An Update on the Quadrant Roadway Intersection: Case Studies

Jonathan Reid, PE, PTOE (Corresponding Author)
Transportation Business Practice and Technical Lead
ARCADIS | Arcadis G&M of North Carolina Inc.
801 Corporate Center Drive, Suite 300
Raleigh NC | 27607
Phone: (770) 757-7601

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ABSTRACT

The Quadrant Roadway Intersection (QRI) was originally published in an Institute of Transportation Engineers article in 2000. It was further developed and included in FHWA's Alternative Intersection and Interchange Informational Report in 2010 and a subsequent FHWA Tech Brief.

The QRI is an innovative intersection design that eliminates direct left turns at the intersection of two roadways by using a roadway in one intersection quadrant to serve all intersection left turns indirectly. Each left turn pattern is different; therefore signing, marking and driver expectation are all challenges for this design.

In 2012, the first two QRI's in the U.S. opened within two months of each other, the first in Fairfield, OH and the second in Huntersville, NC. While both were built as part of larger corridor improvement projects, the two QRI designs have distinctly unique access, design and operational characteristics. The Huntersville QRI repurposed an existing, three-lane roadway in one quadrant that circumscribes existing commercial development, while the Fairfield QRI constructed a new, six-lane roadway in an open, undeveloped quadrant.

This paper presents the planning, public involvement, construction, operations and safety lessons learned from the first two QRI's built, and highlights best practices and challenges in planning, designing, constructing, operating and maintaining future QRI's.

EVOLUTION OF THE QUADRANT ROADWAY INTERSECTION

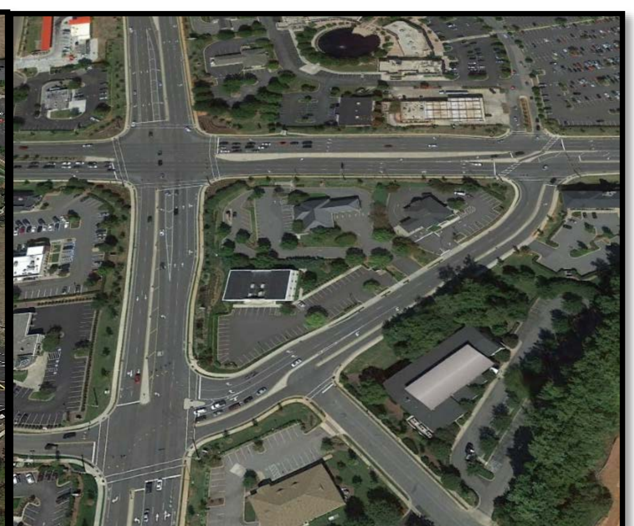
The concept of the Quadrant Roadway Intersection (QRI) was developed by Reid as part of Master's Degree coursework at North Carolina State University in 1999 and submitted and published in the *Institute of Transportation Engineering Journal* in June 2000 (1). The goal of the QRI is to improve intersection operational efficiency by relocating direct left turns at major roadway junctures to be made indirectly using a roadway in one intersection quadrant while reducing roadside impact compared to conventional intersection improvements. The QRI is best suited for intersections where traditional roadway widening and/or turn bay improvements may be difficult or prohibitively expensive due to roadside, property and/or environmental impacts. Detailed operational analysis showed the QRI to provide a 40-50% reduction in average intersection delay and a two-letter level-of-service improvement on average compared to similar conventional intersection improvements.

The QRI was further analyzed in TRB Research Record 1751, where operational results were compared to seven other innovative intersection types. Comparative results showed that the QRI was consistently one of the best preforming innovative intersections, reducing peak-hour intersection delay by an average of 31% and reducing off-peak intersection delay by 20% when volumes and turning movements were compared with conventional intersection design (2). Reid later published a fellowship monograph entitled *Unconventional Arterial Intersection Design, Management and Operations Strategies* in 2004 that included additional QRI research and served as a repository of all innovative intersection design research, concept development and implementations in the U.S. (3). The QRI first appeared in a Federal Highway publication when the *Alternative Intersection / Interchange Informational Report* was published in 2010 (4) and in a separate *FHWA Tech Brief* that same year (5).

First Quadrant Roadways in the U.S.

In 2012, the first two QRI's in the U.S. were opened within two months of each other, the first in Fairfield, Ohio in January 2012 and the second in Huntersville, North Carolina in March 2012. These two designs are depicted in **Figure 1** below. At the current time, there are no other known QRI's constructed in the U.S. or any other country. While these first two U.S. implementations both share the hallmark characteristics of the QRI design and were both implemented at the busiest intersections within larger corridor improvement projects, they are diverse in many ways and serve as "bookends" in the way QRI's are planned, designed, implemented and operated. Comparison of these first two QRI's, their commonalities and unique variations, and their operations and safety results are the basis of this paper and presentation at the 5th Annual TRB Urban Street Symposium.

FIGURE 1: First Quadrant Roadway Intersections in the U.S.



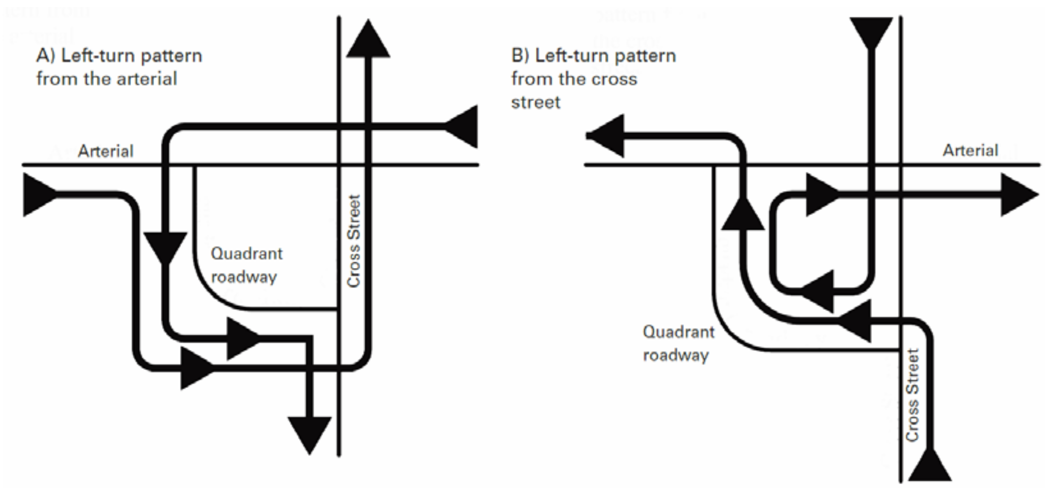
SR 4 @ SR4 BYP, Fairfield OH Opened January 2012 *SR-73 @ US-21, Huntersville Opened March 2012*

BASICS OF THE QUADRANT ROADWAY INTERSECTION DESIGN

Concept Considerations

As its name implies, the defining QRI design principle is the construct of (or repurpose of) a roadway within one quadrant of an intersection that is used to facilitate all left turn movements at that intersection. Redirecting left turn movements eliminates direct left turn signal phases at the main intersection, where only through and right-turn movements are permitted. Each of four indirect left-turning movements use the quadrant roadway in differing turning movement patters, illustrated in **Figure 2**.

FIGURE 2: Quadrant Roadway Left Turn Patterns



The quadrant roadway intersects both intersecting roadways at secondary T-intersections on each roadway. The two T-intersections are ideally located between 500 and 600 feet away from the main intersection to provide sufficient distance for vehicle queuing while minimizing the added travel distance for the indirect left turns using the quadrant roadway. The secondary T-intersections are typically signalized and are coordinated with the main intersection signal to provide optimal vehicle progression on each roadway. This is typically done using a single, master controller, which allows through vehicle movements at two adjacent intersections in one direction and turning movement at the other T-intersection during one signal phase, then switching to through movements at two intersections in the other direction during the second phase. Because there are only two signal phases during each signal cycle, signal loss time (yellow and all red time devoted to clearing the intersection) is minimized, and signal cycle lengths can be made shorter, thus reducing the opportunity for long queues to develop on any intersection approach.

The two-phase signal operations of a QRI also results in a reduction in intersection conflict points (**Figure 3**). The number of conflict points in the combined three intersections (30) are still fewer than a conventional signalized intersection (32 conflict points) and most of the severe crash type conflicts are removed, which creates the expectation of improved intersection safety.

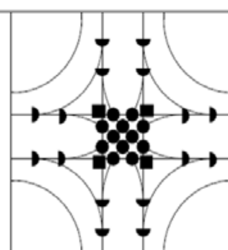
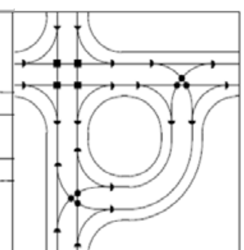
INTERSECTION CONFLICTS / TYPE	 FULL ACCESS	 QUADRANT ROADWAY
■ CROSSING (MAJOR)	4	4
● TURNING (MAJOR)	12	6
◗ DIVERGE (MINOR)	16	20
TOTAL	32	30

FIGURE 3: Quadrant Roadway Conflict Points

Planning Considerations

When considering if a conventional intersection is a suitable candidate for improvement to a QRI, one of the first considerations must be in which intersection quadrant should the quadrant roadway be placed. In many if not most cases, the quadrant roadway location is dictated by either the presence of an existing roadway or the availability of land in a singular intersection quadrant. In the case that there is a choice of two or more quadrants, operational impacts can be modeled for each option available using mesoscopic software tools such as Synchro or FHWA's CapX tools to gain a general understanding of intersection capacity, geometric requirements and expected intersection operations. However, because of the interdependency of the three traffic signals in a QRI, detailed operational analysis requires the use of a microscopic simulation tool such as CORSIM or VISSIM. This level of analysis may be needed to answer questions regarding the total trip time of the various left turn patterns, as project stakeholders and public involvement participants may intuitively object to circuitous and longer trip paths and travel time for left turning movements, especially owners of retail and commercial centers who depend on ease of highway access. The QRI has varying potential access impacts in each of the four intersection quadrants:

- The intersection quadrant containing the quadrant roadway has perhaps the best roadway access, as areas outside the quadrant roadway have access to both main roadways via the signalized T-intersections; the area inscribed by the quadrant roadway has the same signal access plus the potential for right-in/right out access to both main roadways.
- The two quadrants opposite the quadrant roadway may have negative access impacts. While land owners and developers would see immediate potential to provide quadrant access by adding a driveway as a fourth leg to the T-intersection signal, the efficiency of the QRI depends on the signal phasing afforded by the T-intersection. *Every effort should be made to preserve the T-intersection functionality and limit access between the signalized intersection to right-in/right-out driveways.*
- Lastly, the intersection quadrant kiddie-corner from the quadrant roadway may have *perceived* access impacts due to the loss of direct left turns at the intersection, but efficiency gains by the QRI should off-set any perceived impacts to access to this quadrant.

As described earlier, the QRI left turn pattern is different for each intersection approach and thus there are varying impacts to driver expectation and required signing and markings on each approach. For two of the four approach directions, left turns are made from the left side of the roadway, which best meets driver expectation. As illustrated in **Figure 4**, intersection **approach A** directs left turning vehicles to pass through the main intersection (requiring signing and markings to prohibit direct left turns), make a left turn onto the quadrant roadway, then a right turn to complete the left turn movement. Intersection **approach B** directs left turning vehicles to turn left in advance of the main intersection onto the quadrant roadway, then make a second left to complete the left turn movement. Intersection **approach C** directs left turning vehicles to first make a right turn onto the quadrant roadway in advance of the main intersection, then a left turn at the T-intersection to complete the left turn

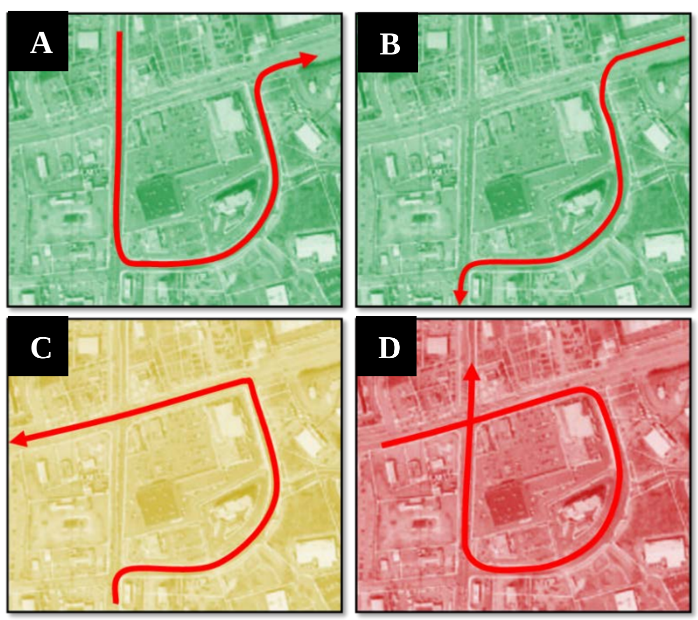


FIGURE 4: Quadrant Roadway Left Turn Guidance

movement. This would require advance signing and perhaps in pavement markings to indicate that all turning traffic is from the right, similar to approaching an interchange with a loop ramp from the right. Intersection **approach D** may be the most difficult QRI movement to convey to motorists, as they must pass the main intersection and then make a right turn onto the quadrant roadway, then a second right turn to complete the left turn movement. This movement requires additional advance signing (recommended on overhead structure) and recommended in-pavement markings.

QUADRANT ROADWAY INTERSECTION CASE STUDIES

The first two QRI's in Fairfield OH and Huntersville NC, depicted previously in Figure 1, illustrate several similarities and differences that will help understand challenges and lead to successful planning and design of future QRI's. **Table 1** describes these project similarities and differences.

TABLE 1: Comparison of Fairfield and Huntersville Quadrant Roadway Intersection Designs

	Fairfield OH Design	**Huntersville NC Design**
Geographical Location	Suburb of Cincinnati	Suburb of Charlotte
Project Context	Part of larger Superstreet Project	Part of larger Superstreet Project
Left Turns Made Indirect	Full Quadrant Roadway (all left turns made indirectly via quadrant roadway)	Partial Quadrant Roadway (eliminates direct lefts on 2 of 4 approaches)
Lanes on Quadrant Roadway	Six	Three
Existing/New Roadway	New roadway constructed	Existing roadway repurposed
Center of Quadrant Roadway	Vacant	Commercial development within
Intersection Control	Secondary T-intersections	Secondary 4-leg intersections
Public Involvement	Appropriate level	Significant pre-planning
Operational Results	Improved operations by 2 letter grades	Improved operations by 3 letter grades

FAIRFIELD (OH) QUADRANT ROADWAY

Planning and Design

The Fairfield QRI, depicted in **Figure 5**, constructed a new roadway at the intersection of SR-4 and SR-4 Bypass in a quadrant where the land was previously owned by the Ohio Department of Transportation. It was not intentionally planned to be a quadrant roadway, as City engineers had no foreknowledge of the formal QRI concept and it was initial referred to as a "Diversion Road". However, the design had all the hallmarks of a QRI and utilized some of the public involvement materials made available later in the planning and design process. There were initially 10 different conventional and innovative alternatives studied as potential intersection improvements and the QRI was shown to operate the best and meet future demands and was therefore selected as the preferred alternative and eventually constructed.

FIGURE 5: Fairfield Quadrant Roadway

The design included a maximum number of lanes on the quadrant (six total) to provide dual left and dual right turn lanes at each end of the quadrant. The intersection spacing was well within the recommended distances, as each T-intersection is between 500 and 550 feet from the main intersection. The design also included overhead signs on span wire and in-pavement markings on the quadrant roadways to assist with directional and lane assignments. Regulatory signing is used to prohibit left turns at the main intersection; however, there were no raised medians or other special signing or markings on either main roadway.

There was an appropriate level of public involvement conducted throughout the planning process, including a project website, continual meetings with business owners, and local paper and TV media announcements, despite there being only a few businesses directly impacted by the QRI.

After Opening

In the weeks and months after opening, lessons learned were identified and published (6). The authors made the following observations about pre- and post-conditions of the first QRI:

- During construction, portions of the newly constructed quadrant roadway were opened before all lanes on the receiving roads were complete, leading to motorist confusion and frustration. Temporary message boards were added as the project opened to help reinforce the new turning patterns.
- Driver habits and inattention created some challenges when the intersection opened, and many illegal left turns were being made. Through education and enforcement, the number of illegal left turns dropped by 90% after the first month.
- New intersections need to stand out more through geometric design. The use of a physical barrier, such as a concrete median or landscaped island, would have been more effective than adding transverse striping to prior left turn lanes in communicating the left-turn restrictions.
- The project met triple bottom-line goals of economic, social and environmental impacts. Neither SR-4 or SR-4 Bypass had to be widened, eliminating roadside wetland impacts. The project also used existing local resources, including a large amount of fill obtained from sites around the city. Economically, the design greatly reduced the impact on commercial properties.

The project's overall success was widely acknowledged, leading to receipt of the *2012 Donald C. Schramm Transportation Improvement Award* from the southwest Ohio chapter of the American Society of Highway Engineers.

Intersection Safety

To evaluate the safety performance of the Fairfield QRI, crash data was collected for the 3 years prior and the 3 years after the QRI opened. The results are summarized in **Table 2** below. Crashes at the main intersection and the Route 4 / Diversion Road T-intersection were reduced in number and severity compared to the prior conventional intersection. However, there were a significant number of crashes, many resulting in injuries, at the Route 4 Bypass / Diversion Road intersection, bringing the 3-intersection total to be greater than the "before" singular conventional intersection. Further evaluation of the crash data showed the clear majority of the SR-4 Bypass / Diversion Road crashes were rear-end crashes (72%), and further engineering studies are on-going to determine if signal timing, driver confusion or other causes is the root of the high-crash rate at this T-intersection.

TABLE 2: Fairfield Intersection Before and After Crash Data

		Sept 2012 to Aug 2015		
Crash Type	**Sept 2007-Aug 2010**	**Route 4 at Route 4 Bypass**	**Route 4 / Diversion Road**	**Route 4 Bypass / Diversion Road**
Total Crashes	77	55	10	90
Injury Crash / Injuries	30 / 45	15 / 19	2 / 3	23 / 37
Fatal / Serious Injury	0 / 2	0 / 0	0 / 1	0 / 1

HUNTERSVILLE (NC) QUADRANT ROADWAY

Planning and Design

The Huntersville QRI was developed to relieve congestion at one of the worst intersections in the Town while maintaining good access to an important commercial center in the northeast quadrant. (7). The intersection of NC-73 / US-21 is located less than 1,000 feet east of the NC-73 / I-77 interchange. There is a large volume of traffic that exits I-77 and turns right on NC-73 then left on US-21. The short distance between the I-77 ramp and US-21 intersection provided inadequate left turn storage on NC-73 approaching US-21 and traffic would often back-up onto the I-77 off-ramp. The QRI design, illustrated in **Figure 6**, was the selected solution to divert left turns onto US-21 to turn right onto the quadrant roadway and right again to go north on US-21. Unlike its Ohio predecessor, the Huntersville QRI was developed by repurposing an existing roadway (Holly Point Drive) in the southeast intersection quadrant. Another difference is the design is only a "half-quadrant roadway", as left turns from NB and SB US-21 are still made directly at the main intersection; only left turns from NC-73 are made indirectly using the quadrant roadway, resulting in the need for three signal phases at the NC-73 / US-21 intersection.

FIGURE 6: Huntersville Quadrant Roadway

Due to the unique "right-to-go-left" turning pattern coming off the interstate ramp and the high volume of traffic making this movement, more significant signing and marking plans were implemented, illustrated in **Figure 7.** On the interstate ramp, signs on cantilever overhead sign structures are used to align motorists with their desired destination of either NC-73 or US-21 (left photo). On eastbound NC-73, an additional overhead sign and in-pavement markings are used to reinforce lane assignments to reach US-21 north and south (center photo). A final overhead sign guides vehicles to turn right in a drop lane onto the quadrant roadway to reach US-21 north (right photo). In the opposite direction, a fourth overhead sign was placed on westbound NC-73 to reinforce the advance left turn movement onto the quadrant roadway. The added cost of these overhead sign structures was outweighed by the necessity to provide clear guidance to motorists making the unique QRI movements.

FIGURE 7: Huntersville Quadrant Roadway Signing and Marking

As both left turn movements add traffic only in the clockwise direction around the quadrant roadway, the quadrant roadway was improved to include two SB/WB lanes and one NB/EB lane. The roadway includes a narrow median dividing the roadway directions with one directional median break to provide access to local business. Also, neither of the quadrant roadway intersections are the desired T-intersections. US-21 at Holly Point Drive is a four-leg, full-access intersection and NC-73 at Holly Point Drive is a Superstreet intersection that provides left turns to a shopping center roadway in the northeast quadrant opposite Holly Point Drive.

There was considerable public involvement associated with the construction of the QRI. Several public meetings were held, where many citizens were skeptical about the design and access impacts. The owners of several business residing along the quadrant roadway were convinced the project would put them out of business. Several fast food businesses and a hotel on US-21 north of NC-73 were fearful that the loss of “easy access” from the interstate would decrease existing and future customers. However, the Town of Huntersville and North Carolina Department of Transportation (NCDOT) partnered with local property and business owners to address access issues. As a result, trailblazing signs were added to the project to guide motorists to individual business. Throughout the public process, the Town and NCDOT remained strong in their commitment that the QRI was the best long-term solution to alleviate intersection congestion and that local businesses would continue to thrive at this intersection.

After Opening

Following the same script of the Fairfield QRI, some of the lanes of the larger NC-73 project were opened a few weeks before the Quadrant Roadway movements were operational, leading to a lot of motorist confusion. Some temporary signing was set up to mitigate the lack of completeness, but the damage was done until the full QRI was operational. After full open, motorists had some difficulty adjusting to the new QRI pattern, as many motorists eastbound on NC-73 either missed or were confused by the right turn directive and turned left from NC-73 at the signalized crossover into the shopping center in the northeast intersection quadrant. The shopping center private loop roadway allowed left turning vehicles to reconnect with US-21 north (a path which some at first thought more convenient). There was such excessive congestion on the shopping center roadway that NCDOT considered closing the left turn access temporarily (or permanently), but that directly contradicted one of the main goals of the project. As a compromise, speed tables were installed along the shopping center roadway. Studies were done to determine that, in fact, the quadrant roadway was the faster left turn path, and through education and enforcement, motorists gradually adapted to the correct pattern.

Operational improvements at the NC-73 / US-21 intersection were immediate upon full opening of the QRI, as congestion and queuing disappeared overnight, causing some to think that people were avoiding the intersection altogether -- a fact disputed by traffic count data that showed no change in overall volumes. Reece, Carroll and Epperson provided before-and-after operational analysis that showed substantial improvement in overall intersection delay, from 121.0 sec/veh average delay before the QRI project to 26.0 sec/veh average delay after (7).

Most businesses quickly embraced the project, for as congestion diminished, motorists who once avoided the intersection (particularly during the morning and afternoon peak periods) returned for shopping and entertainment, and no businesses went under as feared. Several opponents of the QRI later expressed satisfaction with the results, making public statements such as “Traffic seems much lighter and really flows. It took some getting used to, but getting to the bank, library, Target, etc. is really easy and low stress. Everyone’s hard work and patience with the process paid off!”, and “I was really opposed to this intersection when you were planning it and I still don’t understand why you did what you did…but I want to let you know that it works!”.

Intersection Safety

Crash data was collected for 3 years prior and the 3 years after the QRI opened. The results are summarized in **Table 3** below. Unlike the Fairfield location, all three intersections existed prior to construction of the QRI (though two were unsignalized). Total crashes and frontal impact (higher severity) crashes were increased at two of the three intersections, with reductions only at the NC-73 / Holly Point intersection. However, the intersection volume increased by 10,000 vpd (18%) in the years between the before and after crash study periods, so the accident rates when factored my million-vehicle-miles-traveled (MVMT) are not that dissimilar between before and after conditions.

TABLE 3: Huntersville Intersection Before and After Crash Data

	Nov 2006 to Nov 2009			**July 2012 to July 2015**		
Crash Type	**NC-73 at US-21**	**NC-73 / Holly Point**	**US-21 / Holly Point**	**NC-73 at US-21**	**NC-73 / Holly Point**	**US-21 / Holly Point**
Total Crashes	65	35	13	81 (+25%)	28 (-20%)	36 (+177%)
Frontal Impact Crashes	10	23	9	22 (+120%)	5 (-78%)	21 (+133%)
Rear End Crashes	47	11	4	47 (0%)	17 (+55%)	11 (+175%)

CONCLUSIONS

From the implementation of the first two QRI in the U.S., there are clear operational benefits of the QRI compared to conventional intersection design, as both intersections showed significant reductions in average vehicle delay and reduced levels of queuing and congestion at the main intersection. Less clear is the safety impact of the QRI project, though both projects seem to indicate that expected safety improvements due to the reduction in the number and severity of conflict points is more than offset by the introduction of two new signalized intersections, particularly if signal coordination between the three intersections is not optimal.

Because of their diversity in geometry, these two intersections provide no clear-cut guidance on the design of the roadway or number of lanes on the quadrant roadway, which will be likely governed by type of roadway (new or repurposed) and the land uses and access needs for all intersection quadrants on a case-by-case basis. Issues at the non-T intersections in the Huntersville QRI reinforces the principle that wherever possible, the quadrant roadway should be built and protected as T-intersection junctures.

Public involvement should be a significant part of the planning process to understand public perception and access needs and to make appropriate modifications to design. Both intersections had issues with opening portions of the QRI before the whole intersection was complete, which should be avoided in future QRI openings. For both projects, there was a lack of post-project public outreach to understand the impacts of the project to businesses and the traveling public that would have been valuable in understanding issues that could be addressed in future QRI projects. To build on the success of these two intersections, the planning, design and construction of more QRI’s is needed to develop further guidance and best practice planning, design and operational phases.

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