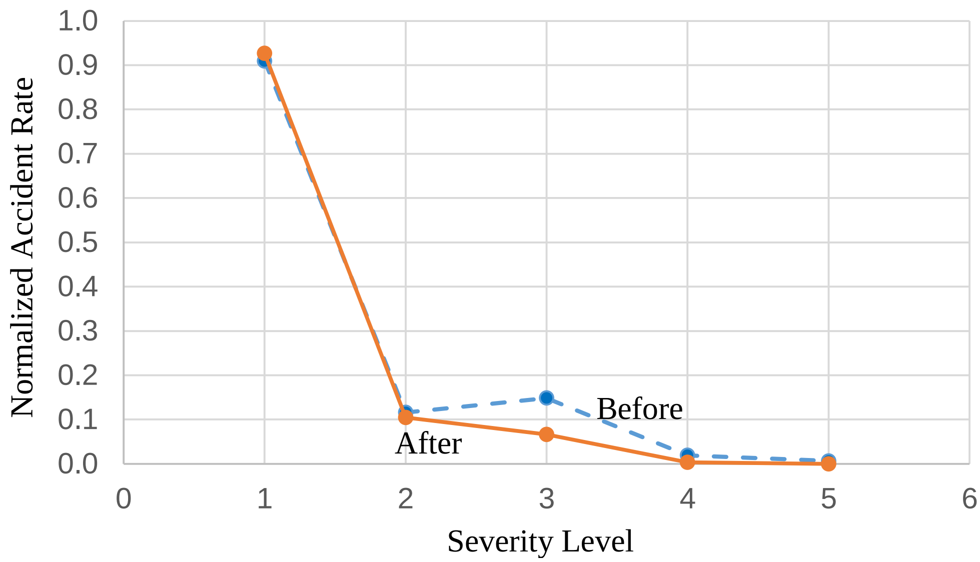

Figure 17: Normalized accident rates for different severity levels before and after double-lane roundabout conversion.

4.0 DISCUSSION

Figure 18 shows the average rate of accidents per year before and after single-lane roundabouts at all locations, whereas Figure 19 shows the average rate of accidents per year per million vehicles before and after single-lane roundabouts at all locations. The results show an 18% decrease in the rate of accidents per year after roundabout installation and a 12% decrease in the rate of accidents per year per million vehicles after roundabout installation.

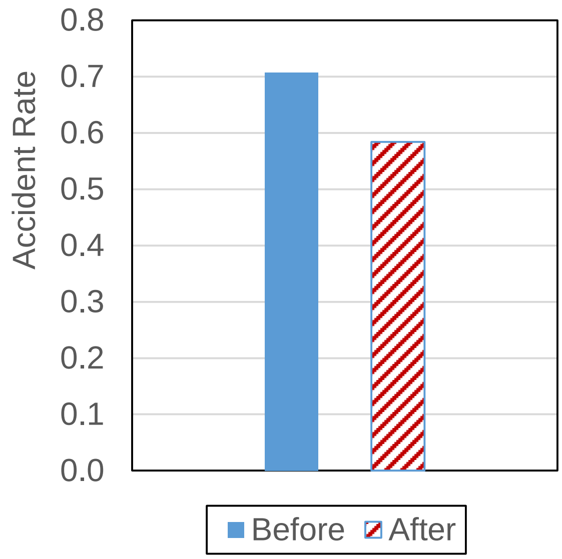

Figure 18: Accident rate per year for all single-lane roundabouts before and after roundabout conversion.

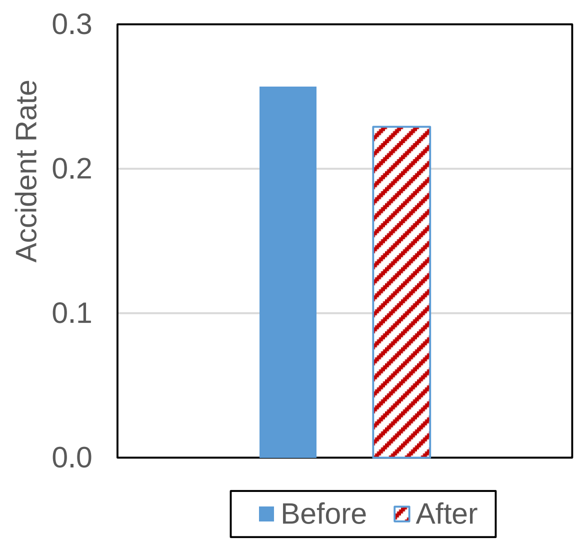

Figure 19: Accident rate per year per million vehicles for all single-lane roundabouts before and after roundabout conversion.

Figure 20 shows the average rate of damages per year before and after single-lane roundabouts at all locations, whereas Figure 21 shows the average rate of damages per year per million vehicles before and after single-lane roundabouts at all locations. The results show a slight increase of 2% in the rate of damages per year after roundabout installation and a slight increase of 5% in the rate of damages per year per million vehicles after roundabout installation.

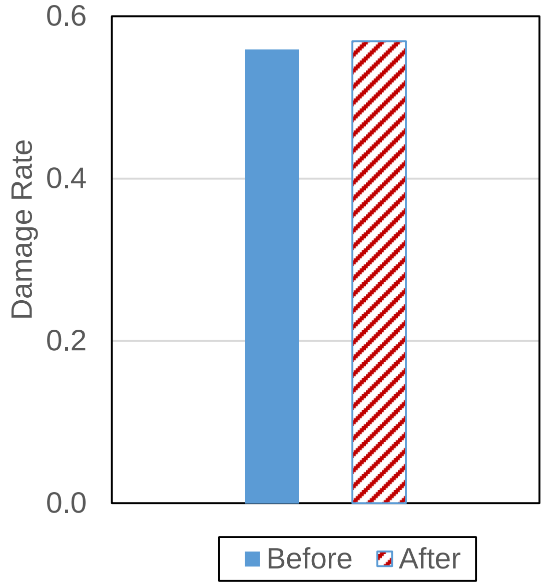

Figure 20: Damage rate per year for all single-lane roundabouts before and after roundabout conversion.

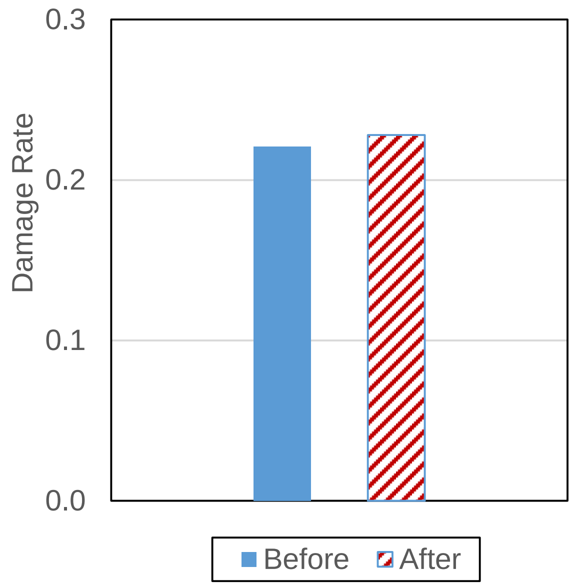

Figure 21: Damage rate per year per million vehicles for all single-lane roundabouts before and after roundabout conversion.

Figure 22 shows the average rate of injuries per year before and after single-lane roundabouts for at all locations, whereas Figure 23 shows the average rate of injuries per year per million vehicles before and after single-lane roundabouts at all locations. The results show a 44% decrease in the rate of injuries per year after roundabout installation and a 38% decrease in the rate of injuries per year per million vehicles after roundabout installation.

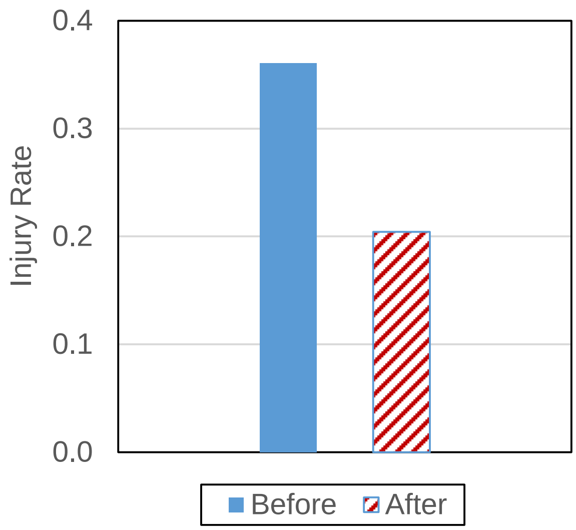

Figure 22: Injury rate per year for all single-lane roundabouts before and after roundabout conversion.

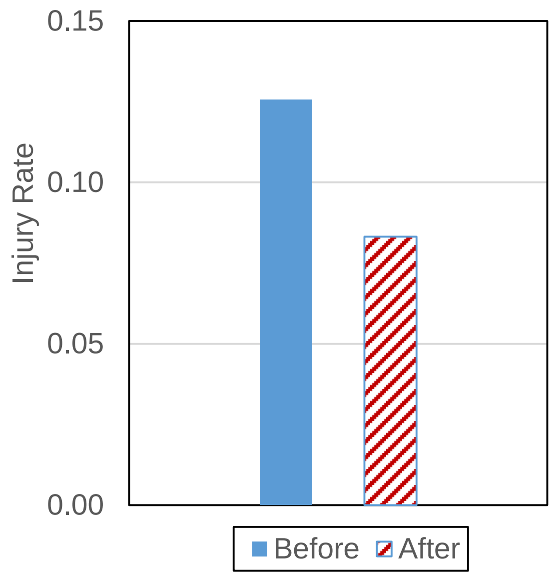

Figure 23: Injury rate per year per million vehicles for all single-lane roundabouts before and after roundabout conversion.

Figure 24 shows the average rate of accidents per year before and after double-lane roundabouts at all locations, whereas Figure 25 shows the average rate of accidents per year per million vehicles before and after double-lane roundabouts at all locations. The results show a large increase of 62% in the rate of accidents per year after roundabout installation and a large increase of 68% in the rate of accidents per year per million vehicles after roundabout installation.

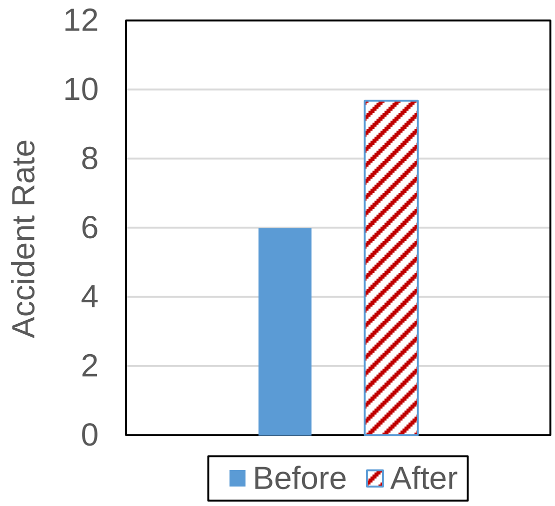

Figure 24: Accident rate per year for all double-lane roundabouts before and after roundabout conversion.

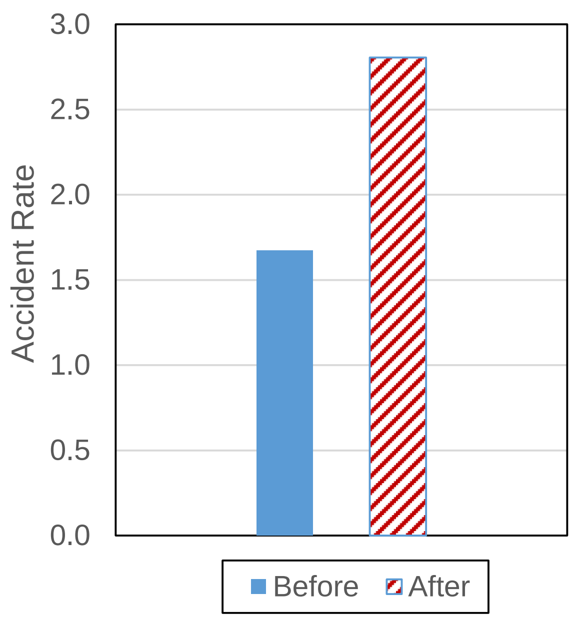

Figure 25: Accident rate per year per million vehicles for all double-lane roundabouts before and after roundabout conversion.

Figure 26 shows the average rate of damages per year before and after double-lane roundabouts at all locations, whereas Figure 27 shows the average rate of damages per year per million vehicles before and after double-lane roundabouts at all locations. The results show a large increase of 60% in the rate of damages per year after roundabout installation and a large increase of 80% in the rate of damages per year per million vehicles after roundabout installation.

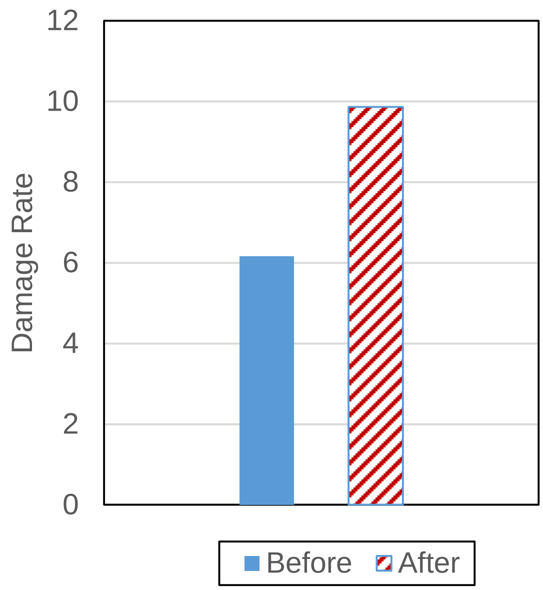

Figure 26: Damage rate per year all for double-lane roundabouts before and after roundabout conversion.

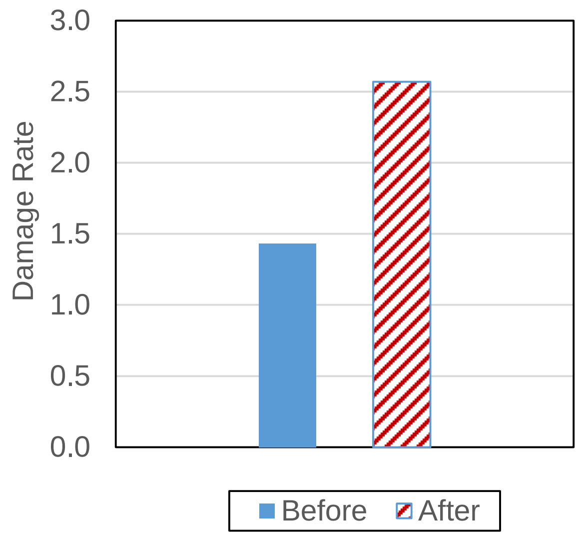

Figure 27: Damage rate per year per million vehicles for all double-lane roundabouts before and after roundabout conversion.

Figure 28 shows the average rate of injuries per year before and after double-lane roundabouts at all locations, whereas Figure 29 shows the average rate of injuries per year per million vehicles before and after double-lane roundabouts at all locations. The results show a 16% decrease in the rate of injuries per year after roundabout installation and an 8% decrease in the rate of injuries per year per million vehicles after roundabout installation.

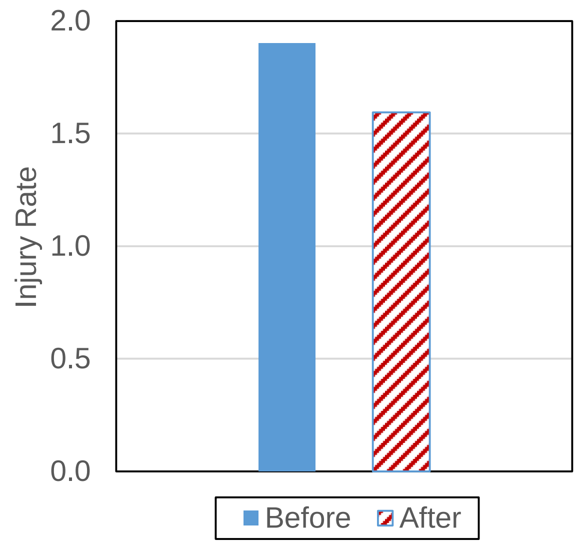

Figure 28: Injury rate per year for all double-lane roundabouts before and after roundabout conversion.

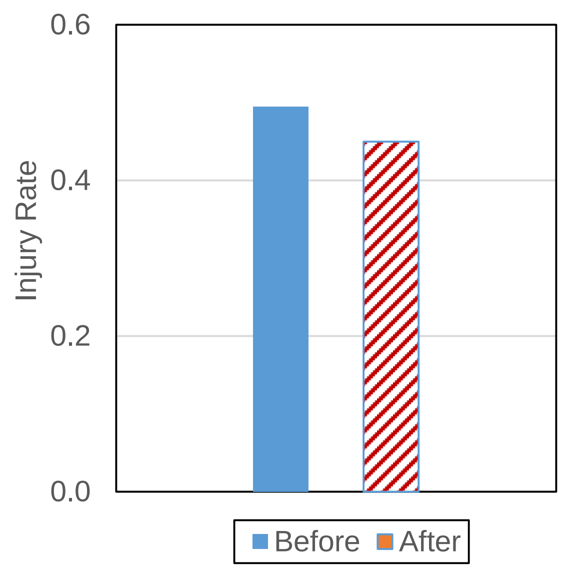

Figure 29: Injury rate per year per million vehicles for all double-lane roundabouts before and after roundabout conversion.

5.0 SUMMARY AND CONCLUSIONS

Seventeen roundabouts in 5 cities in Arizona were used in the study, out of which 11 single-lane and 16 double-lane. 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. Accidents data were collected and broken down into 3 categories: damage, 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 AADT value at the time of roundabout conversion, which is the midpoint of the analysis period. The average rate of accidents, damages, and injuries per year and per year 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 after roundabout conversion and an average of 12% decrease in the rate of accidents per year per million vehicles after roundabout conversion were observed.
2. For single-lane roundabouts, a slight increase of 2% in the average rate of damages per year after roundabout conversion and a slight increase of 5% in the average rate of damages per year per million vehicles after roundabout conversion were observed.
3. For single-lane roundabouts, an average of 44% decrease in the rate of injuries per year after roundabout conversion and an average of 38% decrease in the rate of injuries per year 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 after roundabout conversion and a large increase of 68% in the average rate of accidents per year 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 after roundabout conversion and a large increase of 80% in the average rate of damages per year per million vehicles after roundabout conversion were observed.
6. For double-lane roundabouts, a 16% decrease in the average rate of injuries per year after roundabout conversion and an 8% decrease in the average rate of injuries per year per million vehicles after roundabout conversion were observed.
7. For single-lane roundabouts, the normalized accident rate for severity level 1 increased after roundabout conversion, while the rates of severity levels 2-5 decreased. For double-lane roundabouts, the normalized accident rate for severity level 1 remained approximately the same after roundabout conversion, while the rates of 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, roundabouts increased the rate of damage without injury, but largely decreased the rates of injury and fatality. This can be viewed as a road safety success.

Future research is needed to estimate the potential society cost of roundabout crashes. If a monetary value is assigned to each accident severity, the increase or decrease of the total accident cost due to roundabout conversion can be estimated. Also, the cost of roundabout construction can be considered and the cost-benefit of roundabouts can be analyzed. Finally, warrants need to be developed for roundabout conversion for both single- and multi-lane roundabout conversion.

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