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Public Opinion, Traffic Performance, the Environment, and Safety after the Construction of Double-Lane Roundabouts

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ABSTRACT

This study evaluated the impact of double-lane roundabout conversions on public attitudes, traffic performance, the environment, and safety at two intersections near Bellingham, Washington, and evaluated whether older drivers avoided the roundabouts by taking an alternative route. Driver support for the roundabouts increased from 34% before construction to 70% one year after. One year after construction, more than 40% of drivers did not believe the signs and pavement markings adequately conveyed information about appropriate speeds, right-of-way rules, or navigating the roundabouts in the presence of large trucks. After accounting for other roadway changes, substantial declines were attributed to the roundabout conversions in the delays and queue lengths on minor roads, the proportion of queued vehicles, and fuel consumption and vehicle emissions. Analyses of crash rates per entering vehicles found that the roundabout conversions were associated with reduced rates of injury and fatal crashes combined and increased rates of property damage-only crashes. Only the increase in the property damage-only crash rate at one roundabout was significant. The odds that drivers 70 and older traveled the study corridor versus an alternative route after the roundabout conversions was 0.32 times the odds before. These findings generally are consistent with prior research finding substantial traffic, environmental, and injury-reduction benefits of single-lane roundabouts. However, it seemed the greater complexity of double-lane roundabouts may present challenges as some confusion persisted one year after construction, there was evidence that some older drivers may have taken an alternative route to avoid them, and property damage-only crash rates increased.

Keywords: Roundabouts, double-lane roundabouts, intersection, intersection safety

INTRODUCTION

Intersection crashes accounted for 43% of all police-reported crashes in the United States in 2011 and a slightly larger proportion (47%) of injury crashes (1). Modern roundabouts are circular intersections in which vehicles travel around a center island, with entering traffic yielding to circulating traffic. Roundabouts by design slow the flow of traffic, and vehicles travel in the same direction, eliminating some of the most complicated aspects of traditional intersections and thereby reducing the incidence of severe crashes. Multi-lane roundabouts typically have larger inscribed circle diameters and higher design speeds compared with single-lane roundabouts, and they accommodate higher traffic volumes.

Studies of intersections in Europe and Australia that were converted to roundabouts reported 36-61% reductions in crashes of all severities and 25-87% reductions in injury crashes (2). The safety benefit was greater for small- and medium-capacity roundabouts than for large or multi-lane roundabouts (3, 4). U.S. studies have shown that conversion of traffic signal- or stop sign-controlled intersections to roundabouts reduced injury crashes by 75-84% and all crashes by 35-40% (2, 5-7). Double-lane roundabouts were associated with smaller reductions in police-reported crashes compared with single-lane roundabouts (5, 7, 8) or even with increases in crashes (6).

Roundabouts result in more efficient traffic flow, with studies reporting reductions in vehicle delays of 13-89% and reductions in the proportion of vehicles stopped of 14-52% (9-11). Because roundabouts improve the efficiency of traffic flow, they also reduce vehicle emissions and fuel consumption (12).

Although roundabouts are increasingly common in the United States, they are controversial in some communities. However, after roundabouts had been in place in six communities for more than one year, about 70% of drivers supported the roundabouts, on average, compared with about one-third before construction (13).

Roundabouts may be particularly helpful in reducing crashes involving older drivers. The over-involvement of older drivers in intersection crashes is well documented (14). A study of at-fault drivers in nonfatal intersection crashes showed older drivers are more likely than younger drivers to be cited for failure to yield the right-of-way (15). All traffic flows in the same direction at roundabouts and more slowly than at traditional intersections so that the consequences of failing to yield are likely less severe. Although roundabouts can be beneficial for older drivers, roundabouts have been somewhat less popular among those 65 and older (13), and there may be concerns that older drivers will choose alternative routes to avoid roundabouts.

The safety, traffic performance, and environmental benefits of roundabouts have been demonstrated, but previous research has focused primarily on single-lane roundabouts. There is limited research on drivers' attitudes and experiences related to multi-lane roundabouts in the United States. The current study focuses on double-lane roundabouts constructed in 2009 along Guide Meridian Road near Bellingham, Washington. The objectives were to evaluate the impact of the roundabouts on public attitudes, traffic performance, the environment, and safety, and to evaluate whether older drivers tended to avoid the roundabouts by taking an alternative route.

METHOD

Study Sites

The study focused on two double-lane roundabouts located along Guide Meridian Road approximately 5 miles north of Bellingham, Washington. Guide Meridian Road (State Route 539) is a heavily traveled collector running north-south between I-5 in Bellingham and the Canadian border.

The Guide Meridian Road construction project began in April 2008. Guide Meridian Road had been primarily a two-lane undivided road. During construction, the road was converted to two lanes in each direction, divided with a median and cable barrier. Toward the end of the construction period,

roundabouts were built at four key intersections. The roundabouts at the intersections of Guide Meridian with Pole Road and with Wisser Lake Road, located about 1 mile apart, were studied.

The designs of the two roundabouts are essentially the same. There are two entering lanes on the Guide Meridian Road approaches and one entering lane on the minor approaches (Figure 1). In order to provide consistent lane configurations, yellow edge lines were placed along the outer edge of the truck apron to reduce the portion of the circulatory roadway that serves the minor street to a single lane. The Guide Meridian-Wisser Lake Road roundabout, which became fully operational in October 2009, replaced a four-leg intersection with stop signs on the minor Wisser Lake Road approaches. The Guide Meridian-Pole Road roundabout, which became fully operational in August 2009, replaced a traffic signal-controlled four-leg intersection with a short exclusive left-turn lane and a lane for through and right-turning movements on each Guide Meridian approach.



FIGURE 1 Guide Meridian-Wisser Lake Road roundabout.

Prior to construction, the speed limit was 50 mph on Guide Meridian Road, 50 mph on Pole Road, and 35 mph on Wisser Lake Road. The speed limits remained after construction, but there are 15 mph advisory speed placards on all the roundabout approaches.

Hannegan Road runs parallel to Guide Meridian Road approximately 2 miles east. Similar to Guide Meridian Road before construction, Hannegan Road is a two-lane undivided highway. Hannegan Road could serve as an alternative route for drivers wishing to avoid the roundabouts, and this possibility was explored for older drivers, as described below.

Public Attitudes

Telephone surveys were conducted as construction on the corridor began (April–May 2008) and approximately six months (May–June 2010) and more than one year (February 2011) after the roundabout construction. Random digit dialing methods were used to select representative samples of drivers 18 or older; respondents who drove through the Guide Meridian corridor at least occasionally were interviewed.

For the surveys after roundabout construction, a larger proportion of drivers 70 and older were interviewed to facilitate the comparison of these drivers with younger drivers. In analyses of the after surveys, responses for each age group were weighted by the proportion of that group in the survey conducted before roundabout construction. All results presented below are based on the weighted data set.

In the baseline survey, roundabouts were briefly described, and nearly all respondents (98%) had previously driven through one. In the surveys after construction, only drivers who had driven through at least one of the study roundabouts were interviewed.

The cooperation rate [(total respondents + persons not meeting screening criteria)/(number of households reached)] was 56% in the baseline survey, 53% in the first after survey, and 54% in the final survey. A total of 301, 350, and 356 interviews were completed before, six months after, and more than one year after roundabout construction, respectively.

Traffic Performance

Video cameras recorded traffic flow at the study intersections during 7 a.m.–7 p.m. on three weekdays prior to construction (March–April 2008) and four months after it ended (March 2010). Traffic during the following three peak periods was analyzed: 7 a.m.–9 a.m., 11 a.m.–2 p.m. and 4 p.m.–6 p.m. The extracted data included counts of all vehicles, proportions of heavy vehicles entering the intersections, and turning movements for each travel direction.

Traffic performance before and after the roundabout conversions was analyzed using SIDRA INTERSECTION 5.1 (16). The Washington State Department of Transportation provided the following characteristics of the intersections before and after roundabout construction: lane widths, approach grades, type of pedestrian crosswalks, signal timing, roundabout design dimensions, signs and pavement markings, and exit and entry lane directions.

SIDRA INTERSECTION 5.1 provides two roundabout model options: the SIDRA Standard model and the Highway Capacity Manual 2010 model (17), which is based on research on U.S. roundabouts and reflects general U.S. driver behaviors. The results presented below used the Highway Capacity Manual 2010 model. For analysis of performance at the roundabouts, when the videotaped traffic was not dense enough to observe critical gaps and follow-up headways, the model default values of the two parameters were used.

As noted above, Guide Meridian Road was widened to a four-lane divided road, which likely would improve traffic operation, and a cable barrier was added. To isolate the effects of the roundabouts from these other changes on traffic operations, fuel consumption, and vehicle emissions, several hypothetical intersections were developed using the original traffic controls but with additional travel lanes. Traffic performance was evaluated for these hypothetical intersections and for the unchanged before-construction intersections, using traffic volumes measured four months after the roundabout construction ended. The performance for each scenario was compared with the roundabout performance, which provided an estimate of the effect of the roundabouts over and above the effect of the additional travel lanes. The results below present the hypothesized intersections with the best traffic performance measures.

Separate analyses were performed for the morning, noon, and evening peak periods, and the following measures of intersection performance were reported:

- Degree of saturation, or volume-to-capacity ratio, is the ratio of the traffic volume during a particular time period to the capacity. The highest value among the lane groups is presented.
- Average intersection control delay is the average seconds of delay per vehicle due to the intersection traffic control device, including delay due to deceleration time, queue move-up time, stop time, and acceleration time. It reflects the weighted average of the lane group delays, with weights based on flow rates of the lane groups.
- Maximum control delay is the average seconds of delay per vehicle for the lane group with the highest control delay.

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- 95% queue length is the value (in feet) below which 95% of observed queue lengths fall.
- Proportion queued is the proportion of entering vehicles that are queued, calculated as a weighted average of the lane group values, with weights based on flow rates of the lane groups.

The level of service for each intersection was defined in terms of control delays, using criteria from the Highway Capacity Manual 2010 (17). Six levels of service (A, B, C, D, E, F) characterize the effectiveness of intersections in achieving efficient traffic flow. A represents the highest level of service and F represents the lowest level.

Environmental Effects

The environmental effects of the roundabout conversions were estimated using SIDRA INTERSECTION 5.1, which estimates fuel consumption and pollutant emissions based on a four-element model incorporating measures of cruise, deceleration, idling, and acceleration. The amounts of the following emissions (kg/hr) were estimated: carbon dioxide, hydrocarbon, carbon monoxide, and nitrogen oxide.

Police-reported Crashes

At each intersection, changes in crash rates per entering vehicles from before to after the construction of the roundabout were compared with changes in crash rates at comparable intersections that did not undergo changes. In consultation with the Washington State Department of Transportation, five comparison intersections were selected for the Guide Meridian-Pole Road intersection and 8 comparison intersections were selected for the Guide Meridian-Wiser Lake Road intersection, based on their similarity to the study intersections prior to the roundabout conversion in terms of the traffic control device, intersection layout, and traffic volume.

January 2003-December 2007 and January 2010-December 2011 represented the before and after study periods, respectively. Electronic police-reported crash information was obtained from the Washington State Department of Transportation. The average annual daily traffic volumes for these periods were obtained from the state Department of Transportation and from the public works departments of the city of Bellingham and the counties of Whatcom and Snohomish.

The analysis included crashes that were coded as occurring at the intersection or intersection-related. Percentage changes in the rates of all crashes, property damage-only crashes, and injury and fatal crashes combined were examined for each study intersection, relative to changes at the comparison intersections. As a more rigorous assessment, Poisson regressions were performed for all crashes, property damage-only crashes, and injury and fatal crashes combined. In these models the dependent variable was crash count; the log of traffic volumes was included with its coefficient constrained to be 1; and the independent variables were study period (after vs. before roundabout conversion) and study group (study vs. comparison intersections). An interaction variable for study period and study group tested whether there was a difference between the change in crash rates at the study and comparison intersections. For example, if the estimated parameter for the interaction term was -0.4172 in the injury and fatal crash model, the percentage change in the rates of injury and fatal crashes was calculated as $([\exp(-0.4172)-1] \times 100)$, or a 34% reduction compared with what would have been expected without the roundabout conversion. Models with individual intersection indicators instead of study group indicator also were developed; the estimates for the interaction terms were similar in the two model specifications.

Older Driver Travel Patterns

Vehicles and drivers were photographed at two locations along the Guide Meridian Road study corridor and at two comparable locations on Hannegan Road prior to the roundabout construction (March–June 2008) and after the roundabout construction ended (March–May 2010). Two researchers independently coded driver gender and age category (younger than 20, 20-59, 60-69, 70 and older) and vehicle type

(passenger vehicle vs. others). Agreement rates between the two coders were 97% for both study periods for vehicle type, 80% for the before period and 77% for the after period for age, and 91% for the before period and 92% for the after period for gender. With disagreements, a third researcher served as tie-breaker. Odds ratios tested whether the likelihood of drivers 70 and older taking Guide Meridian versus Hannegan Road changed significantly after the roundabout construction.

RESULTS

Drivers' Experiences with Roundabouts

Before construction, 53% of drivers opposed the installation of roundabouts on Guide Meridian Road; 42% strongly opposed it. The rate of opposition declined to 44% six months after construction and to 27% one year after. Support for the roundabouts increased from 34% before construction to 51% six months after and to 70% one year after. This pattern of change was statistically significant (before/six months after comparison: $\chi^2(4)=16.9$, $p<0.0001$; six months/one year after comparison: $\chi^2(4)=22.1$, $p<0.0001$).

Prior to roundabout construction, 36% of drivers younger than 70 favored the use of roundabouts compared with 27% of drivers 70 and older ($\chi^2(2)=13.3$, $p=0.0013$). Six months after construction, the proportions of drivers favoring the new roundabouts in the two age groups were the same (51%). One year after construction, 65% of drivers 70 and older favored the roundabouts compared with 71% of drivers younger than 70, but the difference was not significant ($\chi^2(2)=1.8$, $p=0.40$).

The top reason for opposing the roundabouts was common across surveys: opponents reported that roundabouts are unsafe or would result in more crashes (31% before, 33% six months after, 27% one year after). Before construction, the other top reasons were that roundabouts are confusing (28%) and a preference for traffic signals (22%). Six months after construction, the other top reasons were problems with right-of-way or yielding (19%) and problems with navigating the roundabouts in the presence of large trucks (16%). One year after construction, the other top reasons were problems with large trucks (16%) and problems with right-of-way or yielding (14%) or a general dislike of roundabouts (14%).

In the survey one year after roundabout construction, respondents were asked whether traffic signs and pavement markings clearly communicated different types of information about the roundabouts. Respondents were most likely to say it was clear that drivers are approaching a roundabout (88%) and least likely to believe it was clear that drivers should not travel beside large trucks in the roundabouts (52%). Substantial proportions also believed it was unclear what speed drivers should travel (41%), which lane has the right-of-way to exit (45%), and which lane the driver needs to be in to exit (31%).

Almost half of the respondents (48% six months after, 40% one year after) said they sometimes took another road instead of driving through the roundabouts, and a large majority of these drivers (79% six months after, 77% one year after) said they took Hannegan Road. The most common reasons for taking other roads were to avoid the roundabouts (45% six months after, 38% one year after) and because no left turns could be made between the roundabouts (12% six months and one year after). Six months after construction, the proportion of drivers 70 and older who reported taking an alternate road was the same as drivers younger than 70 (48%). One year after, a higher proportion of drivers 70 and older reported taking an alternate road than drivers younger than 70 (48% vs. 40%), but this difference was not significant ($\chi^2(2)=3.5$, $p=0.17$).

Traffic Performance and Environmental Effects

In general, traffic volumes at peak hours changed little from the before to the after period at the study intersections. The average hourly counts of entering traffic during the study peak periods were 1,334 (large trucks 4.4 %) before and 1,259 (large trucks 6.3%) after at the Guide Meridian-Pole Road intersection, and 1,139 (large trucks 4.0%) before and 1,066 (large trucks 7.7%) after at the Guide Meridian-Wiser Lake Road intersection. Few pedestrians were observed. As the traffic performance and

environmental effects of the roundabout conversions were consistent across the peak periods at each intersection, the average measures across the peak periods are reported.

The second column in Table 1 (scenario 1) shows the estimated traffic performance and environmental measures for the original Guide Meridian-Pole Road intersection, using the traffic volume before roundabout construction. The subsequent columns summarize the same measures for three scenarios using the traffic volume measured after construction of the roundabout — the original intersection, a hypothetical signalized intersection with expanded travel lanes, and the roundabout. The estimated traffic performance for the original intersection with the after traffic volumes (scenario 2) was similar to performance at the original intersection (scenario 1). All the estimated traffic performance measures for the hypothetical expanded intersection (scenario 3) were substantially better than the measures estimated for the original intersection with the after traffic volumes. The levels of service also improved. However, the estimated fuel consumption and emissions in these two after models were not substantially different from those estimated for the original intersection.

When compared with the hypothetical expanded Guide Meridian-Pole Road signalized intersection, three of the five traffic performance measures for the roundabout (scenario 4) were substantially improved. The control delay on the minor approach lane with the longest delay decreased by 33%, the 95% queue length on the lane with the longest queue decreased by 64%, and the proportion queued at the intersection decreased by 35%. Traffic congestion, as measured by the volume-to-capacity ratio, increased slightly (3%), and the average intersection control delay increased by 22%. The levels of service for the intersection overall (A) and for the worst approach (B) were the same for the hypothetical intersection and the roundabout. Fuel consumption decreased by 34%, and vehicle emissions decreased by 34–45%.

Similarly, Table 2 summarizes the same information for the original two-way stop sign-controlled Guide Meridian-Wiser Lake Road intersection, a hypothetical two-way stop-sign controlled intersection with expanded travel lanes, and the roundabout conversion. Most of the traffic performance and environmental measures estimated for the original intersection with the after traffic volume (scenario 2) were similar to these measures at the original intersection (scenario 1). However, there were increases in the estimated average intersection control delay and the control delay on the minor approach lane with the worst delay. This was due to a substantial increase in peak-hour left-turning traffic from the eastbound Wiser Lake Road approach. There were two possible reasons for the increase. Drivers could not make left turns between the roundabouts due to the installation of the median cable barrier, and it was easier to make left turns from the minor road at the roundabout than at the two-way stop sign-controlled intersection before the roundabout conversion. Both the before and after traffic volumes on Wiser Lake Road approaches were much lower than the traffic volumes on the Guide Meridian Road approaches. All the estimated specific traffic performance and environmental measures were substantially better for the hypothetical intersection (scenario 3) than for the original intersection with the after traffic volume.

When compared with the hypothetical expanded Guide Meridian-Wiser Lake Road intersection, four of the five traffic performance measures were substantially improved for the roundabout (scenario 4). Traffic congestion, as measured by the volume-to-capacity ratio, decreased by 32%; control delay on the minor approach lane with the longest delay decreased by 90%; the 95% queue length on the lane with the longest queue decreased by 50%; and the proportion queued decreased by 43%. The average intersection control delay increased by 12%. Fuel consumption decreased by 23%, and vehicle emissions decreased by 0–33%.

The overall intersection level of service was an A for all four intersection models. The level of service for the worst approach was an F for the original intersection with the original traffic flow and after traffic flow and for the expanded stop sign-controlled intersection, but improved to an A for the roundabout.

TABLE 1 Results of Models of Traffic Performance and Environmental Measures Before and After the Construction of Roundabouts at the Guide Meridian-Pole Road Intersection

	Models with traffic volumes after roundabout construction				Percent change: roundabout vs. hypothetical modified intersection
	Scenario 1: Before period	Scenario 2: Intersection before construction	Scenario 3: Hypothetical signalized intersection with expanded travel lanes ¹	Scenario 4: Roundabout	
Traffic Operations					
Degree of saturation (vehicle-to-capacity-ratio)	0.52	0.50	0.33	0.34	3
Average intersection control delay (sec)	13.1	12.5	6.4	7.8	22
Maximum control delay (sec)	28.4	27.0	16.2	10.9	-33
95% queue length (ft), worst lane	393.6	370.2	89.1	32.3	-64
Proportion queued (%)	60.0	58.1	53.6	34.7	-35
Intersection level of service	B	B	A	A	--
Level of service, worst approach	C	C	B	B	--
Fuel Consumption and Emissions					
Fuel consumption (gal/hr)	35.9	35.6	34.4	22.8	-34
Carbon dioxide (kg/hr)	340.2	337.9	326.2	216.2	-34
Hydrocarbons (kg/hr)	0.5	0.5	0.5	0.3	-40
Carbon monoxide (kg/hr)	26.3	26.4	25.5	14.1	-45
Nitrogen oxide (kg/hr)	0.9	0.9	0.9	0.5	-44

¹Hypothetical signalized intersection: On Guide Meridian Road approaches, right lane (through and right turn), middle lane (through), short exclusive left-turn lane, optimized two-phase signal timing with permitted left turn.

TABLE 2 Results of Models of Traffic Performance and Environmental Measures Before and After the Construction of Roundabout at Guide Meridian-Wiser Lake Road Intersection

	Models with traffic volumes after roundabout construction				Percent change: roundabout vs. hypothetical modified intersection
	Scenario 1: Before period	Scenario 2: Intersection before construction	Scenario 3: Hypothetical stop sign-controlled intersection with expanded travel lanes ¹	Scenario 4: Roundabout	
Traffic Operations					
Degree of saturation (vehicle-to-capacity ratio)	0.40	0.48	0.44	0.30	-32
Average intersection control delay (sec)	6.7	8.7	5.7	6.4	12
Maximum control delay (sec)	51.7	82.6	73.1	7.6	-90
95% queue length (ft)–worst lane	138.1	124.6	50.9	25.4	-50
Proportion queued (%)	78.7	77.1	32.4	18.4	-43
Intersection level of service	A	A	A	A	-
Level of service -worst approach	F	F	F	A	-
Fuel Consumption and Emissions					
Fuel consumption (gal/hr)	32.7	34.3	27.1	20.9	-23
Carbon dioxide (kg/hr)	309.6	325.5	257.5	198.4	-23
Hydrocarbons (kg/hr)	0.5	0.5	0.3	0.3	0
Carbon monoxide (kg/hr)	25.8	26.4	13.8	11.8	-15
Nitrogen oxide (kg/hr)	0.9	0.9	0.6	0.4	-33

¹Hypothetical stop sign-controlled intersection: Through and left turn travel lane added to Guide Meridian Road approaches.

Crash Analyses

At the intersections converted to roundabouts and at comparison intersections, crashes were examined for the 5 years before construction began and 2 years after it ended. Table 3 shows the before and after crash counts and the rates of crashes per million entering vehicles for all crashes, property damage-only crashes, and injury and fatal crashes combined at the two study intersections and their corresponding comparison intersections. From the before to the after study period, the rate of injury and fatal crashes decreased at both the Guide Meridian-Pole Road intersection and at the comparison intersections, but the decrease was larger at the roundabout (57% vs. 34%). The rate of property damage-only crashes increased at both the Guide Meridian-Pole Road intersection and the comparison intersections, and the increase was larger at Guide Meridian-Pole Road (36% vs. 19%). The rate of total crashes decreased by 3% at Guide Meridian-Pole Road and by 7% at the comparison intersections.

The rate of injury and fatal crashes decreased at both the Guide Meridian-Wiser Lake Road intersection and its comparison intersections, but the decrease was larger at the roundabout (100% vs. 30%) (Table 3). At the Guide Meridian-Wiser Lake Road intersection, the rates of all crashes and property damage-only crashes increased by 8% and 94%, respectively. At the comparison intersections, the rates of total crashes and property damage-only crashes decreased by 48% and 68%, respectively.

TABLE 3 Before and After Intersection Crash Counts and Crash Rates (Per Million Entering Vehicles) by Crash Severity at Guide Meridian-Pole Road and Guide Meridian-Wiser Lake Road Intersections and Comparison Intersections

Crash severity	Average crash counts per year		Crash rates (per 1 million vehicles)			Average crash counts per year per intersection		Crash rates (per 1 million vehicles)		
	Before ¹	After ²	Before ¹	After ²	Percent change	Before ¹	After ²	Before ¹	After ²	Percent change
	Guide Meridian-Pole Road intersection					Comparison intersections (5 combined)				
No Injury	5	6.5	0.67	0.91	36	2.5	2.8	0.39	0.46	19
Injury and fatality ³	3.6	1.5	0.48	0.21	-57	2.0	1.2	0.30	0.20	-34
Total ⁵	8.6	8	1.16	1.12	-3	4.6	4	0.71	0.66	-7
	Guide Meridian-Wiser Lake Road intersection					Comparison intersections (8 combined)				
No Injury	2	4	0.35	0.68	94	1.3	0.4	0.33	0.11	-68
Injury and fatality ⁴	1.6	0	0.28	0	-100	1.5	1.1	0.39	0.27	-30
Total ⁵	3.6	4	0.63	0.68	8	2.9	1.6	0.74	0.38	-48

¹The before period was 60 months long (January 2003 - December 2007).

²The after period was 24 months long (January 2010-December 2011).

³At Pole Road intersection, 13 possible, 4 evident and 1 serious injury crashes before; 3 possible injury crashes after. At comparison intersections combined, 34 possible, 14 evident and 1 serious injury crashes before; 7 possible, 3 evident and 2 serious injury crashes after.

⁴At Wiser Lake Road intersection, 7 possible and 1 evident injury crashes before. At comparison intersections combined, 35 possible, 21 evident, 4 serious and 1 fatal injury crashes before; 11 possible, 4 evident and 3 serious injury crashes after.

⁵Total count includes crashes of unknown severity.

Table 4 summarizes the Poisson regression models. Based on the interaction term between the study vs. comparison intersections and the after vs. before study periods, the rate of property damage-only crashes at the Guide Meridian-Pole Road roundabout was an estimated 13% higher and the rate of injury and fatal crashes was an estimated 34% lower than would have been expected without the roundabout conversion. The rate of all crashes at the roundabout was an estimated 4% higher. None of these changes was significant.

At the Guide Meridian-Wiser Lake Road roundabout, the rate of property damage-only crashes was an estimated 502% higher (Table 4) and the rate of injury and fatal crashes was 100% lower than would have been expected without the roundabout conversion. The rate of all crashes at the roundabout was an estimated 107% higher relative to what would have been expected without the roundabout conversion. Only the change in the rate of property damage-only crashes was significant.

TABLE 4 Poisson Regression Modeling Results for Rates of All crashes, Property Damage-Only Crashes, and Injury and Fatal Crashes Combined

	Guide Meridian-Pole Road intersection		Guide Meridian-Wiser Lake Road intersection	
	Percent change in crash rates	p value	Percent change in crash rates	p value
Property damage-only crashes				
After vs. before period	19.3	0.437	-68.1	0.005
Study vs. comparison intersections	74.3	0.019	5.8	0.871
Effect of roundabout conversion: interaction between study vs. comparison intersections and after vs. before period	13.2	0.763	501.6	0.004
Injury and fatal crashes combined				
After vs. before period	-34.2	0.194	-30.0	0.184
Study vs. comparison intersections	61.3	0.083	-27.9	0.385
Effect of roundabout conversion: interaction between study vs. comparison intersections and after vs. before period	-34.1	0.552	-99.6	0.586
All crashes				
After vs. before period	-6.6	0.708	-48.5	0.003
Study vs. comparison intersections	64.2	0.006	-13.9	0.555
Effect of roundabout conversion: interaction between study vs. comparison intersections and after vs. before period	3.5	0.921	107.3	0.128

Analysis of Older Driver Behavior

A total of 6,003 and 10,028 drivers were photographed on Guide Meridian Road before and after the roundabout conversion; 5,079 and 7,300 drivers were observed on Hannegan Road before and after the roundabout conversion. On both roads in both study periods, the proportions of drivers 70 and older were less than 5% of all drivers. The proportion declined from the before to the after period on both roads (from 4% to 1% on Guide Meridian Road; from 4% to 3% on Hannegan Road). The odds that older drivers were traveling on Guide Meridian Road versus Hannegan Road were significantly lower in the after period than in the before period (odds ratio (OR)=0.32, 95% confidence interval (CI)=0.23, 0.44).

DISCUSSION

On a heavily traveled roadway near Bellingham, Washington, the conversion of stop sign- and traffic signal-controlled intersections to double-lane roundabouts resulted in improved traffic performance at intersections, according to most measures, and reduced fuel consumption and vehicle emissions. Drivers' acceptance of double-lane roundabouts improved over time such that two-thirds supported them after one year. The rates of serious crashes declined relative to the rates that would have been expected without the roundabout conversions, although not significantly. These results are consistent with prior research, which found that conversions of traditional intersections to single-lane roundabouts are associated with substantial benefits in traffic operations, air quality, fuel consumption, and serious crashes.

There also were some indications, however, that the increased complexity of double-lane roundabouts may present some challenges for motorists. Confusion about some aspects of navigating the roundabouts persisted one year after the construction ended, there was evidence that some older drivers may have taken an alternative route to avoid them, and the rates of property damage-only crashes increased relative to the rates that would have been expected without the roundabout conversions.

Because roundabouts are fairly new in the United States, design practices and standards still are evolving. Navigating double-lane roundabouts requires drivers to absorb a lot of information in a relatively short period of time. The results of the telephone surveys point to the importance of developing signs and lane markings that are clear, unambiguous, and easily comprehended. For example, entering vehicles may not expect vehicles in the inner circulating lane to exit in front of them, which is allowed in some designs. Signs need to convey clearly that entering traffic must yield to both lanes of traffic. Both roundabouts in the current study had 15 mph advisory speed placards on the approaches, but some drivers were unclear about what speed they should travel. Both roundabouts had truck aprons that provided an additional traversable area around the center island for large trucks and signs indicating drivers should not travel next to large trucks in the roundabout. However, some drivers still were confused about navigating the roundabouts in the presence of trucks. More prominent, simpler signs may be needed. Although signage at roundabouts has been the subject of some research (18), well-controlled comparisons of alternative signs and lane designs may be warranted.

It is likely that conversions of traditional intersections to roundabouts often are part of other changes to a roadway. This was the case in the current study. Generally, it is not clear in prior research whether the estimated effects of roundabout conversions were isolated from the effects of other changes. However, in the current study, the analyses of traffic operations, fuel consumption, and vehicle emissions isolated the effects of the roundabouts by comparing the roundabouts with hypothetical intersections with the original traffic controls, but with increased capacity and with traffic counts from the after traffic observations. The hypothetical intersections presented are those that resulted in the best traffic performance among a number of different hypothetical intersections. They do not necessarily reflect the specific intersection designs that would be selected by the local traffic engineers.

The improvements in most measures of traffic operations and reduced fuel consumption and vehicle emissions in the current study are consistent with prior research (9, 10, 12, 19). The estimated average vehicle control delays at the roundabouts increased slightly when compared with those at the hypothetical signal- and stop sign-controlled intersections with increased capacity. This was due to the relatively small increases in vehicle delays on Guide Meridian Road. Prior to the construction of the roundabouts, traffic on Guide Meridian Road either moved continuously with no traffic control or was controlled by a traffic signal with a green phase that favored the heavier traffic on Guide Meridian. At the roundabouts, traffic on Guide Meridian Road yielded to circulating traffic and slowed prior to entering the roundabout. The change in the control of traffic flow led to the increase, but it also resulted in substantially shorter average vehicle delays and improved levels of service on the minor roads.

The modest increases in average vehicle control delays and the declines in vehicle emissions may appear inconsistent. However, the measures of emissions are based primarily on stopped vehicles and queue lengths, which improved with the roundabout conversions, rather than average control delays.

There have been concerns that some older drivers may find roundabouts confusing or intimidating and might take alternative routes to avoid them. The current findings suggest that these concerns may be warranted. One year after the roundabouts were constructed, drivers 70 and older were less likely than younger drivers to favor roundabouts, and also more likely to report taking an alternate route. Neither of these differences was significant, but they are consistent with the finding that drivers estimated to be 70 or older were less likely to drive on Guide Meridian, compared with a parallel road without roundabouts, after the roundabouts were built. While statistically significant, this finding is only suggestive because the proportion of older drivers on these roads was very small. However, it is a concern because roundabouts may be especially beneficial for older drivers, given their over-representation in crashes at intersections.

Studies of roundabout conversions have found reductions in crashes, especially more severe crashes. However, most prior research focused on single-lane roundabouts. In the present study, there were no evident, serious, or fatal injury crashes at the double-lane roundabouts, and only 3 crashes involving possible injuries. There were larger decreases in the rate of injury and fatal crashes combined at the study intersections than at the comparison intersections. The differences were not statistically significant, possibly due to the small samples of crashes. The rates of property damage-only crashes were higher at the roundabouts than would have been expected, but the difference at the Guide Meridian-Pole Road roundabout was not significant. Increases in overall crash rates at the roundabouts relative to the comparison intersections were not significant at either roundabout. Thus, the effects of the roundabout conversions on crashes were mixed. Future research using larger samples of crashes is needed to determine more definitively the effects of multi-lane roundabouts on crashes of different severities and type.

There are several limitations to the current study. Some important traffic flow parameters such as critical gaps and follow-up headways could not be observed from the videotapes of traffic flow at the roundabouts because the traffic was not heavy enough; this limited the ability to tune the traffic models to represent field conditions. The roundabout traffic performance results presented in the study were the Highway Capacity Manual 2010 model results only. A comparison of these results with the SIDRA standard roundabout model results found that the Highway Capacity Manual 2010 model estimated lower capacities than the SIDRA standard model. For the crash analyses, the after periods were relatively short and the samples of crashes, especially for serious crashes, were too small to draw definitive conclusions. Baseline crash rates were noticeably higher at the Guide Meridian-Pole Road intersection than at the comparison intersections. This may have been due to unknown differences between the study and comparison intersections. In addition, the effects of the roundabout conversions on crashes and older driver behaviors could not be isolated from the other changes occurring on Guide Meridian Road. As noted above, the observed samples of older drivers were small, and the absolute changes, even though significant, also were small. Even though at least two researchers classified drivers by age, coding the age of drivers from photographs relies on coder judgment. The study examined relatively short-term effects of the roundabouts. When roundabouts are part of a larger effort to increase capacity on a roadway, it is likely that the effects on traffic performance, emissions, and even safety may accrue some years after the construction.

As roundabouts proliferate across the United States, it is hoped there will be increased consistency and understandability in designs, lane markings, and signs. In particular, roundabout designers should pay close attention to ensuring that signs and lane markings are clear and prominently displayed. It also appears that transportation professionals could do a better job of communicating the safety benefits of roundabouts to the public as well as the rules for navigating double-lane roundabouts.

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