Crash and Injury Reduction Following Installation of Roundabouts in the United States

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ABSTRACT

Objectives. This study estimated potential reductions in motor vehicle crashes and injuries associated with the use of roundabouts as an alternative to signal and stop sign control at intersections in the United States.

Methods. An empiric Bayes procedure was used to estimate changes in motor vehicle crashes following conversion of 24 intersections from stop sign and traffic signal control to modern roundabouts.

Results. There were highly significant reductions of 38% for all crash severities combined and of 76% for all injury crashes. Reductions in the numbers of fatal and incapacitating injury crashes were estimated at about 90%.

Conclusions. Results are consistent with numerous international studies and suggest that roundabout installation should be strongly promoted as an effective safety treatment. (*Am J Public Health.* 2001;91:628–631)

Nearly half of all motor vehicle crashes that result in injuries occur at intersections.[1] In the United States during 1998, approximately 937 000 nonfatal injury crashes and 8600 fatal crashes occurred at intersections or were intersection related.[1] Traffic signals and stop signs are the primary devices used to regulate traffic flow at intersections to prevent collisions between conflicting traffic movements. Throughout the rest of the world, modern roundabouts have become increasingly popular as an alternative to intersections with traffic signals and stop signs, but they are seldom used in the United States. The main difference between modern roundabouts and older traffic circles, or rotaries, is the design speed. Drivers typically enter older rotaries at speeds of 30 mph or more, whereas modern roundabouts are designed for very low traffic speeds, about 15 mph (Figure 1).

Numerous studies, mostly in the international literature, indicate that converting intersections with stop signs or traffic signals to roundabouts is associated with substantial reductions in motor vehicle crashes. For example, Schoon and van Minnen[2] studied the conversion of 181 Dutch intersections with traffic signals or stop signs to modern roundabouts and reported that crashes and injuries were reduced by 47% and 71%, respectively; crashes resulting in more severe injuries (requiring hospital admissions) were reduced by 81%. Troutbeck[3] reported a 74% reduction in the rate of crashes involving injuries following conversion of 73 intersections to roundabouts in Victoria, Australia. These and similar studies may overestimate the magnitude of crash reductions associated with such conversions by failing to control for regression-to-the-mean effects—a major problem affecting the validity of many road safety improvement studies.

US experience with modern roundabouts is rather limited to date, but there has been growing interest in their potential benefits and, recently, a relatively large increase in the construction of roundabouts. Garder[4] conducted an extensive review of existing and planned US installations and reported strong activity in several states. A recent, but limited, before-and-after crash study, conducted by Flannery and Elefteriadou,[5] was based on 8 roundabouts, 3 in Florida and 5 in Maryland. Results were promising, suggesting consistent reductions in crashes and injuries, but the analyses were limited in scope.

The present before-and-after study was designed to better estimate the nature and magnitude of crash reductions following installation of modern roundabouts in the United States. It included a greater number of intersections and employed more powerful statistical analysis tools than the simple before-and-after comparisons used in prior studies.

Methods

We employed the empiric Bayes approach to properly account for regression to the mean while normalizing for differences in traffic volume between the before and after periods. The change in safety at a converted intersection for a given crash type is the difference between B, the expected number of crashes that would have occurred in the after period without the conversion, and A, the number of reported crashes in the after period.

To eliminate regression-to-the-mean effects and to reduce uncertainty in the results, B was, in general, estimated by an empiric Bayes procedure.[6] In essence, a regression model is used to first estimate the annual number of crashes that would be expected at intersections with traffic volumes and other characteristics similar to the intersection being analyzed. The expected annual number of crashes at the intersection before conversion is then estimated as a weighted average of the regression prediction and the count of crashes in the period before conversion.

Factors then are applied to the expected annual number of crashes to account for the length of the after period and differences in traffic volumes between the before and after periods. The result is an estimate of B. The procedure also produces an estimate of the variance of B. The significance of the difference ($B-A$) is established from this estimate

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of the variance of B and by assuming that the after period counts are Poisson distributed. Uncertainty in the estimates of safety effects also can be described with the use of likelihood functions, which have been presented, along with full details of the empiric Bayes procedure, in the full project report (available from the authors [B.N.P, P.E.G, and D.L., unpublished data, 1999]).

The analyses were confined to 8 states—California, Colorado, Florida, Kansas, Maine, Maryland, South Carolina, and Vermont—where a total of 24 intersections were converted to modern roundabouts between 1992 and 1997. Of the 24 intersections studied, 20 were previously controlled by stop signs and 4 by traffic signals. Fifteen of the roundabouts were single-lane circulation designs, and 9—all in Colorado—were multilane. Summary data for the study intersections are given in Table 1. For each intersection, crash data were obtained for periods before and after conversion. Data were extracted from police crash reports and, when these were not available, from report summaries. Police reports convey the detection and apparent severity of injuries, either through the so-called KABCO scale (Killed, A injury, B injury, C injury, Only property damage) or by separating injuries into 3 categories: possible injury, nonincapacitating injury, and more severe incapacitating injury. In this study, "possible" injury was not counted as injury. Injury databases derived from police reports have known limitations, especially in regard to injury severity.

FIGURE 1—View of a roundabout in Cecil County, Md.

From data about intersections not converted and a consideration of existing models, the regression models required for the empirical Bayes estimates of safety effect were assembled. New models were calibrated for urban intersections controlled by stop signs, whereas other models were adopted from Lord[7] for signalized intersections and from Bonneson and McCoy[8] for rural stop sign–controlled intersections. (Full details of the model calibration and application are provided in the project report available from the authors [B.N.P, P.E.G, and D.L., unpublished data, 1999]).

TABLE 1—Details of the Sample of Roundabout Conversions

Jurisdiction	Year Opened	Control Before Conversion[a]	Single or Multilane	Annual Average Daily Traffic: Before	Annual Average Daily Traffic: After	Months: Before	Months: After	Crash Count Before: All	Crash Count Before: Injury	Crash Count After: All	Crash Count After: 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.

TABLE 2—Estimates of Safety Effect for Groups of Conversions to Roundabouts

Group Characteristic Before Conversion and Jurisdiction	No. of Crashes During Period After Conversion		Crashes Expected During After Period Without Conversion (SD)		% Reduction in Crashes	
	All	Injury[a]	All	Injury[a]	All	Injury[a]
Single lane, urban, stop controlled						
Bradenton Beach, Fla	1	0	9.9 (3.6)	0.0 (0.0)		
Fort Walton Beach, Fla	4	0	16.9 (3.9)	2.7 (1.1)		
Gorham, Me	4	0	6.8 (1.4)	0.9 (0.4)		
Hilton Head, SC	9	0	42.8 (6.0)	8.2 (1.9)		
Manchester, Vt	1	1	1.7 (0.7)	0.0 (0.0)		
Manhattan, Kan	0	0	4.2 (1.2)	1.2 (0.5)		
Montpelier, Vt	1	1	4.3 (1.8)	1.1 (0.6)		
Santa Barbara, Calif	17	2	17.97 (4.9)	0.0 (0.0)		
West Boca Raton, Fla	7	0	8.1 (3.0)	2.6 (1.3)		
Entire group (9)	44	4	112.6 (10.2)	16.6 (2.6)	61	77
Single lane, rural, stop controlled						
Anne Arundel County, Md	14	2	24.6 (4.0)	6.2 (1.7)		
Carroll County, Md	4	1	15.2 (2.6)	3.2 (0.9)		
Cecil County, Md	10	1	14.3 (2.9)	5.6 (1.4)		
Howard County, Md	14	1	36.7 (5.5)	7.7 (2.1)		
Washington County, Md	2	0	14.4 (3.1)	4.2 (1.3)		
Entire group (5)	44	5	105.2 (8.4)	26.9 (3.4)	58	82
Multilane, urban, stop controlled						
Avon, Colo	3	0	19.9 (4.9)	0.0 (0.0)		
Avon, Colo	17	1	12.2 (3.1)	0.0 (0.0)		
Vail, Colo	14	. . .	19.1 (4.4)	. . .		
Vail, Colo	61	. . .	50.9 (7.6)	. . .		
Vail, Colo	8	. . .	9.8 (2.1)	. . .		
Vail, Colo	15	. . .	11.8 (2.3)	. . .		
Entire group (6)	118		123.7 (11.0)	. . .	5	. . .
Urban, signalized						
Avon, Colo	44	1	49.8 (7.0)	5.4 (1.7)		
Avon, Colo	13	0	30.1 (5.7)	2.3 (1.0)		
Avon, Colo	18	0	52.1 (7.0)	5.3 (1.7)		
Gainesville, Fla	11	3	4.8 (1.5)	1.3 (0.5)		
Entire group (4)	86	4	131.7 (10.9)	15.0 (2.7)	35	74
All conversions (24)	292	14	472.6 (20.4)	58.5 (5.1)	38	76

Note. Ellipses (. . .) indicate that data are not available.
[a]Crashes involving injuries.

Results

Table 2 summarizes the estimated crash reductions. Because injury data were not available for the period before construction of the 4 roundabouts in Vail, Colo, estimates for injury crashes are based on 20 of the 24 intersections. Overall, the empiric Bayes procedure estimated highly significant reductions of 38% for all crash severities combined and of 76% for injury crashes. These estimates were slightly lower than those obtained by a simple before-and-after comparison instead of the empirical Bayes procedure.

Table 2 also summarizes estimated crash reductions for selected groups of conversions. Of note is the smaller safety effect observed for the group of urban intersections that previously were multilane and controlled by stop signs. It is possible that this result may be due to differences in the safety performance of single-lane vs multilane roundabout designs. However, a firm conclusion cannot be made because of other important differences between conversions in Colorado and those in other states. For example, the 2 Avon, Colo, roundabouts that previously were multilane and controlled by stop signs are part of freeway interchanges that also include nearby intersections that were controlled by 4-way stop signs. The multilane roundabouts do seem to be effective in eliminating most incapacitating injury crashes.

For completeness, partial results also are given for individual conversions in a group. Readers are cautioned about drawing conclusions from these results, because there is a significant likelihood that the change in safety for individual conversions is due to chance. In some cases, however, there may be logical explanations for an apparent deterioration in safety following roundabout conversion. At the Gainesville site, for example, officials were unable to secure adequate right-of-way to construct a roundabout to design specifications that would accomplish the desired deflection and speed reduction. This may explain the apparent absence of crash reduction at this site. Another example is the Santa Barbara site, which was the only one that was controlled by all-way stop signs before conversion. In light of evidence that all-way stop sign control is already a safety improvement, it should not be surprising that there would be little or no benefit from further conversion to a roundabout.

Effects on fatal crashes and crashes causing incapacitating injuries are more difficult to measure owing to the small samples, but indications are that such crashes were substantially reduced. For the 20 converted intersections with injury data, there were 3 fatal crashes during the before period and none during the after period. The fatal crashes may have contributed to the fact that the roundabouts were constructed and may therefore contribute to the regression-to-the-mean phenomenon. There were 27 incapacitating injury crashes during the before period and only 3 during the after period. Taking into account the durations of the before and after periods and increases in traffic volume, and adjusting for regression to the mean (estimated to be roughly 22%), we found that the observed value of 3 incapacitating or fatal injury crashes during the after period is substantially and significantly less than the 26.6 expected. The estimated reduction in fatal and incapacitating injury crashes is 89% ($P<.001$).

There were 4 reported crashes involving pedestrians during the before period and 1 (with minimal injuries) during the after period. Four bicyclists were injured during the before period and 3 during the after period. However, these samples are too small to give conclusive evidence on the safety of these road-user groups at roundabouts.

Discussion

Results of this study indicate that converting conventional intersections from stop sign or traffic signal control to modern roundabouts can produce substantial reductions in motor vehicle crashes. Of particular note are the large reductions found in the number of crashes involving injuries, especially those involving incapacitating and fatal injuries. Given the large numbers of crashes involving injuries (700 000) and property damage (1.3 million) that occur each year at traffic signals and stop signs in the United States,[1] widespread construction of roundabouts can produce substantial reductions in injuries and property damage.

Crash reductions resulting from conversion of conventional intersections to modern roundabouts can be attributed primarily to 2 factors: reduced traffic speeds and elimination of specific types of motor vehicle conflicts that frequently occur at angular intersections. These conflicts include left turns against opposing or oncoming traffic, front-to-rear conflicts (often involving the lead vehicle stopping or preparing to stop for a traffic signal or stop sign), and right-angle conflicts at traffic signals and stop signs. Retting et al.[9] reported that crashes associated with these 3 intersection traffic conflicts account for two thirds of police-reported crashes on urban arterials. Red light–running crashes, which involve side impacts at relatively high speeds, are especially likely to produce injury[10]; such impacts are virtually nonexistent at roundabouts.

Some have expressed concern that older drivers may have difficulty adjusting to roundabouts. However, in this study, the average age of crash-involved drivers did not increase following the installation of roundabouts, which suggests that roundabouts do not pose a problem for older drivers.

Roundabouts are neither feasible nor appropriate at all intersections. Sufficient right-of-way must be available. Typically, a modern roundabout has an outer diameter of approximately 100 feet (30 m). This allows for large enough deflections to reduce speeds to an appropriate level. However, more land can be saved with a roundabout than with signalization, because approach roads can be kept narrower. Capacity constraints and limited rights-of-way eliminate from consideration many busy urban intersections, especially those located in central business districts. Also, intersections with high volumes of both bicycle and motor vehicle traffic may not be good candidates for roundabouts. A procedure is needed for estimation of the likely safety consequences of a contemplated installation. In the meantime, it is suggested that future installations be patterned after the ones that were found in this study to produce very positive safety results. □

Contributors

R. A. Retting managed the project, participated in the study design and analyses, and finalized the paper. B. N. Persaud planned the study, supervised data collection and analyses, and drafted the paper. P. E. Garder contributed to the study design, analyses, and writing of the paper. D. Lord participated in data collection and analyses.

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