North Carolina's First Quadrant Left: History and Lessons Learned

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ABSTRACT

North Carolina's first Quadrant Left roadway project was recently constructed in Huntersville, a suburb of Charlotte. This paper will outline the history of this innovative intersection design in North Carolina, describe the benefits of quadrant roadways, and explain the history of the subject Quadrant Left intersection. The subject Quadrant Left intersection was previously a complex all-movement signal causing significant delays and backups onto a nearby congested Interstate. There were significant public and media concerns with the proposed design including concerns with access to area businesses, navigation, and introduction of additional traffic signals. This Quadrant Left was designed and constructed due to successful capacity analysis and design, input from other Quadrant Left projects in the United States, and perseverance of project stakeholders. Initial observations included concerns with compliance and improper navigation, however these issues were controlled with additional signing and marking, improved access control, and improved motorist familiarity with the design. After two years of operation, the Quadrant Left project has successfully met its expected goals based on operational capacity analysis and safety analysis after construction. Continuous public outreach and education, greater motorist familiarity, and improved national designs were deemed essential throughout project development. This case study may be used as a template for other potential Quadrant Left projects in the United States.

1. INTRODUCTION

This paper is organized into six sections. Section 1 provides an introduction and background information. Section 2 describes the subject site with characteristic operational and safety problems. Section 3 considers countermeasures to improve operational problems and describes predicted operational results. Section 4 discusses the implementation of the Quadrant Left design and public reactions. Section 5 provides the resultant operations and safety of the Quadrant Left three months and two years after implementation. Section 6 provides the summary and conclusions of this study.

A common traffic operational and safety issue occurs along congested urban arterials during peak hours. The primary function of urban arterials is to move large traffic volumes focusing on mobility while providing some level of access to local development *(1)* as indicated in *A Policy on Geometric Design of Highways and Streets*, also known as the Green Book published by the American Association of State and Highway Transportation Officials (AASHTO). As peak traffic volumes increase along major non-freeway arterials, traffic signals are often implemented with complex signal phasing. As signal phases are added, such as for protected left-turn movements, green time is often reduced for main street through movements.

J. D. Reid and J. E. Hummer stated, "much of the vehicle delay incurred at conventional arterial intersections is caused by high left-turn demand," and that a quadrant roadway intersection can reduce intersection delays and travel times *(2, 3)*. In 2000, Reid stated that a quadrant roadway intersection, also commonly known as a Quadrant Left, "removes left-turn movements from the main arterial intersection through the use of an additional roadway in one intersection quadrant." Reid performed operational analysis comparing a conventional design to a Quadrant Left design using CORSIM microsimulations. This analysis concluded that despite the greater travel distance for left-turns redirected to the quadrant roadway, the Quadrant Left provided a 22 percent travel time reduction and significantly reduced average intersection delays (-215%) compared to a conventional all-movement signal *(3)*.

At the time of Reid's analysis in 2000, a Quadrant Left design had not yet been implemented *(3)*. In 2001, Reid and Hummer compared a variety of unconventional arterial intersection designs at seven North Carolina and Virginia intersections including a Quadrant Left, a superstreet, a continuous flow intersection, and others. This analysis concluded that the Quadrant Left provided the lowest average total time at four of the seven intersections. However, "intersection delay and travel time likely would not reach full potential until some time after the unconventional design is implemented and drivers gain familiarity with turning patterns" *(3)*.

2. SITE DESCRIPTION

2.1 Town of Huntersville

The Town of Huntersville is geographically located in the south central portion of North Carolina as shown in Figure 1. The southern town limit shares a border with the City of Charlotte, North Carolina's most populous city and a major United States financial center. Due to its proximity to Charlotte and its central location in the state, Huntersville has been and continues to be an attractive place to live and visit. Over the past 20 years, Huntersville has experienced nationally recognized population growth. In the early 1990's, Huntersville's population was estimated at 3,500 people; in 2014 the population is approaching 50,000 people and rapidly increasing. Due to the demands placed on the

existing transportation network by rapidly increasing local trips, coupled with trips associated with interstate (I-77) and intrastate travel, the efficiency of the existing transportation system is rapidly diminishing.

FIGURE 1 Huntersville, NC Vicinity

2.2 US 21 and NC 73 Intersection

The US 21 and NC 73 intersection is the subject intersection where a Quadrant Left was installed. Not until 1975 did these two roadways intersect at the existing location of the Quadrant Left intersection. In the 1950s, prior to the interstate highway system, US 21 was constructed as a major north-south highway in North Carolina. NC 73 was a state highway that ran east to west in a location about three miles north of its existing location. In the 1960s Duke Power constructed a dam on the Catawba River and flooded a large area of land just northwest of Huntersville and created Lake Norman. This massive lake, 33 miles long by 9 miles wide, removed many roadways (including NC 73) that served all directions of travel. Due to the construction of Lake Norman, NC 73 was eventually relocated to where it exists today. In 1975, Interstate 77 was constructed as a parallel facility to US 21, separated by only 600 feet. A map of the subject intersection is shown in Figure 2.

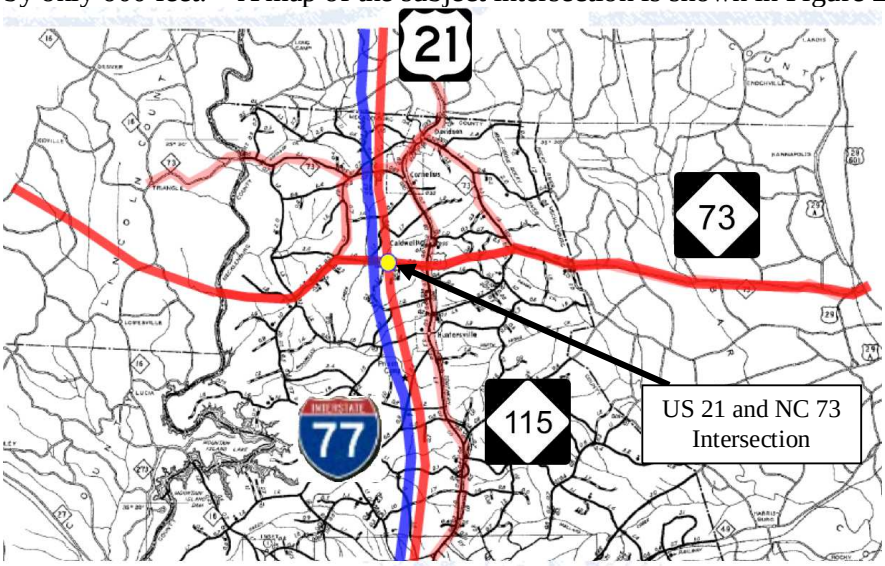

FIGURE 2 US 21 and NC 73 Intersection

2.3 I-77 and NC 73 Interchange

In 1993, the most significant event in the history of Huntersville occurred: the opening of the I-77 and NC 73 interchange. Due to the rapid growth brought on by the interchange and its close proximity to the US 21 and NC 73 intersection, major congestion began to occur in both peak and off-peak hours often resulting in major vehicle queuing and delays leading to failing levels of service for both the US 21 and NC 73 intersection and the I-77 and NC 73 interchange.

As with most interchange construction, commercial development is sure to follow. The I-77 and NC 73 interchange was no different. Due to the rapid development of a broad mix of uses including big box retail, highway commercial, office, and residential this area quickly became a destination location. Figure 3 shows the significant growth in the vicinity of the interchange. The aerial photo on the left is from 1993 before the I-77 interchange opened, and the aerial photo on the right is from 2007 before the Quadrant Left was installed.

FIGURE 3 I-77 and NC 73 Interchange Vicinity Growth

The demands became too great for the US 21 and NC 73 intersection to not only process intrastate traffic but also local destination trips. The intersection proximity to the interstate along with the development that occurred created a high demand for turning movements. This created a complex eight-phase traffic signal at this location. The signal phasing coupled with limited travel lanes resulted in frequent crashes, long delays and queues, which often resulted in back ups on to neighboring I-77.

3. STRATEGIES FOR IMPROVING OPERATIONS

In 2007, funding was made available to widen NC 73 and increase capacity at the US 21 intersection. During the planning process a traditional widening concept was created. This traditional widening would create dual left turn lanes, dual through lanes and right turn lanes on every approach at the intersection. On the surface, this concept seemed to solve the capacity issues at this intersection and on all four approaching legs. One issue still remained; the intersection would continue to operate as a complex, eight-phase traffic signal. Due to the time required to serve all traffic at an eight-phase signal and the close proximity to the I-77 off-ramp, vehicle queuing and a short merging distance for eastbound NC 73 to northbound US 21 continued to be an issue. The design of the traditional widening project of the intersection (long storage bays and tapers) resulted in blocking access into many of the businesses; this not only became contentious amongst business owners, but elected officials and transportation staff as well.

Due to the existing road network built over time in this area, it became apparent that Holly Point Drive, a public-maintained city street, could provide for an alternative design solution called a Quadrant Left intersection. Even though very few examples could be found where a Quadrant Left intersection had been utilized in a built upon urban environment, conceptually it seemed to solve some issues relating to intersection proximity, reduction in the number of signal phases at US 21 and NC 73, and access to businesses. The interchange and subject intersection vicinity is shown in Figure 4.

FIGURE 4 I-77 and NC 73 Interchange Vicinity

Before construction of the NC 73 project, very poor operations occurred near the US 21 and NC 73 intersection during peak travel hours, frequently causing stopped traffic to queue across multiple adjacent intersections and crashes. Stopped queues on NC 73 would often extend from US 21 down the I-77 northbound ramp and onto I-77 during peak hours.

Traffic analysis for the project recommended using the Quadrant Left design redirecting left turns onto US 21 via Holly Point Drive. This recommendation was based on analysis that indicated better long-term network operations with the Quadrant Left design compared to keeping all left-turns at the NC 73 and US 21 intersection.

Table 1 shows a summary of the NC 73 project capacity analysis performed in 2008 and 2009. Project design year 2030 analysis was based on roadway project forecast volumes that included expected growth. This analysis shows the observed poor operations in 2006 before the roadway project. If the roadway project were not constructed, 2030 peak hour delay would be expected to worsen to more than 7 minutes average delay per vehicle at the subject intersection.

If the NC 73 project included widening and maintained the all-movement eight-phase signal at NC 73 and US 21, 2030 peak hour delays were still expected to nearly double compared to 2006 analysis.

If the NC 73 project included widening and the Quadrant Left design, 2030 peak hour levels of service and delays were expected to be greatly improved compared to 2006

analysis, and network analysis indicated that the quadrant roadway should cause an 11% total network delay reduction. The US 21 intersection is also expected to experience about one-third of the average delays with the Quadrant Left compared to an all-movement signal. This significant improvement can be attributed to the reduction of signal phases at the US 21 intersection.

TABLE 1 US 21 and NC 73 Intersection Vicinity Capacity Analysis

Peak Hour Intersection Levels of Service and Delay (in seconds)	2006 Existing All-Movement US 21 Signal	2030 No-Build All-Movement US 21 Signal	2030 Build All-Movement US 21 Signal	2030 Build Quadrant Left
NC 73 and US 21	**F / 121**	**F / 467**	**F / 212**	E / 77
NC 73 and Holly Point Drive	**F / 108 ***	**F / ~ ***	C / 22 *	C / 22
US 21 and Holly Point Drive	D / 25 *	**F / ~ ***	C / 16 *	B / 18

* Intersection analyzed as unsignalized. Worst movement level of service and delay shown.
~ Delay too high for analysis software to calculate.

Additional project capacity analysis compared 2030 No Build and 2030 Build Quadrant Left total network delay, and this study indicated the project should cause a peak hour 46% total network delay reduction. Comparing the 2006 Existing and 2030 Build Quadrant Left total network delay, this study indicated the project would cause a 44% peak hour network delay reduction.

Resultantly, the capacity analysis recommended the Quadrant Left design due to considerable levels of service and delay improvements in the design year 2030 peak hours.

4. IMPLEMENTATION AND PUBLIC REACTIONS

The decision was made by federal, state, and local authorities to implement a Quadrant Left design with construction beginning in 2009 and construction completion in 2012.

The roadway was designed with no left turn movements from NC 73 onto US 21. Left turns remain from US 21 onto NC 73. Vehicles that want to make a left off NC 73 onto US 21 must use Holly Point Drive, which is the Quadrant Left roadway. Traffic signals were added at either end of Holly Point Drive to help traffic through the quadrant roadway intersections. Although this increased the number of traffic signals in this area, they are simpler signals utilizing fewer phases, and hence are greatly improving progression of traffic between signals.

The NC 73 and Holly Point Drive intersection is a signalized directional crossover. The directional crossover treatment for this signal allows for a two-phase signal and reduces the potential for crashes since side street left-turn and through movements are not permitted. This intersection also provides access into the neighboring shopping center.

The US 21 and Holly Point Drive intersection is a split-phased intersection with no protected left-turn phases off US 21. The split-phasing allows this intersection to operate as a three-phase signal. This signal is split-phased due to the allowance of a fourth leg to the intersection. This forth leg accesses a hotel, restaurants, and a bank; however full access was granted until such time traffic volumes become detrimental to the operations of the Quadrant Left roadway.

Traffic traveling on eastbound NC 73 to northbound US 21 will travel through the US 21 intersection and then turn right onto Holly Point Drive, and then turn right from Holly

Point Drive onto northbound US 21. Traffic traveling on westbound NC 73 to southbound US 21 will turn left onto Holly Point Drive before the US 21 intersection, and then turn left from Holly Point Drive onto southbound US 21. Overhead signs and advanced in-street pavement markings were deployed to help traffic navigate through the new traffic patterns via the quadrant roadway.

Figure 5 shows the new traffic patterns to redirect the NC 73 left turns via the quadrant roadway. This image was included on the Town of Huntersville website and in public outreach materials.

FIGURE 5 NC 73 and US 21 Quadrant Left Operation

Before construction began in 2009, area businesses and local officials expressed concerns about the Quadrant Left intersection and that roadway construction would impact the access and daily operations of their businesses. The contractor maintained driveway accesses throughout the entire roadway project and delays were minimized to the best of their ability. Very few complaints were registered from the business owners and patrons during the construction process. The major concerns of area business owners were the restriction of left-turn movements at the US 21 intersection.

Town and state officials expressed the importance of a strong public outreach and education process for the Quadrant Left operation due to the unusual maneuver the travelling public was being asked to make. Multiple media releases were presented to local newspapers, television stations, and websites to describe the Quadrant Left purpose and

redirected turning movements. A visualization of the Quadrant Left network is shown in Figure 6, and this visualization was shared with the public before implementation.

FIGURE 6 NC 73 and US 21 Quadrant Left Visualization

Soon after the media released project details, the public outcry began. Some emails and phone calls to public officials touted this Quadrant Left concept as the "stupidest" idea in history. One quote exclaimed, "how long will we live with this stupid idea before the great designers stand up and say they made a mistake and turn the intersection of highway 21 and 73 into a normal intersection?" Shortly after the opening of the Quadrant Left in 2012, the email and phone responses had a much different tone. Multiple citizens said, "the restriction of left turns makes no sense, but the intersection sure works 100 times better!" One of the most memorable public responses was, "just wanted to express to the town of Huntersville, that after a couple of months of withholding judgment, I am convinced that the new traffic patterns at exit 25 [I-77 and NC 73 interchange] have made a HUGE and positive difference in moving traffic through those intersections."

5. ACTUAL QUADRANT LEFT OPERATIONS

5.1 Field Observations Three Months After Opening

Three months after the opening of the Quadrant Left intersection both State and Town officials visited the site during the PM peak to observe overall operation of the intersection, vehicle queuing, signal efficiency, and motorist behavior. The most notable observation was the lack of vehicle queuing at any of the intersections and no spillback of traffic to the I-77

interchange. The intersections and approaches were nowhere near capacity, unlike before the construction project. Due to the unconstrained "feel", it was reported that intersection users felt as if the number of vehicles travelling through the intersection was cut in half. Several travel time runs concluded the signal system was timed appropriately and had excellent coordination. Even though the intersection was operating efficiently, officials observed several drivers violating the left turn restrictions and promptly being pulled over by Huntersville Police Department officers. It was also noticed that the travelling public were self-policing drivers attempting to make the restricted left turn by blowing their horns to keep them moving. Even though a vigorous public outreach and education campaign was attempted, it appeared drivers were tentative and seemed to not trust the signage and pavement markings guiding them to turn in a different direction than they had been used to for many years.

Area business owners continued to be concerned over the new traffic pattern and change in access in and around the intersection area. This was to be expected since patrons would not only have to navigate a new unconventional intersection, but also find new ways in and out of limited access driveways that were full access prior to the roadway project.

5.2 Operation Evaluation Two Years After Opening

An operational capacity analysis was performed in 2014 by the North Carolina Department of Transportation (NCDOT) Congestion Management Section for the US 21 and NC 73 intersection and vicinity. Capacity analysis was performed using current (2014) AM/PM peak hour volumes to compare traffic operations with the Quadrant Left in place (as the intersection operates presently in 2014) to how the intersection would operate if the Quadrant Left project had not been constructed (with or without NC 73 widening that occurred with the Quadrant Left project). Synchro/SimTraffic, version 7 was used for this analysis. Based on our assumptions and analysis, the US 21 and NC 73 intersection analysis level of service (LOS) results are shown in Table 2.

TABLE 2 US 21 and NC 73 Intersection Operational Evaluation (2014)

US 21 and NC 73 Intersection 2014 Peak Hour Intersection Analysis Comparisons	US 21 (North-South) and NC 73 (East-West) Intersection AM/PM Peak Hour (2014)		
	All-Movement Intersection Without NC 73 Widening	All-Movement Intersection With NC 73 Widening	Current Geometry: All-Movement Intersection With NC 73 Widening
	AM/PM	AM/PM	AM/PM
Overall Intersection LOS	**F/F**	D/D	C/C
Max. Intersection Movement Volume-to-Capacity Ratio	**1.58/1.57**	**0.97**/0.90	0.92/0.90
Intersection Delay in Seconds	**195/210**	45/47	26/25
Worst Movement LOS	**F/F**	**F/F**	D/D
Synchro/SimTraffic Max. Queuing★	**>1000'/>1000'**	**>1000'/>1000'**	587'/**838'**
I-77 NB Off-Ramp spill back to gore point?	**Yes**	**Yes**	No, but queue from US 21 beyond I-77 NB ramp on NC 73

★ Maximum queue of Synchro 95% maximum queuing and SimTraffic Maximum Queuing

If the Quadrant Left project was not constructed and the subject intersection remained all-movement, very poor traffic operations would occur during peak hours with frequent spillback across multiple adjacent intersections. Stopped queues on NC 73 would often extend from US 21 down the I-77 northbound ramp and onto I-77.

If the subject intersection reverted to all-movement with the constructed NC 73 widening (current geometry without Quadrant Left), the subject intersection would operate at overall LOS D, but near capacity with multiple movements operating at LOS F with some spillback. Stopped queues on NC 73 would still extend from US 21 down the I-77 northbound ramp to I-77.

As the intersection operates presently in 2014, the analysis indicates the subject intersection operates at overall LOS C with all movements operating acceptably at LOS D or better, and traffic queues do not extend down the I-77 northbound ramp onto I-77.

Travel time runs were performed in May 2014 as part of the routine signal timing for the NC 73 corridor. A review of the actual travel time runs in the AM peak hour on Eastbound NC 73 (from the I-77 Southbound ramp to Holly Point Drive) indicates vehicles averaged 90 seconds to travel approximately 2,350 feet between these points at an average travel speed of 24 miles per hour. A review of the AM peak hour "Current Geometry with Quadrant Left" analysis file indicates a travel time of 95 seconds and an average arterial speed of 17 miles per hour along this same approach and distance. Therefore, it can be assumed that the analysis is reasonably calibrated to field conditions and is slightly more conservative than actual field conditions.

The network analysis using 2014 counts indicates that the existing geometry with the Quadrant Left operates significantly better than the other geometric alternatives without the Quadrant Left. The existing geometry also maximizes the service life of roadway project improvements.

5.3 Safety Evaluation Two Years After Opening

A preliminary crash analysis was performed in 2014 by the NCDOT Traffic Safety Unit for the US 21 and NC 73 intersection vicinity, including intersections and public road sections impacted by the Quadrant Left project as shown in Figure 7.

FIGURE 7 US 21 and NC 73 Preliminary Safety Evaluation

An evaluation was performed of actual crashes that occurred in the three years before construction and the last 1.63 years after construction completion. Some segments and intersections had a slight decrease or increase in crashes. Preliminary data suggests that with the magnitude of changes occurring in this area due to the Quadrant Left countermeasure implementation, safety was not degraded. While there has been a small increase in crashes, it is relatively insignificant considering the development in the area. This preliminary review was not able to account for volumes changes, development changes, environmental changes, or weather changes.

Additional crash analysis is proposed once data is available for the full three years after implementation of the Quadrant Left.

5.4 Field Observation Two Years After Opening

Two years after implementation the intersection operates well. Overall operations along this section of NC 73 have greatly improved. Drivers seem to be used to the new patterns though

there are still some complaints and observations of illegal left turns from NC 73 directly onto US 21, despite signs and pavement markings. The issues today on NC 73 are with traffic signals west of the quadrant roadway. Prior to the project the congestion at US 21 metered traffic downstream on NC 73 across the interchange. Now that more traffic can be processed through US 21 more efficiently, complex-phased traffic signals downstream can serve as bottlenecks along NC 73 and operate over capacity during peak times of the day.

Most businesses have seemed to embrace the project and have realized the area is much easier to get to since congestion has diminished. Citizens who once avoided the area due to congestion now find their way to the area for shopping and entertainment.

An aerial of the existing Quadrant Left intersection and vicinity is shown in Figure 8.

FIGURE 8 US 21 and NC 73 Existing Quadrant Left Intersection

6. SUMMARY AND CONCLUSIONS

The close proximity of the subject intersection to the I-77 interchange, coupled with the need to process intrastate and local traffic, and the need to provide access to local businesses could not all be achieved with a traditional intersection. Not realizing the solution to the problem had already been solved with the construction of Holly Point Drive years earlier, the quest continued for a better answer. The research performed by J. D. Reid and J. E. Hummer on unconventional intersection designs led the design team to the discovery of the Quadrant Left intersection. Their research showed great promise in eliminating complex multi-phase signals by replacing them with several simple two phase signals connected by a Quadrant Roadway. Once project stakeholders realized the operational benefits of the Quadrant Left intersection, and since Holly Point Drive was practically built in the desired location for such a roadway, the intersection finally had a viable solution to meet operational demands.

One of the main challenges faced with implementing the Quadrant Left is its unconventional design. Due to the novelty of this intersection design, the project team decided to go above and beyond the typical signage and marking plan by introducing overhead signs and advanced in-street pavement markings. This decision proved to play a key role in the success of the intersection's functionality by providing heightened guidance and wayfinding. Because there were no physical barriers to prevent traffic from turning left from NC 73 these additional signs and markings helped to enforce the "no left turn" restriction as motorists could not claim they did not realize where they should have gone to access US 21 instead of making the left hand turn.

Initially many comments were received regarding how this design was going to make drivers travel further to access US 21. Most of these comments centered on how asinine it was to make motorists travel this extra distance and that the design just did not make sense. Although it is true that you must travel further to accomplish what was once just a single left turn, overall travel time has been reduced. Once the Quadrant Left was implemented citizens began to realize the extra distance did not necessarily translate to extra travel time and the design actually made sense and was good for the area.

One thing that proved very beneficial was the robust public outreach program that was key to making this project a success. By providing information on what is being built, how to navigate it, and why the design was chosen over other designs, the number of complaints received was reduced, even though many complaints were received during the time soon after the opening of the Quadrant Left.

Since the opening of the Quadrant Left, traffic delay and congestion on NC 73 has been greatly reduced in the area from I-77 and to the east. The greatly increased capacity in this area has brought to the forefront the capacity issues that NC 73 has from I-77 and to the west. While issues continue to exist with traffic turning left from NC 73 onto US 21, the amount of traffic making this illegal move seems to have reduced significantly. With the exception of some drivers that use adjacent parking lots to access US 21 instead of Holly Point Drive, most drivers appear to be using the Quadrant Left as it was intended to be used.

In the end the implementation of a Quadrant Left intersection at this location has been a success. The increases in LOS, reductions in delay and reductions in queuing support this and correlate to the benefits that Reid and Hummer's analysis indicated would be experienced. The results of this study indicate the Quadrant Left design is a viable alternative that should be considered to improve operations at similar congested intersections.

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