Continued Reliance on Traffic Signals: The Cost of Missed Opportunities to Improve Traffic Flow and Safety at Urban Intersections

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September 2005

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ABSTRACT

Traffic congestion and motor vehicle crashes are widespread problems, especially in urban areas. Opportunities to improve traffic flow and safety can be missed when traffic signals are installed at locations suitable for roundabouts. The present study examined ten signalized intersections in Northern Virginia that were newly constructed or recently modified. Standard traffic engineering algorithms were used to estimate the effects on traffic delays and motor vehicle crashes if these intersections had been constructed as roundabouts. It was estimated that roundabouts would have reduced vehicle delays by 62-74 percent, depending on intersection, thus eliminating more than 300,000 hours of vehicle delay on an annual basis. Annual fuel consumption would have been reduced by more than 200,000 gallons, with commensurate reductions in vehicle emissions. Based on previous research on crash risk, it is estimated that construction of roundabouts in place of traffic signals could have prevented 62 crashes, 41 with injuries, between 1999 and 2003 at five of the intersections for which crash data were available. These results show the magnitude of the traffic flow and safety costs when traffic signals are installed at locations suitable for roundabouts.

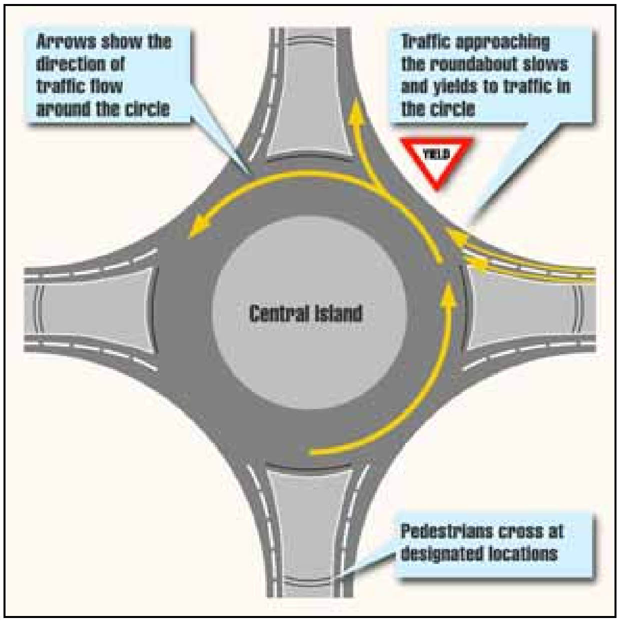
INTRODUCTION

Traffic congestion and vehicle delays are widespread and worsening, especially in urban areas. In 2002, an estimated 3.5 billion vehicle-hours of delay were experienced by motorists in the 85 largest U.S. metropolitan areas, resulting in an estimated 5.7 billion gallons of wasted fuel (Schrank and Lomax, 2004). On a nationwide basis, about 40 percent of traffic congestion is attributed to bottlenecks or "chokepoints," defined as locations where traffic is funneled from sections with higher capacities into ones with restricted capacities (Federal Highway Administration, 2004). These bottlenecks include traffic signals and stop signs.

Many intersections controlled by stop signs or traffic signals can be converted to roundabouts to increase vehicle capacity and reduce traffic delays. The modern roundabout (Figure 1) is a type of circular intersection that is distinct from older traffic circles and rotaries in two principal ways: vehicles entering the roundabout must yield to those already within the circulating roadway, and roundabout geometry produces very slow vehicle speeds (about 15-20 mph) compared with older traffic circles.

Roundabouts can provide substantial traffic flow benefits compared with conventional intersections. They bring conflicting traffic streams into a steady flow and allow vehicles to safely merge without the stop-and-go conditions caused by stop signs and traffic signals. And by eliminating left turns, roundabouts eliminate delays caused by left-turning vehicles waiting for safe gaps in oncoming traffic. Evaluations of intersections converted to roundabouts from stop signs and traffic signals have reported significant reductions in vehicle delay and traffic congestion (Retting et al., 2002; Retting et al., 2005).

Figure 1
Typical Roundabout



Roundabouts also can provide considerable safety benefits. An evaluation of motor vehicle crashes following the conversion of 23 intersections to roundabouts from either stop signs or traffic signals found that crashes of all severities were reduced by 40 percent and injury crashes were reduced by 80 percent (Persaud et al., 2001).

Despite the tens of thousands of roundabouts in successful operation throughout the world, only about a thousand have been built in the United States. Until recently, roundabouts have been slow to gain support in this country, and their level of acceptance varies. Between 1992 and 2004, about a thousand roundabouts were built in several states including California, Colorado, Florida, Maryland, Kansas, Nevada, Utah, Washington, and Wisconsin. Other states have resisted building roundabouts or have been slow to adopt them. Skepticism and opposition to roundabouts may be due in part to negative experience with traffic circles or rotaries built in the early to mid-1900s.

One impediment to the construction of roundabouts involves logistical challenges associated with converting existing intersections. Temporary traffic control measures, which can be expensive, must be implemented during the construction process to maintain orderly and safe traffic flow. However, this problem can be minimized or avoided by constructing roundabouts when new intersections are first built and when major modifications are proposed for existing intersections. When such occasions arise and roundabouts are not considered, opportunities are missed for transportation agencies to improve safety and mobility. Given the robust nature of land development and roadway construction in urban and suburban communities, these missed opportunities occur routinely.

The Washington, D.C., suburbs of Fairfax and Prince William counties, located in Northern Virginia, exemplify the type of rapid land development and population growth taking place in many metropolitan areas. This so-called “urban sprawl” results in construction of many new intersections, as well as major modifications of existing intersections to accommodate increased traffic volume, including installation of traffic signals and roadway widening. Although many new and substantially modified intersections are good candidates for roundabouts, traffic signals have been the traffic control of choice for transportation agencies in Virginia. In recent years, many new traffic signals have been installed throughout these growing suburban counties.

The purpose of the present study was to examine a sample of signalized intersections in Northern Virginia that were newly constructed or recently underwent major modifications and to determine the extent to which hypothetical roundabouts could have affected traffic flow and safety.

METHODS

Traffic flow and motor vehicle crash data were analyzed for ten Northern Virginia intersections where, during the 5-year period preceding the study, either new traffic signals were installed or major roadway modifications were made to existing signalized locations. Major modifications included roadway widening, installation of turn lanes, and upgrading/expansion of existing traffic signal systems. These locations were deemed to be good candidates for roundabouts based on several factors including traffic volume and existing intersection geometry. The locations selected were representative of many signalized intersections in urban and suburban communities. In addition to the ten signalized intersections, one stop-sign-controlled intersection was included that was under review by the Virginia Department of Transportation (VDOT) at the time of the study for possible installation of a new traffic signal. Table 1 provides a list of the study sites.

Table 1
Northern Virginia Study Sites

Intersection type/location	Annual average daily traffic	Effective date of change
New traffic signals		
Route 234 at Spriggs Rd	29,300	September 2002
Route 234 at Aden Rd	24,300	September 2004
Route 619 at Braemar Pkwy	14,750	November 2004
Route 123 at Silverbrook Rd	26,600	April 2004
Fairfax County Pkwy at Weihle Rd	46,600	December 2000
Roberts Pkwy at New Guinea Rd	16,400	November 2000
University Blvd at Armstrong St	14,500	June 1999
Modified intersections		
Route 28 at Linton Hall Rd	41,600	November 2004
Route 234 at Lee Hwy	22,100	December 2002
Route 123 at Lee Chapel Rd	28,600	May 2003
Being considered for a traffic signal		
Route 234 at Gum Springs Rd	12,900	Under review at time of study

Standard operational measures of intersection performance were computed for the locations operating under traffic signal control and then compared with values estimated for the same intersections operating with hypothetical roundabouts. These operational measures included average vehicle delay, proportion of vehicles queued (defined as vehicles required to stop or slow from the approach speed), and fuel consumption. The traffic analysis software package aaSIDRA version 2.1 (Akcelik & Associates, 2004), designed specifically for analyzing traffic flow at signalized intersections and unsignalized intersections (including roundabouts), was used to compute these measures.

All analyses were based on traffic counts collected over a 48-hour period during typical weekday morning (7:00 to 9:00 a.m.), mid-day (11:00 a.m. to 1:00 p.m.), and evening (4:00 to 6:00 p.m.) peak hours during September 2004. Traffic counts were collected and cataloged into 15-minute periods. Traffic count data included the number of vehicles observed for each direction of travel and turning movement. For each 2-hour period, the "peak" hour was defined as the four consecutive 15-minute periods in which the greatest number of vehicles were observed. These peak hours were selected for analyses. Altogether, 30 hours of peak-hour traffic flow data were analyzed.

Hypothetical roundabouts were designed so as to roughly match the vehicle capacity provided by the existing signalized intersections. This was controlled chiefly by limiting the number of lanes to the intersection. For example, a signalized intersection approach with no more than one exclusive lane for each movement (left, right, through) was replaced in the hypothetical roundabout by a single-lane approach. Any signalized intersection approach with two exclusive lanes for any movement was replaced in the hypothetical roundabout by a two-lane approach. Thus, the number of approach lanes at the roundabouts was frequently less than at the signalized intersections they replaced because extra turn lanes were not required. Figure 2 shows the original signalized intersection for one of the study sites (Route

Figure 2
Approximate Dimensions of the Existing Signalized Intersection and a Conceptual Roundabout at one of the Study Sites (Route 619 at Braemar Parkway)

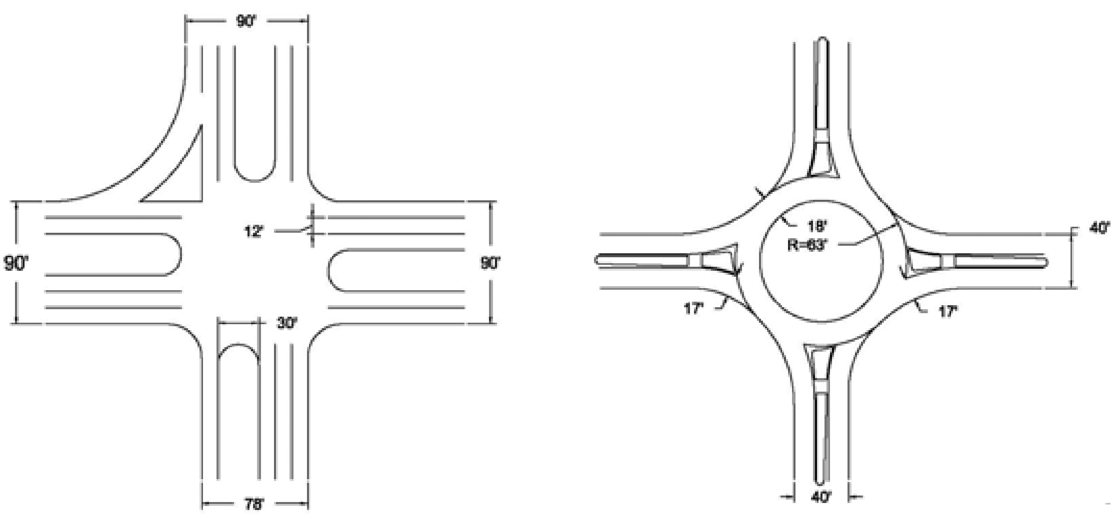


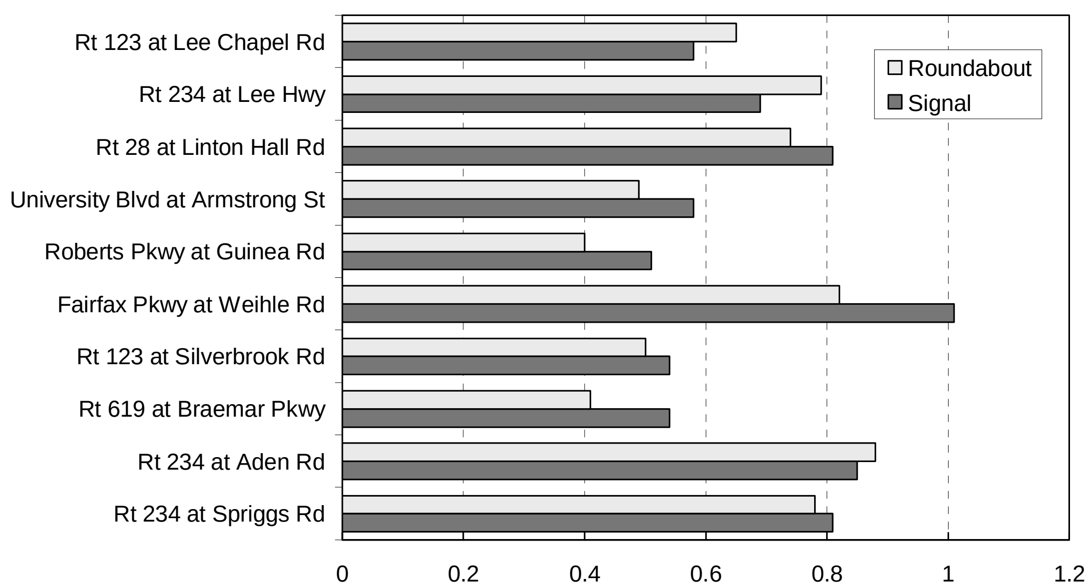
Table 2
Number of Traffic Lanes for Hypothetical Roundabouts

Location	Number of traffic lanes on approach legs
Route 234 at Spriggs Rd	Southbound approach single-lane; other approaches two-lane
Route 234 at Aden Rd	All approaches single-lane
Route 619 at Braemar Pkwy	All approaches single-lane
Route 123 at Silverbrook Rd	All approaches two-lanes
Fairfax County Pkwy at Weihle Rd	Northbound approach two-lane; other approaches three-lanes
Roberts Pkwy at New Guinea Rd	Southbound and eastbound approaches single-lane; other approaches two-lane
University Blvd at Armstrong St	All approaches single-lane
Route 28 at Linton Hall Rd	Westbound approach two-lanes; other approaches single-lane
Route 234 at Lee Hwy	All approaches two-lanes
Route 123 at Lee Chapel Rd	Eastbound approach single-lane; other approaches two-lane
Route 234 at Gum Springs Rd	All approaches single-lane

619 at Braemar Parkway) and the replacement roundabout with roughly equivalent capacity. Table 2 provides a summary of the number of traffic lanes included in the design of the hypothetical roundabouts.

To confirm that hypothetical roundabouts and signalized intersections provided comparable levels of vehicle capacity, the volume-to-capacity (V/C) ratios for critical traffic movements were computed for each intersection with traffic signals and then modeled for the same intersections with roundabouts. The V/C ratio is a measurement of traffic flow quality that compares the number of vehicles using a given road with the number of vehicles the facility is designed to accommodate. For example, a V/C ratio of 0.85 indicates that 85 percent of the capacity is being used. Figure 3 shows the average V/C ratios during the morning peak hours for the ten intersections with traffic signals compared with those for the same intersections with hypothetical roundabouts. Similar results for these intersections were found for the mid-day and evening peak hours.

Figure 3
Volume-to-Capacity Ratios for Intersections Operating with Traffic Signals and Hypothetical Roundabouts (morning peak hours)



Results of the aaSIDRA analyses were provided for peak-hour traffic volumes. These results then were extrapolated to estimate potential reductions in vehicle delay and fuel consumption on a daily and annual basis using the following assumptions. Based on generally accepted characteristics of typical traffic flow patterns (Institute of Transportation Engineers, 1992; Robinson, 2000), it was assumed that 10 percent of daily traffic volumes and 15 percent of daily vehicle delay occur during the peak hour. It also was assumed that fuel consumption is directly related to traffic volume and that there are approximately 250 non-holiday weekdays in one year.

Potential crash reductions associated with the conversion of signalized intersections to roundabouts were estimated for a subset of the study sites. Crash reduction factors were applied to historical crash data for five intersections for which crash data were available for at least 1 year with traffic signals in place. Crash data were not available for two intersections, and for three other intersections traffic signals were installed less than 1 year prior to the study. Police-reported crash data were obtained from VDOT for the most recently available 5-year period (1999-2003). Table 3 provides a summary of the intersections used in the crash analysis.

Table 3
Intersections Used in Crash Analysis

	Number of months with traffic signals in place
Route 234 at Spriggs Rd	15
Roberts Pkwy at New Guinea Rd	36
Route 234 at Lee Hwy	59
Route 28 at Linton Hall Rd	60
Route 123 at Lee Chapel Rd	60
Total	230

Crash reduction factors were based on a previous evaluation of the safety benefits of converting signalized intersections to roundabouts. Eisenman et al. (2005) analyzed five urban intersections that were converted from traffic signals to roundabouts and estimated crash reductions based on a total of 138 months of data before conversions and 141 months after. Roundabouts were estimated to reduce crashes by 37 percent and injury crashes by 75 percent. The Eisenman et al. study provides the most recent and comprehensive data analyses regarding likely crash reductions for intersections converted to roundabouts. However, although the study accounted for the type of traffic control (traffic signal) prior to construction of a roundabout, it did not account for other site-specific characteristics such as the number of traffic lanes. Therefore the crash analysis is less precise than the traffic flow analyses, which did account for specific intersection characteristics.

RESULTS

Vehicle delay was the principal operational measure chosen to define traffic congestion. Table 4 compares average vehicle delays for the ten signalized intersections with those for the same locations

Table 4
Average Vehicle Delay (seconds/vehicle)

Site	Morning Signal	Morning Roundabout	Morning % Change	Mid-Day Signal	Mid-Day Roundabout	Mid-Day % Change	Evening Signal	Evening Roundabout	Evening % Change
New traffic signals									
Rt 234 at Spriggs Rd	32	12	-62	21	11	-48	43	14	-67
Rt 234 at Aden Rd	24	14	-42	13	9	-31	30	10	-67
Rt 619 at Braemar Pkwy	15	9	-40	13	9	-31	15	9	-40
Rt 123 at Silverbrook Rd	19	10	-47	17	10	-41	12	10	-17
Fairfax Pkwy at Weihle Rd	67	14	-79	32	9	-72	53	12	-77
Roberts Pkwy at Guinea Rd	31	6	-81	30	6	-80	73	9	-88
University Blvd at Armstrong St	18	2	-89	20	2	-90	25	2	-92
Average	29	10	-67	21	8	-62	39	9	-74
Modified intersections									
Rt 28 at Linton Hall Rd	32	12	-62	37	13	-65	44	14	-68
Rt 234 at Lee Highway	47	16	-66	30	12	-60	50	14	-72
Rt 123 at Lee Chapel Rd	31	11	-65	25	10	-60	29	11	-62
Average	37	13	-65	31	12	-62	41	13	-68

using hypothetical roundabouts. For both groups of intersections (new traffic signals and recently modified locations), roundabouts would have substantially reduced average vehicle delays during the morning, mid-day, and evening peak hours. Average reductions across the study sites ranged from 62 to 74 percent.

Results from Table 4 were extrapolated to estimate reductions in vehicle delay on a daily and annual basis. If roundabouts had been constructed in place of signalized intersections at the ten study sites, vehicle delays for all sites combined would have been reduced by approximately 1,300 hours on a daily basis and 325,000 hours annually. These cumulative reductions in vehicle delay were based on 250 workdays and do not include any additional reductions that might accrue on weekends or holidays.

Table 5 compares the estimated proportions of vehicles that waited in a queue to enter an intersection or made a complete stop. For both groups of intersections (new traffic signals and recently

Table 5
Proportions of Vehicles Queued

Site	Morning Signal	Morning Roundabout	Morning % Change	Mid-Day Signal	Mid-Day Roundabout	Mid-Day % Change	Evening Signal	Evening Roundabout	Evening % Change
New traffic signals									
Rt 234 at Spriggs Rd	0.63	0.68	8	0.62	0.47	-24	0.77	0.68	-12
Rt 234 at Aden Rd	0.91	0.84	-8	0.78	0.34	-56	0.73	0.66	-10
Rt 619 at Braemar Pkwy	0.73	0.43	-41	0.62	0.31	-50	0.67	0.53	-21
Rt 123 at Silverbrook Rd	0.48	0.31	-35	0.64	0.18	-72	0.3	0.26	-13
Fairfax Pkwy at Weihle Rd	0.94	0.64	-32	0.65	0.36	-45	0.89	0.76	-15
Roberts Pkwy at Guinea Rd	0.83	0.31	-63	0.83	0.27	-67	0.87	0.41	-53
University Blvd at Armstrong St	0.81	0.39	-52	0.83	0.31	-63	0.86	0.57	-34
Average	0.76	0.51	-33	0.71	0.32	-55	0.73	0.55	-24
Modified intersections									
Rt 28 at Linton Hall Rd	0.69	0.69	0	0.66	0.53	-20	0.66	0.79	20
Rt 234 at Lee Highway	0.85	0.68	-20	0.86	0.46	-47	0.9	0.73	-19
Rt 123 at Lee Chapel Rd	0.83	0.49	-41	0.81	0.25	-69	0.81	0.41	-49
Average	0.79	0.62	-22	0.78	0.41	-47	0.79	0.64	-19

modified locations), roundabouts would have reduced the proportions of vehicles being queued. Average reductions across the study sites for the three peak hours studied ranged from 19 to 55 percent.

The aaSIDRA model can estimate reductions in fuel consumption associated with the construction of roundabouts in place of traffic signals. It is estimated that roundabouts constructed in place of signalized intersections would have reduced annual fuel consumption at the ten study sites combined by approximately 16 percent, equivalent to 940 gallons of fuel on a daily basis and 235,000 gallons annually. Annual reductions in fuel consumption do not include any additional reductions that might accrue on weekends or holidays. Reductions in fuel consumption also would correspond with commensurate reductions in vehicle emissions (Akcelik & Associates, 2004).

Table 6 provides crash histories and estimated crash reductions for the five intersections with available crash data. Using the crash reductions reported by Eisenman et al. (2005), the construction of roundabouts in place of traffic signals at these five locations could have prevented an estimated 62 total crashes and 41 injury crashes between 1999 and 2003.

Table 6
Crash Histories (1999-2003) and Estimated Crash Reductions

	Number of months with traffic signals in place	Injury crashes	Total crashes
Route 234 at Spriggs Rd	15	8	20
Roberts Pkwy at New Guinea Rd	36	0	8
Route 234 at Lee Hwy	59	15	59
Route 28 at Linton Hall Rd	60	18	47
Route 123 at Lee Chapel Rd	60	14	33
Total	230	55	167
Crash reduction factor		-75%	-37%
Estimated number of crashes prevented by roundabouts		41	62

Implications for the Intersection of Route 234 and Gum Springs Road

At the time of this study, VDOT was conducting engineering studies to determine the feasibility of installing a new traffic signal at the stop-sign-controlled intersection of Route 234 and Gum Springs Road (Figure 4). VDOT determined this intersection met established criteria for installation of a new traffic signal. However, VDOT determined that installing a traffic signal at this location would require widening of the roadway to allow additional turn lanes on both Route 234 and Gum Springs Road. Construction of turn lanes would affect adjacent wetlands, and mitigating this effect would cost an estimated $2 million.

A conceptual roundabout design was prepared for this intersection based on existing lane configurations. All roundabout approaches were designed with single-lane entries and exits to provide levels of capacity roughly equivalent to those associated with the likely traffic signal alternative.

Figure 4
Route 234 and Gum Springs Road

Constructing either a signalized intersection or a roundabout in place of the stop sign control would reduce peak-period traffic delays, but a roundabout would provide greater traffic flow benefits. Compared with a traffic signal, a roundabout would reduce average vehicle delay during the various peak hours by an estimated 13-63 percent and reduce the incidence of vehicle queuing by 10-41 percent (Table 7). This is equivalent to eliminating more than 6,000 hours of vehicle delay annually. Another important advantage of a roundabout is that fewer traffic lanes would be needed, thereby eliminating the costly efforts required to mitigate the effect of road widening on adjacent wetlands.

Table 7
Traffic Signal vs. Roundabout Alternative, Route 234 and Gum Springs Road

	Traffic Control		Percent change
	Traffic Signal	Roundabout	
Average vehicle delay (seconds/vehicle)			
Morning	15	13	-13
Mid-day	27	10	-63
Evening	19	12	-37
Proportion of vehicles queued			
Morning	0.69	0.62	-10
Mid-day	0.63	0.37	-41
Evening	0.76	0.56	-26

DISCUSSION

This case study illustrates the missed opportunities to improve traffic flow and safety when roundabouts are not considered for busy intersections that are widened or where new traffic signals are installed. These missed opportunities translated into more than 300,000 hours of vehicle delay and 200,000 gallons of fuel an annual basis for the ten sites studied for traffic flow effects, and an estimated 62 crashes at the five sites examined for potential safety effects. Negative effects of traffic signals, including increased vehicle queuing, delays, fuel consumption, and crashes, can be expected to last for many years. It is important to note that traffic flow benefits resulting from the conversion of signalized intersections to roundabouts were not confined to the morning and evening peak hours, but were evident during the mid-day period as well.

The methods used in this study may, to some degree, overestimate or underestimate the effects of installing roundabouts. For example, effects might be overestimated for summer months if traffic volumes are lower during this time. Still, it is more likely that effects were underestimated. Even though real-world roundabouts can provide more vehicle capacity than the conventional intersections they replace (Retting et al., 2002; Retting et al., 2005), roundabouts in this study were configured with vehicle capacities roughly equivalent to those of existing signalized intersections by setting key geometric design elements that influence the rate of traffic flow based on the lane configurations of the existing signalized intersections. In addition, annual estimates of traffic flow benefits and fuel savings were computed only for weekdays. Roundabouts can provide traffic flow benefits on weekends as well, although this effect was not documented. The number of crashes estimated to have been prevented by roundabouts may be greater than expected because many crashes are not reported to police and thus are not taken into account. Regardless of the precise degree to which roundabouts improve traffic flow and safety, the identified benefits are substantial.

Based on the magnitude of benefits identified in this study, widespread nationwide construction of roundabouts in place of traffic signals would have profound cumulative effects on vehicle delay and fuel consumption. The total number of signalized intersections in the United States is estimated to be 265,000 (Institute of Transportation Engineers, 2004). The proportion of signalized intersections at which roundabouts would be beneficial and feasible is subject to debate, with some engineers suggesting widespread use of roundabouts at busy intersections and others preferring traffic signals. However, if just 10 percent of signalized intersections were converted to roundabouts, and the reductions in fuel consumption and vehicle delays estimated in this study were assumed, annual fuel consumption would be reduced by more than 5 million gallons and annual vehicle delays would be reduced by about 8 million hours.

In addition to operational and safety benefits, roundabouts eliminate the expense of installing and maintaining traffic signals; installation of a traffic signal costs an estimated $150,000 (City of Hampton, VA, 2005). Roundabouts also eliminate the electricity consumption and routine maintenance required to operate traffic signals, estimated at $3,000 annually (Washington State Department of Transportation, 2005). There also are costs associated with roundabout construction; however, because costs for building roundabouts vary widely based on site-specific factors, it is not possible to make generalized cost comparisons between roundabouts and traffic signals.

At several sites included in this study, traffic signal installation and road construction was associated with real estate development. As a condition of the zoning approval process, real estate developers often are required by state and local governments to fund transportation improvements. Land development is an ideal opportunity to consider roundabouts.

Despite their benefits, roundabouts may not be the best solution at all locations. Roundabouts may not be feasible at locations where topographic or site constraints limit the ability to provide appropriate geometry. Also, intersections with very unbalanced traffic flows (i.e., very high traffic volumes on the main street and very light traffic on the side street) may preclude roundabouts for reasons of traffic flow. However, as the proportion of minor street traffic volumes increase, roundabouts typically become more feasible and provide greater reductions in vehicle delays compared with traffic signals.

ACKNOWLEDGMENT

This work was supported by the Insurance Institute for Highway Safety.

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