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Does Your Interchange Design Have You Going Around in Circles?

by Joe G. Bared and Evangelos I. Kaisar

America is facing a national crisis as increased traffic and the ensuing congestion and delays negatively affect commerce, the environment, and quality of life. Traffic congestion is such a problem that engineers and researchers across the country are making it their personal missions to find innovations that will enhance traffic flow, ultimately leading to alleviation of congestion. The roundabout might be one alternative to diamond interchanges.

Barry Crown

Roundabouts, like this one in the United Kingdom, are common in Europe.

An informal study of four case problems and several simulation scenarios examining geometric design and control delay suggests that well-designed roundabouts may be a viable option for some stop- or signal-controlled diamond interchanges with low-to-moderate volumes. The study compares the delay caused by a diamond interchange with the delays at interchanges containing double- or single-roundabouts. Comparisons were made using data from computer-simulated models for roundabout traffic operations and for signalized intersections.

Based on the modeling scenarios, roundabout interchanges provide noticeable reductions in control delays, which directly affect the amount

of time that drivers sit in traffic. The modern roundabout also uses a narrower bridge, therefore contributing to savings in construction costs.

Quick Overview on Selecting Appropriate Interchanges

In *A Policy on Geometric Design of Highways and Streets*, the American Association of State Highway and Transportation Officials (AASHTO) presents six warrants (i.e., selection criteria) for interchanges and grade separations, including reductions in bottlenecks, crashes, and traffic volumes. Selecting the most appropriate type of interchange depends on various factors such as the number of intersection approaches, expected traffic movements, expected volumes, design controls, rights-of-way, and topographies. Planners should perform engineering reviews prior to any construction to determine the appropriate interchange configuration for a given situation. Moreover, accommodations for bicyclists and pedestrians must be considered in order to provide access to all users, including people with disabilities.

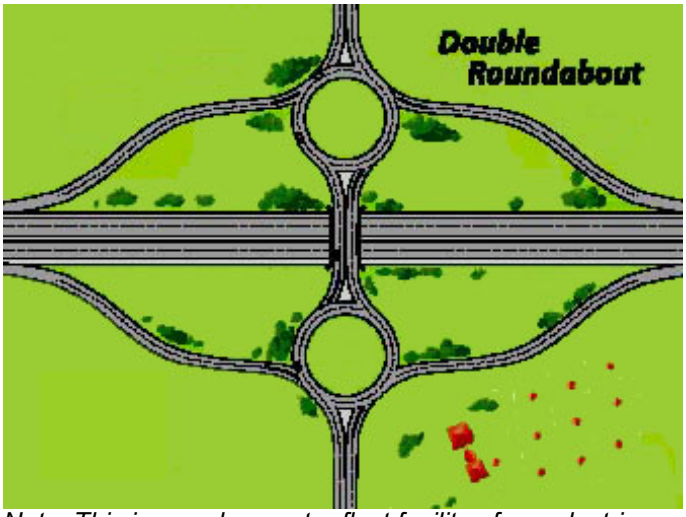
For additional guidance on the design selection process, engineers can reference AASHTO's policies, *Guidelines for Preliminary Selection of Optimum Interchange Type for Specific Location*, by N.J. Garber and M.D. Fontaine; *Single Point Urban Interchange Design Operations Analysis* by C.J. Messer, J.A. Bonneson, S.D. Anderson, and W.F. McFareland; or *Grade Separated Intersections: Intersection and Interchange Design* by J.P. Leisch.

In *Guidelines for Preliminary Selection of Optimum Interchange Type for Specific Location*, Garber and Fontaine recommend using a diamond interchange for low-traffic volumes of less than 1,500 vehicles per hour (vph) and a single-point urban interchange for volumes between 1,500 and 5,500 vph. A single-point urban interchange yields higher delays when the crossroad and left-turn volumes do not balance. Additionally, Garber and Fontaine contend that a single-point interchange design is too expensive and intricate to construct where there are rights-of-way restrictions. Garber and Fontaine's results also indicate that when compared with diamond interchanges, single-point urban interchanges yield approximately 5-second delay savings per vehicle for up to a total flow of 4,500 vph. These delay savings do not apply to single-point interchanges with designs requiring a frontage road, where a diamond interchange (or a tight diamond interchange) often will be a more favorable design configuration.

This study compares conventional diamond interchanges with round-abouts at ramp terminals in terms of delay only.

Introducing Double- and Single-Roundabouts

In both rural and suburban areas, the most predominant interchange is the diamond type, featuring a relatively simple design and implementation that accommodates low-to-medium traffic volumes, with partial access control and limited right-of-way. Although a diamond interchange is the most common interchange type, it creates unnecessary delay at signals and stop signs and may cause spillback onto a freeway. An alternative to the conventional or tight diamond interchange is a double-roundabout interchange.



Note: This image does not reflect facilites for pedestrians or bicyclists. For details, refer to the sidebar, "Pedestrians Also Need to Get Around."

This illustration shows two roundabouts at the ends of both ramp terminals in place of a signal- or stop-contolled intersection onto the cross-street.

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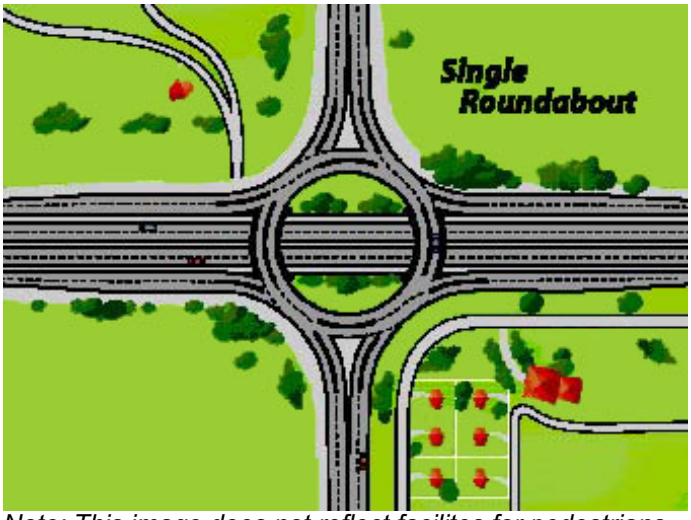

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In this drawing, one roundabout is located at the ends of both ramp terminals in lieu of a signalized, single-point crossing onto the surface street.

Some of the first modern double-roundabout interchanges in the United States were built in the mid-1990s in Colorado and Maryland. According to the National Cooperative Highway Research Program (NCHRP) Report No. 264, the new design creates smooth flows with less delay and eliminates spillback onto the freeway. In practice, preliminary results show that both Colorado and Maryland experienced notable success in improving traffic operations and safety. In Colorado, double roundabouts replaced stop-controlled intersections that were assisted by traffic officers during peak flow conditions.

The single-roundabout interchange is suitable for tight urban areas with moderate capacity requirements. A single-roundabout interchange requires two curved bridges as part of the circulatory roadway, whether the roundabout is above the mainline or under the mainline. The number of lanes at entries and exits are comparable to those in a double-roundabout interchange.

Roundabouts with large inscribed diameters greater than 90 meters (295 feet) are not advisable because they encourage speeding and diminish the expected safety benefits. A disadvantage of the single-roundabout interchange is the need to widen the bridges to meet intersection sight-distance requirements at the off-ramp terminals and the necessity to comply with stopping sight-distance requirements for circulating vehicles.

In addition to reducing delay, roundabouts can handle more than four legs of traffic efficiently when a frontage road is present. Expected advantages of well-designed double-roundabout interchanges include crash reductions (approximately 20 to 70 percent fewer fatal injury crashes) and delay reductions when operating below capacity. Savings in construction costs for the double roundabout are noticeable because the bridge size is reduced by at least two left-turn lanes.

Maryland State Highway Administration

Completed and opened to traffic in November 1998, these two single-land roundabouts move traffic between MD 103 and MD 100 in Howard County, MD.

Pedestrians Also Need to Get Around
A message from FHWA's Office of Civil Rights

When reviewing a given intersection to improve safety or mobility, planners and engineers need to consider pedestrian, bicyclist, and other user access as part of the traffic solution. The solution should accommodate non-motorized traffic, unless non-motorized travel is prohibited. Intersection configuration evaluations should include how to safely accommodate these users, especially people with disabilities.

Although roundabouts may be appropriate for decreasing vehicle-related crashes and increasing vehicle flow at intersections, the absence of a stop sign or signal might present problems for other users crossing streets. For example, motorists exiting the roundabout often may not yield to those on foot, and busy roundabouts provide few gaps long enough for pedestrians to cross safely. A constant stream of traffic might be especially problematic and unsafe for children, the elderly, and those with mobility-related, visual, or cognitive impairments. Visually-impaired pedestrians, who rely on auditory cues from traffic to cross safely, may find it difficult to interpret the direction of oncoming traffic and gaps for crossing because of the constant sound of circulating traffic.

In July 2002, representatives from FHWA and The Access Board, an independent Federal agency charged with developing design standards for complying with the Americans with Disabilities Act (ADA), met to examine options that improve roundabout accessibility. Roundabouts, as with other public rights-of-way, should accommodate pedestrians with disabilities. As a minimum, the group established a goal to educate design engineers more fully about accommodation issues and share best practices on accommodating all pedestrians and other non-motorized users in the design of intersections.

Some design treatments that engineers and planners might use to facilitate foot traffic in roundabouts include:

- Providing pedestrian yield signs for motorists in both directions of a crossing requiring drivers to stop for pedestrians waiting on the crosswalk
- Placing speed tables at pedestrian crossings to further slow the entering and exiting traffic
- Adding auditory and tactile indicators to identify crossing locations for pedestrians with visual disabilities (Since July 26, 2001, detectable warnings/truncated domes are required on all curb ramp crossings.)
- Incorporating barriers, such as low-growing bushes or guardrails, along the street side of sidewalks to guide pedestrians to the crossing location and prevent people with visual disabilities from inadvertently crossing a roundabout roadway at unsafe locations
- Installing pedestrian-activated crossing signals, including devices that halt traffic only when a pedestrian is present in the crosswalk (This treatment enables pedestrians who are unable to determine gaps to cross the street.)
- Designing single-lane roundabouts with single entry lanes, rather than multilane roundabouts, to shorten the crossing distance and enhance pedestrian visibility at vehicle entry and exiting points (This eliminates the possibility of multiple-threat pedestrian crashes.)
- Adding pedestrian-accessible medians and splitter islands to reduce crossing distances and allow those on foot to negotiate one direction of traffic at a time
- Installing rumble strips to reduce the speed of vehicles entering or exiting the roundabout and make the sound of cars more detectable to visually-impaired pedestrians
- Moving pedestrian crossings slightly away from the inscribed circle by a convenient distance, such as one or two car lengths, may eliminate some pedestrian/vehicle conflicts
- Adding landscaping buffers, truncated-domes, etc., as “physical boundaries” to help guide pedestrians with visual disabilities to crossings

With half of all injury-related highway crashes and one-fifth of all fatality crashes occurring at intersections, finding solutions to reduce the number and severity of intersection-related crashes is clearly a vital ingredient in meeting the goal of improving highway safety. Roundabouts have a role in improving motorist safety and increasing mobility at intersections.
The risk to pedestrians, especially people who have visual or mobility impairments, the elderly, or children, must be evaluated carefully when deciding on intersection configurations. Slower motorist approaches and exit speeds, and shorter pedestrian crossing distances, are needed at roundabouts to increase pedestrian safety. Additional research is warranted for designing roundabouts that better accommodate pedestrians and people with disabilities.

The Access Board’s proposed guidelines currently indicate that a traffic signal is needed at roundabouts to accommodate sight-impaired pedestrians, who may not be able to differentiate the direction of traffic or traffic gaps when vehicles are moving in a circular direction. This is one option.

"The challenge for design engineers and planners is to find ways to build in pedestrian accessibility where appropriate," says Ed Morris, FHWA's director of civil rights. "FHWA and our partners are looking for viable alternatives that will help pedestrians reach their destinations in a safe and timely manner."

For more information about this topic, please contact the FHWA Office of Civil Rights at 202– 366– 4634 or the Office of Safety at 202– 493– 3314.

Analysis Methodology

The typical double-roundabout interchange analyzed in this study includes a four-lane crossroad intersecting two-lane off- and on-ramps from the freeway.

The study used the measurement units of effectiveness recommended in the Transportation Research Board's *Highway Capacity Manual* to compare the three types of interchanges for control delay. Control delay encompasses deceleration, acceleration, move-up, and stop delays.
The United Kingdom TRL Software Bureau's *Assessment of Roundabout Capacity and Delay (ARCADY)* computer program, which aids in roundabout design, crash predictions, and traffic flow, was used to determine delay and queuing for roundabouts. ARCADY 4 can model peak periods and applies to single-island roundabouts with three to seven legs.

These two single-lane roundabouts are located at the ramp ends of the interchange between U.S. 301 and MD 291 in Kent County, MD.

The study model used the Texas Transportation Institute's *PASSER III* software to help determine cycle length (ranging from 60 to 120 seconds), optimum phase timing, and time offset between the two signals for diamond interchanges. PASSER III minimizes intersection delay only for undersaturated conditions; however, phase timing and offset are reliable in oversaturated conditions. The diamond interchange is controlled by two three-phase signals that are coordinated according to five given sequences.

To estimate stop delay, signal-timing data were fed into the Federal Highway Administration's (FHWA) traffic microsimulation model, *Corridor Simulation (CORSIM)*, which provides comprehensive

capabilities such as traffic operational analysis, geometric design/traffic operational evaluation, and assessment of mitigation strategies under congested conditions. Control delay was assumed to be 1.3 times stop delay for the sub-network (at the crossroad) of the signalized diamond interchange.

Three case problems for two-lane roundabouts and one case problem for a single-lane roundabout were included in this study. The scenarios for the two-lane roundabouts were:

1. Weekday peak—30 percent left-turning traffic volume from the cross-street and 60 percent left-turning volume from the off-ramps
2. Weekday off-peak—20 percent left-turning volume from the cross-street and 40 percent left-turning volume from the off-ramps
3. Weekend—20 percent left-turning volume from the cross-street and 60 percent left-turning volume from the off-ramps

Proportions of turns were assumed to be constant on all approaches, and 10 percent of the traffic was assumed to be trucks.

Comparable geometries were selected for all three interchange configurations—the diamond, the double roundabout, and the single roundabout. For the diamond interchange, the crossroad had four through-lanes: two in each direction with exclusive 76-meter (249-foot) right-turn and 106-meter (348-foot) left-turn lanes. The two intersections were offset by 90 meters (295 feet) from stop bar to stop bar.

For the roundabout, the two approach lanes were flared from 3.7 meters (12 feet) to 4.5 meters (14.8 feet) per lane. The off-ramps for the diamond interchange were flared from one lane to two lanes at the entry to provide a 60-meter (197-foot) right-turn lane. Similarly, the double-roundabout interchange and single-roundabout interchange off-ramps were flared to two lanes at the entry from 5 meters (16 feet) to 9 meters (30 feet) total width.

The inscribed circle diameter (ICD) of the double-roundabout interchange was 55 meters (180 feet), while the ICD for the single-roundabout interchange was 85 meters (279 feet). This relatively small ICD for the single roundabout can be achieved only by providing tight retaining walls along the freeway. Except for the ICD, the approach and entry geometries are similar; however, the diamond interchange has extra right- and left-turn lanes on the crossroad.

Comparing the Scenarios

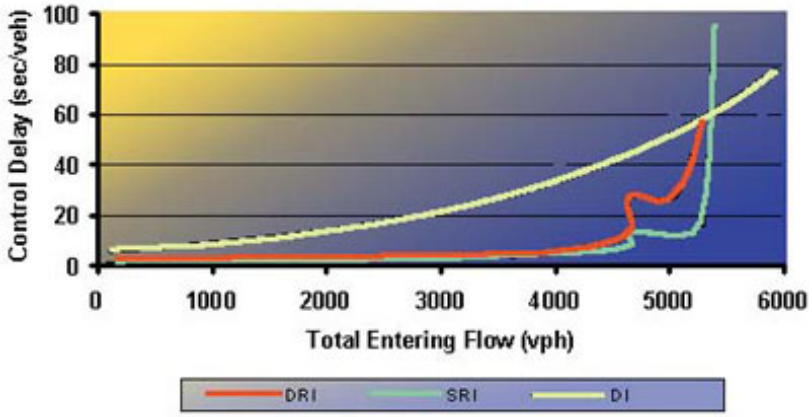
For the weekday off-peak and weekend scenarios, the savings by the roundabouts in control delay range from a few seconds to about 30 seconds per vehicle. Savings are slightly higher in the weekday peak case, when the left-turn percentage of the crossroad is higher.

The capacity of the single roundabout is slightly higher than that for the double roundabout because of the larger ICD. Although the savings in delay between the diamond interchange and the double-roundabout interchange/single-roundabout interchange are noticeable, the capacities of the roundabouts are relatively moderate with total entering

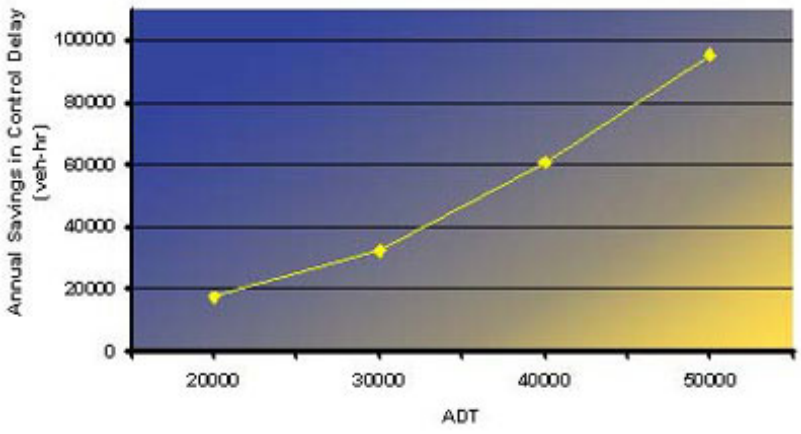
flow less than 4,500 vph. Capacities for these roundabouts are limited because the entries have a maximum of two lanes without storage lanes for left- and right-turning vehicles. At this point, the constraint of two-lane roundabouts is recommended for the safety of American users who are slowly adapting to a new intersection environment.

In the weekday off-peak scenario, the capacity is approximately 4,300 vph for the double-roundabout interchange and 4,700 for the single-roundabout interchange. A slightly higher capacity can be attained by allowing a longer distance between the double-roundabout circles. The weekend scenario shows the capacity of the double-roundabout interchange as smaller at 4,000 vph, with the single-roundabout interchange capacity at 4,600 vph. The capacity of the weekday peak scenario is also 4,000 vph for the double-roundabout interchange and 4,300 vph for the single-roundabout interchange.

Some traffic flow imbalances between opposing entrances were selected within and outside the scenarios. Their impacts were minimal at lower flows and noticeable at higher volumes. A last scenario was modeled for single-lane roundabouts only.



This chart shows an exponential form of control delays as a function of total entering flow (vph) for a double (DRI) and a single roundabout interchange (SRI), compared with a signalized diamond interchange (DI).



This chart shows a steady increase in annual savings in control delay for a double roundabout compared with a signalized diamond interchange as a function of average daily traffic.

Estimated Savings in Delay

Traffic volume distributions for weekdays and weekends were selected from the Maryland State Highway Administration's *Traffic Trends* report. By applying the savings per vehicle to the daily traffic flow distributions for weekdays and weekends, the authors of the study derived annual savings in vehicle-hours.

The percentage of daily distribution per hour was multiplied by a selected average daily traffic (ADT) of 20,000 to 50,000 to determine the hourly traffic flow entering the interchange at the crossroad. The flow rate then was multiplied by the seconds per vehicle saved at this flow. All 24 hours of a weekday and weekend day were added separately to determine respective daily savings. Annual savings were finally added for 107 days of weekends and holidays and 258 weekdays. When added up over a year, 30,000 total entering vehicles a day would yield an annual savings in delay of 35,000 vehicle-hours per year. Although savings in delay generally are expected, this analysis does not consider a complete daily variation of directional splits, meaning that the results cannot be generalized.

Conclusions from This Roundabout Study

In addition to the expected safety benefits of well-designed roundabouts, this study showed that traffic operation is more efficient in roundabouts than at diamond interchanges for low-to-moderate traffic flows up to total entering volumes of around 4,500 vph. Roundabouts noticeably reduce control delay in terms of seconds per vehicle, with savings in delay being slightly higher when the proportion of left-turning vehicles is greater and the capacity is smaller.

The annual savings in delay are considerable at higher average daily traffic levels, which might better justify the economic benefits of a double-roundabout interchange. In addition, the bridge surface required for the double-roundabout interchange is approximately one-third less than for the diamond interchange.

A roundabout interchange does not necessarily require more right-of-way than a diamond interchange because the left- and right-turn lanes are not required. However, in a double-roundabout interchange, the circles might need to be offset by a greater distance to accommodate higher flows with long queues.

The single-roundabout interchange may be suitable for urban environments where the right-of-way is restricted. However, the bridges might have to be widened to provide required intersection and stopping sight distances. Similarly, the limitation applies where the total entering volumes should not exceed approximately 4,500 vph.

In conclusion, the study's simulations show that using double roundabouts at interchange ramp terminals with low and medium flows will result in noticeably less delay than stop-controlled and signalized diamond interchanges. Other side benefits include increases in safety and the ability to use narrower bridges. Similarly, for single-roundabout interchanges in tight urban settings, the delay benefits are significant although the savings in bridge structure are limited because of sight-distance requirements.

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See also: Bared J.G., and Kaisar, E.I. "Comparison of Diamond Interchanges with Roundabout Interchanges." Conference Proceedings of the 2nd International Symposium on Highway Geometric Design. p. 513-521. Sponsored by Transportation Research Board of the USA and Road and Transportation Research Association of Cologne Germany. Mainz, Germany. June 2000.

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