Project 2120 | April 2023

SJSU SAN JOSÉ STATE UNIVERSITY

MINETA TRANSPORTATION INSTITUTE

Modeling and Evaluating Alternatives to Enhance Access to an Airport and Meet Future Expansion Needs

Srinivas S. Pulugurtha, PhD, PE, FASCE Abimbola Ogungbire, MS Chirag Akbari, MTech

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Report 22-64

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April 2023

A publication of the
Mineta Transportation Institute
Created by Congress in 1991

College of Business
San José State University
San José, CA 95192-0219

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No 22-64	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Modeling and Evaluating Alternatives to Enhance Access to an Airport and Meet Future Expansion Needs		**5. Report Date** **6. Performing Organization Code**
7. Authors Srinivas S. Pulugurtha, https://orcid.org/0000-0001-7392-7227 Abimbola Ogungbire, https://orcid.org/0000-0002-1176-0422 Chirag Akbari, https://orcid.org/0000-0003-4983-5386		**8. Performing Organization Report** CA-MTI-2120
9. Performing Organization Name and Address Mineta Transportation Institute College of Business San José State University San José, CA 95192-0219		**10. Work Unit No.** **11. Contract or Grant No.** 69A3551747127
12. Sponsoring Agency Name and Address U.S. Department of Transportation Office of the Assistant Secretary for Research and Technology University Transportation Centers Program 1200 New Jersey Avenue, SE Washington, DC 20590		**13. Type of Report and Period Covered** **14. Sponsoring Agency Code**
15. Supplemental Notes		

16. Abstract

The continued growth of air travel calls for the incessant construction effort at many airports and their surroundings. Thus, there is a need to determine how airports can better manage existing infrastructure to accommodate this growth. This study, therefore, focuses on (1) investigating how changes in transportation infrastructure have affected travel time reliability (TTR) of the surrounding road network within the airport vicinity over time, and, (2) exploring selected unconventional intersection designs and proposing new inbound/outbound access routes from the nearby major roads to the airport. The efficiency of road networks that surrounds large airports is discussed using Charlotte Douglas International Airport (CLT) as the case study. Firstly, an assessment of how transportation projects impact link-level travel time reliability (TTR) was performed using historical data. Secondly, an assessment of how future transportation projects would affect the traffic in the airport vicinity was performed. A simulation network was developed using the Vissim software, where the peak-hour turning movement counts were used with the existing signal design to replicate and calibrate the base scenario. Unconventional intersection designs such as continuous flow intersections (CFI), mini-roundabouts, and restricted crossing U-turn (RCUT) intersections were considered along with selected bridge design options to determine the impact on TTR. The results were compared with the conventional signalized intersection design. The connectivity projects led to an increase in TTR measures at most of the links within its vicinity after the project's completion of the project. Similarly, parking areas exhibited the same characteristics, including those used by ridesharing companies. The simulation model showed that unconventional designs like RCUT and direct entry-exit ramps effectively reduced delay as well as the number of stops, increasing our understanding of how expansion projects affect TTR and potentially improving infrastructure optimization.

17. Key Words Airport, Expansion, Access, Operational Performance	**18. Distribution Statement** No restrictions. This document is available to the public through The National Technical Information Service, Springfield, VA 22161.		
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 77	**22. Price**

Form DOT F 1700.7 (8-72)

DOI: 10.31979/mti.2023.2120

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Acknowledgments

The authors sincerely thank the Charlotte Douglas International Airport (CLT) and Charlotte Department of Transportation (CDOT) for their help with the data required for this research. They also thank the staff of the North Carolina Department of Transportation (NCDOT) and the Regional Integrated Transportation Information System (RITIS) for their help with travel time data. The National Performance Management Research Data Set used in this research is based upon work supported by the Federal Highway Administration (FHWA) under contract number DTFH61-17-C-00003.

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Executive Summary

The continued growth of air travel warrants the constant expansion of airports to meet increasing demand. With a forward-thinking mindset and focus on continuous economic growth, airports such as Charlotte Douglas International Airport (CLT) sees themselves rising beyond the horizon. Thus, there is a need to determine how airports can better manage their existing infrastructure to accommodate growth. This study, therefore, focuses on:

i. investigating how changes in transportation infrastructure has affected the travel time reliability (TTR) of the surrounding road network within an airport's vicinity over time; and,

ii. exploring selected unconventional intersection designs and proposing new inbound/outbound access routes from the nearby major roads to the airport.

The study was performed using CLT as the case. The assessment of the impact of transportation projects on link-level TTR of the surrounding road network within the airport was done using travel time and road data. In addition, transportation projects within the airport vicinity were tracked using imagery data from Google Earth. Transportation projects considered for this analysis include road connectivity, parking lots, and staging grounds for ride-sharing vehicles. TTR measures, such as average travel time (ATT), planning time (PT), buffer time (BT), buffer time index (BTI), travel time index (TTI), and planning time index (PTI) were computed. A before-and-after study design was used to estimate the change in TTR measures within the airport's vicinity.

The impact of connectivity projects on TTR measures reduced with an increase in distance to the construction site. After the connectivity project implementation, the farther away from the airport, the less impact the new connectivity has on TTR. The percentage change in BT and BTI for the surrounding road links due to the selected connectivity project was similar; hence, one of these can be used for analysis and modeling. There is an expected increase in travel time on road links on Wilkinson Blvd due to the new project's construction. However, a substantial increase in TTR measures was not recorded until the implementation of Little Rock Rd's connectivity project. This road connectivity makes it easy for Wilkinson Blvd to attract traffic from I-85 directly to the airport. The effect of parking lots and staging areas for ride-sharing vehicles on TTR measures are similar, and the result shows a shift in demand on road links after the construction of both facilities. Most airports are adopting predictive analytics to optimize car park occupancy and maximize revenue. This research demonstrates that understanding how the demand and travel time changes will help airports such as CLT in planning and allotting resources.

Part of CLT's expansion plan is to add a taxiway which could affect and lead to the relocation of existing roads and intersections. Selected intersections (West Blvd, Byrum Dr, and Steele Creek Rd intersection, and Wilkinson Blvd and N Josh Birmingham Pkwy intersection), which could potentially be affected by the taxiway construction, are considered for the study. While conventional intersection designs would help manage high-traffic volumes, especially high left-turning volumes, unconventional intersections bring many advantages. They are effective in managing high-traffic volume and reducing delay and travel time compared to normal intersection designs and are also economical. For the purposes of the study, a calibrated road network was developed in the Vissim software, and unconventional intersection designs, such as continuous flow intersections (CFI), mini-roundabouts, and restricted crossing U-turn (RCUT) intersections, were designed for the West Blvd, Byrum Dr, and Steele Creek Rd intersection and were compared with the conventional intersection design. Similarly, intersection designs such as CFI and bridge designs such as entry-exit bridge and a direct ramp from I-85 were designed for the Wilkinson Blvd & N Josh Birmingham Pkwy intersection. The performance of these designs was recorded every five years, with a traffic increment rate of three percent.

1. Introduction

A large airport is often considered to be like a “city,” which includes the airport with its terminals, apron, runways, and parking decks, and on-airport businesses such as air cargo, logistics, offices, retail, and hotels. Airports play a vital role in enhancing the economic development of a region. The aviation sector accounted for more than 5.2 percent of the United States’ Gross Domestic Product (GDP) and generated $1.8 trillion in total economic activity (USDOT, 2020). The International Air Transport Association (IATA) estimated a 100 percent increase in passenger traffic by 2035 from the current level (IATA, 2022). At the same time, recent studies indicate that airport and airspace capacity already constrain flight operations at many large airports in the United States. To meet growing demand, airports such as Charlotte Douglas International airport (CLT) are developing plans to expand and increase airport capacity.

While economic development is the primary benefit of airport expansion, it is unclear how the airport’s increased passenger trips can be better managed using existing road infrastructure. The addition of runways/taxiways at the airport often leads to the relocation/full closure of some of the existing roads. This necessitates a reconfiguration of the traffic flow at the earliest phase of airport expansion and a formulation of better access management strategies to proactively improve the road’s operational performance. However, there is little research available on the surface traffic consequences of proposed airport expansion projects. There is a need to research, model, and evaluate the effect of airport expansion on traffic in its vicinity.

Large airports are major trip attractors and generators (Desai & Vala, 2017). The increase in the number of enplaning and deplaning passengers is expected to further increase the number of trips attracted to or generated by an airport. It is important to assess temporal variations in operational performance on existing roads around airports, understand what works (or may not), and develop plans to improve access to them. These plans may include direct and fast inbound/outbound access from/to the airport to/from major roads or other conventional or unconventional solutions (for example, intersection designs). There is a need to research traffic patterns over time and evaluate alternative strategies for fast inbound/outbound access from/to the airport.

Although the specific nature and scope of access-related problems vary from one large airport to another, the challenges associated with airport expansion and access concerns are relatively common to many. This research provides useful insights to airport managers/authorities by exploring data-driven methodologies, highlighting the inbound/outbound surface traffic access issues and evaluating alternatives for their effective management.

1.1 Research Objectives

The study's objectives are:

1. to analyze the spatial and temporal variations in travel times of major road links within the airport's vicinity,

2. to develop microscopic simulation models to assess the effectiveness of conventional and unconventional alternatives for relocating or closing the existing roads, and

3. to propose new inbound/outbound access routes from major roads near to the airport.

1.2 Report's Organization

The remainder of the report comprises three chapters. Chapter 2 describes travel time analysis by the type of transportation project that could potentially affect the travel time reliability (TTR) within the airport vicinity. Chapter 3 presents an analysis of different alternative intersection designs for improved operational performance and access to/from the airport. Chapter 4 provides a summary, conclusions, and the scope for future work.

1.3 Study's Contribution

The study helps airport planners assess temporal variations in operational performance on existing roads around the airport, understand what works (or may not work), and develop plans to improve access to the airport. Furthermore, the outcomes serve as guidance and recommendations for airport managers/authorities to identify the best alternative designs for enhancing fast inbound/outbound operations at the airport during and after new expansion activities. The simulation models help evaluate the operational performance of alternatives not only considering current conditions but also for future conditions with increased passenger traffic.

2. Impact of Transportation Projects on Link-Level Travel Time Reliability

2.1 Background

The primary goal of a large airport is regional economic vitality and connectivity to many cities and towns. Many large airports currently operate at or above capacity, generating high traffic volumes, resulting in congestion and declining TTR on road links in their vicinity. The endlessly growing number of passengers and airline operations associated with airport expansion also catalyze congestion and TTR (Perez, 2015). Hence, the need for airport expansion is accompanied by specific transportation projects such as road connectivity, development, and construction of parking lots, new transit lines, etc. to accommodate the growing demand. While air travelers often demand high reliability of travel time, the development of transportation infrastructure often results in an increase in travel time and delays along airport access roads when not balanced with growing demand (Knowles, 2006). It is still unclear how implementing these transportation projects at CLT affects the effectiveness of roads within its vicinity as the demand for transportation needs increases along the access roads.

CLT, in Charlotte, North Carolina, is currently a gateway for over 43 million air travelers per year. It is the sixth busiest airport in the United States, with significant growth in airline operations and passenger travel in the past twenty years. The airport recorded a spike of over 22 million total passengers from 2005 to 2019 (CLT, 2017). The continued growth is evidence that CLT is close to capacity, hence the need for the airport's expansion to meet the increasing demand. With a forward-thinking mindset and focus on continuous economic growth, airports such as CLT see themselves rising beyond the horizon. Although access problems among large airports could vary spatially, the TTR on road links providing access to the airport and challenges associated with many large airport expansion projects are relatively similar (Jose & Ram, 2019).

The efficiency of a road network surrounding a large airport such as CLT is affected by the TTR disrupted by transportation projects following an airport's expansion, and it often raises major concerns. This study seeks to address the following research questions and issues. First, how can we assess the impact of a transportation project on the TTR of surrounding road networks within an airport (Martinelli & Xu, 1996; Kim et al., 2001; Abdelmohsen & El-Rayes, 2016). In other words, how can we conveniently say how much the infrastructural changes within an airport vicinity affect the TTR of surrounding road links in the face of an ongoing expansion project? The second problem is the plausible difficulty in measuring the success of an infrastructural change within the airport's vicinity. While a few existing paradigms have studied the effect of construction on TTR (Kukkapalli & Pulugurtha, 2018), this study measured the effect of projects such as road connectivity, parking areas for ridesharing vehicles, and parking lots in CLT's vicinity.

2.2 Literature Review

This section discusses past literature on TTR and airport road networks. It also highlights gaps in the literature.

2.2.1 Travel Time Reliability (TTR) Definition

While "reliability" is a term often associated with a system and has been used in different contexts within various fields of engineering, it is usually used hand-in-hand with travel time in transportation. Because of its wide usage, there is no fixed definition of reliability in the context of travel time. Asakura & Kashiwadani (1991) define reliability as the degree to which a trip between a given origin and destination can be consistent in terms of travel time with a specific level of service (LOS). However, several recent studies have defined TTR as the variation in expected versus actual travel time (Kukkapalli & Pulugurtha, 2018; Dixit et al., 2019; Rilett et al., 2021). A higher variation value implies a reduced reliability value and vice versa.

Although these definitions are appropriate in the general context of travel time studies, they might not be suitable for networks surrounding airports. When air travelers are involved, other parameters include considerations such as the cost of missed flights. Reliability could be defined as the variation in the perceived time to get to an airport and the actual time to do so. This could vary from traveler to traveler and airport to airport (Jose & Ram, 2019).

2.2.2 Travel Time Reliability (TTR) Measures

Several measures were employed to assess the value of uncertainty or unreliability caused in a transportation system. Most of these measures were computed using travel time as the main factor. They include travel time index (TTI), buffer time (BT), buffer time index (BTI), planning time (PT) and planning time index (PTI) (FHWA, 2006). TTI is defined as the ratio of average travel time (ATT) to the free flow travel time (Kittleson et al., 2012). The BTI is the percentage of extra time travelers need to ensure on-time arrival. Lomax and Schrank (2002) further described the BTI as the ratio of the difference in the travel time of the most congested hour of a day and the ATT divided by the ATT. The PTI is the 95th percentile travel time ratio to the free flow travel time (Lyman & Bertini, 2007). PT is the travel time of the most congested hour of the day when considering vehicles leaving in the same one-hour period. These TTR measures have different uses depending on the type of traveler and trip. Some TTR measures seem more appropriate for specific travelers or purposes than others (Pulugurtha et al., 2015). For example, BTI is more beneficial for travelers in commercial vehicles and freight carriers, while PTI is more advantageous for personal vehicle users (Sekhar & Asakura, 2008).

2.2.3 Transportation Projects, Access Roads and Airport

Traffic flow defines an airport network's reliability. The more congestion, crashes, construction, and maintenance, the lower the network's reliability (Kukkapalli & Pulugurtha, 2021). The airport road network is comprised of different nodes and links (Mahmassani et al., 2013). The traffic characteristics at every intersection and road link vary with the time of day. The traffic condition of airport access roads is defined by several factors, including the peak hour determined by the flight schedule at the airport. Most domestic flights at large airports such as CLT are scheduled to operate in the daytime, while international flights operate at night. Therefore, nighttime traffic within airport access is slightly higher compared to other non-airport serving networks.

TTR is studied as a user perception measure, and changes that occur on the network are due to the user's choice and behavior. When it comes to getting to the airport on time, travelers visualize delays and wait times as perceived delays in catching their flights. Hoel and Shriner (1998) argued that travelers' perceptions of TTR is key in assessing travel time variation on airport access roads. Due to the uncertainty of travel time experienced in airport networks, air travelers often fear that they will miss their flight and thus have less TTR than other travelers.

Road connectivity within an airport's vicinity is often needed to accommodate a large airport's growth (Tveter, 2017). Over the years, the road network connectivity within CLT has changed significantly. While the concept of connectivity generally refers to how well streets are connected, the method of assessing connectivity vary significantly. One way is to focus on the number of intersections (Cervero & Ewing, 2010; Gladhill & Monsere, 2012; Hajrasouliha & Yin, 2015; Knight & Marshall, 2015; Wang et al., 2018), and several studies have measured the connectivity of road networks (Marshall & Garrick, 2011; Tal & Handy, 2012; Knight & Marshall, 2015). Some of these studies define road connectivity as the number of links connected to each node, i.e., the link-node ratio (Marshall & Garrick, 2011). The link represents the smallest element of a road network with homogeneous characteristics (Marshall & Garrick, 2011). Overall, not many researchers have examined the effect of connectivity within an airport from a TTR perspective.

2.2.4 Travel Time Reliability (TTR) Analysis

Recent advancements in modeling the effect of construction projects on travel time reliability have employed construction activity data and travel time data to readily access and validate the effect of construction on road links' TTR (Kukkapalli & Pulugurtha, 2018). They provided a concise discussion of the mechanism that allows the effect to be measured when the expansion or construction project is unmeasured. The literature highlight congestion, capacity, and traffic delay due to construction as major contributors to TTR (Martinelli & Xu, 1996; Kim et al., 2001; Yesantarao & Pulugurtha, 2017; Kukkapalli & Pulugurtha, 2018). During expansion projects, conditions might warrant the closure of specific lanes and the movement of heavy vehicles around the construction surroundings depending on the nature and intensity of work, all of which influence road capacity (Kim et al., 2001).

Demand for airport roads often outpaces available road capacity (Failla et al., 2014). This is no different for CLT as air traffic continues to increase traffic demand of the surrounding road network use. Airport users, unlike other road users, perceive the reliability of roads differently; they tend to place a slightly higher value on travel time (Jose and Ram, 2019). Therefore, the reliability of an airport access network might vary somewhat from the popular definition of travel time reliability, as can be found in Mahmassani et al. (2013) and Kukkapalli and Pulugurtha (2018). At large airports, the morning and evening peak times depend on flight schedules at the airport. While most local flights operate in the afternoon, the non-airport-related traffic interacts with airport traffic, creating a false peak time for the airport access network (Jose & Ram, 2019).

Previous studies have defined TTR as the consistency in measured travel time across different times of the day. Studies that researched the impact of congestion on TTR also investigated factors such as crashes, adverse weather conditions, and construction (Hojati et al., 2016; Mathew & Pulugurtha, 2021; Pulugurtha & Koilada, 2021; Mathew & Pulugurtha, 2022). In a bid to identify the factors responsible for the varying BTI, Hojati et al. (2016) studied the impact of traffic incidents on freeway TTR. They found incident type effects BTI. The variability consideration in travel time analysis includes times of day, day of the week, and month of the year (Pulugurtha & Koilada, 2021). Thus, seasonal trends in the dataset were also observed (Schroeder et al., 2013).

Mane & Pulugurtha (2020) argued that land use, in addition to network characteristics, effects link-level TTR; however, it varies by area type and speed limit of the road link (Kodupuganti & Pulugurtha, 2019; Mane & Pulugurtha, 2020). The impact of transportation projects on TTR was explored in a few studies. Transportation projects such as toll roads and light rail and roads have been examined against TTR of surrounding road links (Pulugurtha & Pasupuleti, 2010; Mathew et al., 2020; Mathew & Pulugurtha, 2020). Reza et al. used a time series approach to forecast short-term travel time variations due to an incident. A few other studies adopted this approach while evaluating the economic impact of TTR change in road user travel behavior (Duddu et al., 2018; Pulugurtha et al., 2019).

Simulation-based studies have also been explored for travel time and TTR related analyses. The number of signals negatively affects arterial street performance (Pulugurtha & Kodupuganti, 2017; Pulugurtha & Imran, 2021). Instantaneous data reveals that dynamic predictive routing provides better estimates than the advanced traveler information system. Kroes et al. (2018) proposed a practical framework to estimate the advantages of improving TTR, which has been replicated using Amsterdam Schiphol Airport data to quantify the benefits of improved travel time reliability.

Overall, while many studies focused on route-level or network-level analysis, not many studies have explored the link-level impact of a transportation project on TTR.

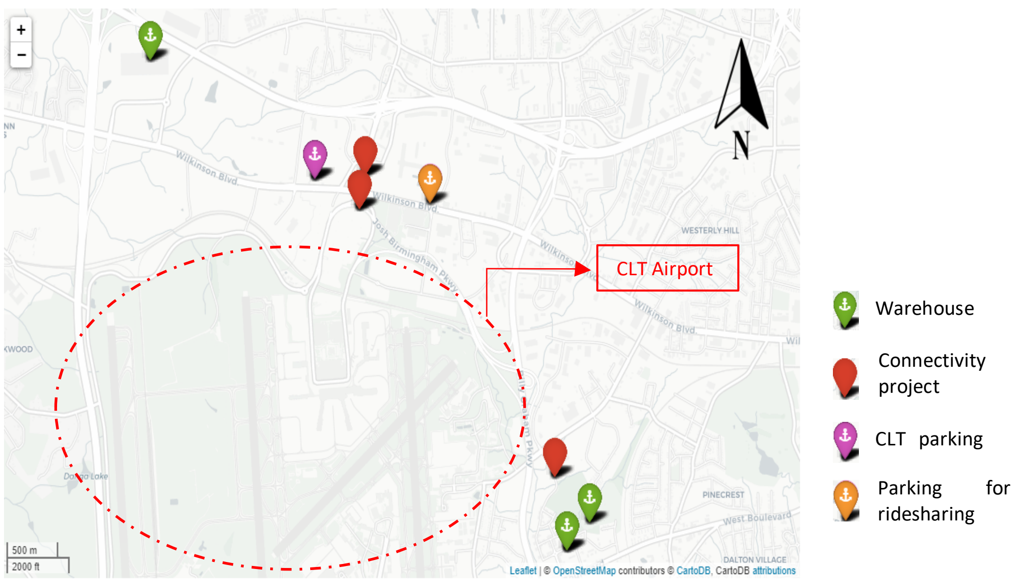
2.3 Methodology

This section details the study area, data collection procedure, data processing, and analysis.

2.3.1 Study Area and Method of Data Collection

CLT airport was considered for assessing the effect of airport expansion projects on the TTR of surrounding road links. Transportation projects within the airport's access were targeted for this analysis, as shown in Figure 1. Past studies have explored the effect of construction on travel time (Martinelli & Xu, 1996; Kim et al., 2001; Yesantarao & Pulugurtha, 2017; Kukkapalli & Pulugurtha, 2018; Kukkapalli & Pulugurtha, 2021) using different techniques. This study employed a similar data-driven approach to assess the effect of transportation projects on TTR.

Figure 1. Transportation Projects within the Airport Area in the Last Ten Years



Google Earth was used to investigate the location where the transportation projects have been carried out within the airport's vicinity in the last ten years. The changes within the airport's vicinity were streamlined to include road connectivity activities, parking and staging areas for ridesharing vehicles, and the introduction of a parking lot on Wilkinson Blvd

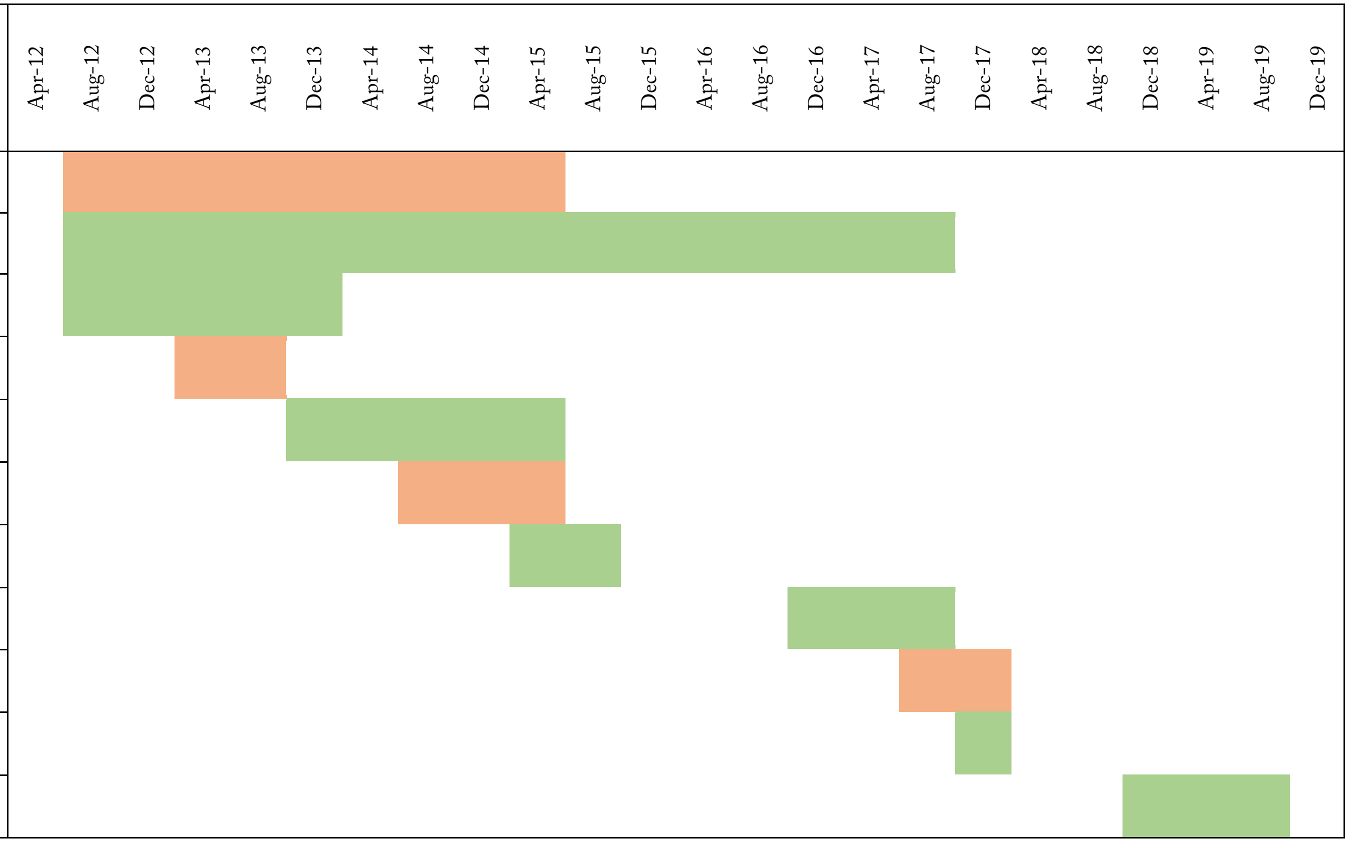
Combinations of image types, including street, satellite, and 3D, were employed to better view and capture the construction site (Pulugurtha et al., 2015). If construction activity is sighted within the airport's vicinity, a slider is used to view historical images of that area. The location is explored with satellite, street, and 3D images to better understand how that area has changed over time. A date range between the start and end of each activity is recorded, as shown in Table 1. Even though historical images for the last ten years were monitored, construction that started or spanned the

COVID-19 period was excluded from the analysis. Figure 1 shows the location of the infrastructural changes identified within the airport's vicinity.

The National Performance Management Research Data Set (NPMRDS) was obtained alongside the Highway Performance Monitoring System (HPMS) dataset. Data for selected activities were extracted using locations and time periods. For example, the location of "Activity 1" was identified in the HPMS shapefile using the Geographic Information System (GIS) tool, and road links within a 1-mile radius of the activity site were selected. The link identifiers were used to query travel time information in the NPMRDS database. The vehicle probe-based dataset contains information for all road links and their corresponding average speed, free flow speed, and travel time information.

Table 1 Activity Chart for the Construction Projects with the Airport from 2012 to 2019

Activity	Start Date	End Date	Duration (months)
#1	Aug-12	May-15	10
#2	Aug-12	Sep-17	33
#3	Aug-12	Feb-14	8
#4	Apr-13	Nov-13	19
#5	Nov-13	Jun-15	9
#6	Jul-14	May-15	61
#7	Mar-15	Sep-15	6
#8	Oct-16	Sep-17	7
#9	Jul-17	Mar-18	5
#10	Sep-17	Feb-18	26
#11	Nov-18	Aug-19	11



NB. Construction activities within the last 10 years were identified. Activities within periods of COVID-19 were excluded from the analysis. The visualization was made at an interval of 4 months. The orange bars signify selected projects analyzed in this study, and the green bars represent other construction projects identified within the airport vicinity. Activities description is as follows: Activity 1: Construction of inbound on Josh Birmingham to Billy Graham Pkwy; Activity 2: Re-Construction of Boulevard homes; Activity 3: Construction of Norfolk Southern Rail Service; Activity 4: Construction of the Lyft & Staging Area; Activity 5: Siting of CARO car rental on Wilkinson Blvd; Activity 6: Construction of N Josh Birmingham Pkwy to Little Rock Road; Activity 7: Construction of CPCC Harris Campus Dr to Connect Boulevard homes; Activity 8: South view recreation center; Activity 9: CLT Airport Parking lot on Wilkinson Blvd; Activity 10: Expansion of the Lyft & Uber Staging Area; Activity 11: Construction of Amazon CLT4.

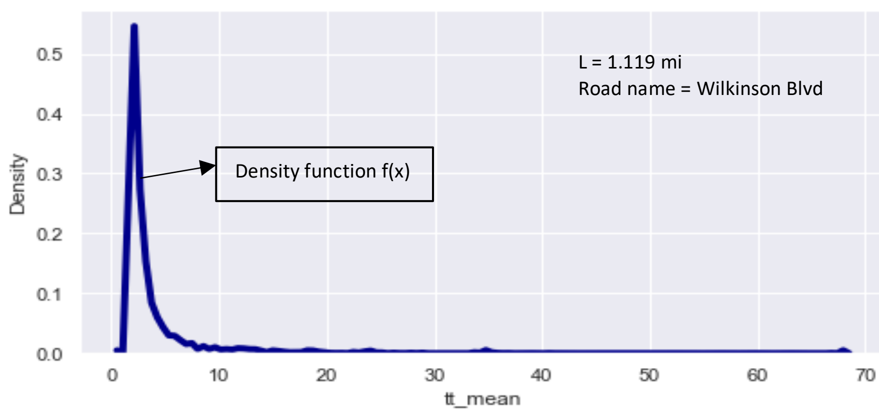
2.3.2 Processing Raw Travel Time Data

Travel time data were collected at the road link level at 5-minute intervals. The data was aggregated for vehicles traveling in the same 1-hour interval. The data was examined at 1-hour intervals to generate nth-percentile travel time for the different 1-hour intervals. The density function f(x) represents the probability distribution of ATT on road links. The nth-percentile travel time on the road link is represented as:

$$n_{th}\, perc\ tt \ = \ Pr(x \ < \ k)$$

i.e., the probability of x being less than a number k is equal to n percent for n = (5 to 95 at an interval of 5). A database with average travel times, minimum travel times, maximum travel times, and 5th to 95th percentile travel times at 5 percent intervals was compiled (Wakabayashi & Matsumoto, 2012; Sisiopiku & Islam, 2012).

Figure 2. Density Plot of Travel Time on a Link of Wilkinson Blvd



2.3.3 Outlier Strategy

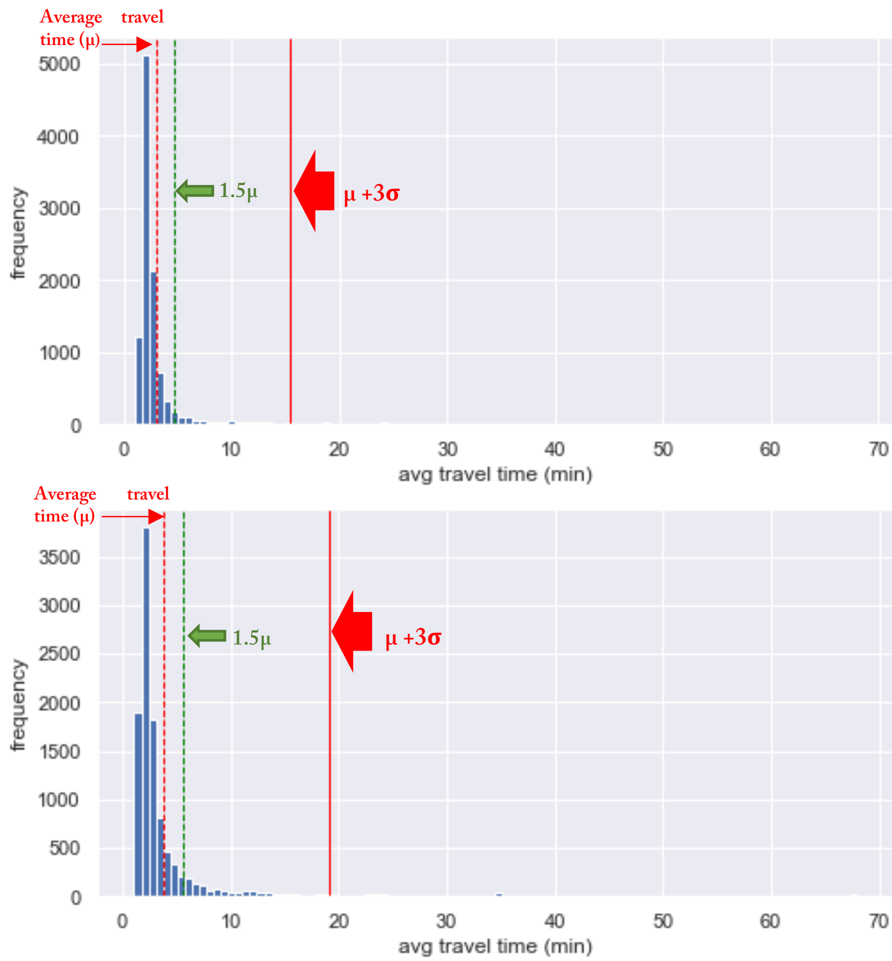
Extreme events exist in the data, as shown in Figure 2. Such events could potentially affect the ATT and must be excluded. However, it is unclear how the boundary of exclusion for extreme travel time events can be defined. Visual inspection of travel time distribution was employed on each road link; Figure 3 shows examples of two road links being visually inspected. A boundary of three standard deviations above the ATT was a reasonable boundary for most road links. However, there was an alternative criterion for low-volume road links; the boundary is 1.5 times the ATT. Therefore, a reasonable boundary was defined, and the event considered is expressed as:

$$tt_{i,j,k} \ < \ max\{[\mu(tt_{j,k}) \ + \ 3s.d_{i,j}], [1.5\mu(tt_{j,k})]\}$$

where $tt_{i,j,k}$ is the travel time on day *i*, road link *j* and in the same 1-hour time interval *k*. $\mu(tt_{j,k})$ is the ATT of link *j* for vehicles that traveled in the same 1-hour time interval *k*, and $s.d_{i,j}$ is the standard deviation of travel time on road link j for vehicles that traveled in the same 1-hour time interval k. For each 1-hour period, there is an exclusion of events outside the defined boundary.

As a result, the average standard deviation was cut down by 30 percent. Holidays were also excluded since only a few vehicles will be moving on holidays (Alemazkoor et al., 2015).

Figure 3. Travel Time Distribution for Two Road Links with the Defined Boundary



2.3.4 Estimating Travel Time Reliability (TTR) Measures

PT, PTI, TTI, BT, and BTI were computed for each road link, each day of the year, and each hour before, during, and after each construction activity. The computed reliability measures are shown in Table 2. Consequently, as also listed in Table 2, reliability measures were computed for each period of the day (morning peak, evening peak, and mid-day period). To explain the variation between a traveler's expected travel time and actual travel time based on days of the week variation, an approximate ATT was taken on the same day of the week three months before, during, and after the construction. For example, an approximate value of expected travel time on Wednesdays before the start of construction on April 1, 2013 is the ATT on the 2nd, 9th, 16th, 23rd, and 30th of January; the 6th, 13th, 20th, 27th of February; and the 6th, 13th, 20th, and 27th of March. This moving average accounts for both days of the week variations and seasonal variations in the ATT. This was done for every road link within a 1-mile radius of the construction site.

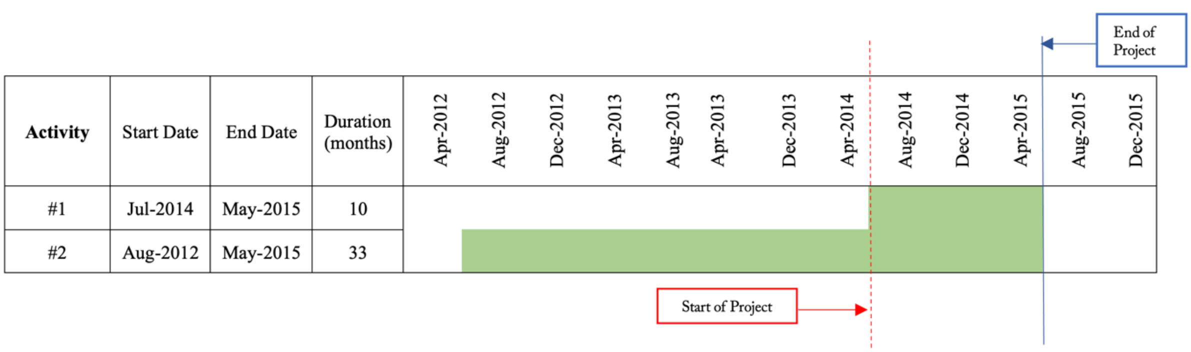
Table 2. Travel Time Reliability (TTR) Measures Computed

Measure	Definition	Equation
Average Travel Time (ATT)	This is obtained by dividing the sum of travel time on each road link within the hour by the number of observations.	$ATT = \frac{Sum(TT_{i,j})}{N_{i,j}}$
Planning Time (PT)	This is the travel time of the most congested day.	$PT = 95th\ Percentile\ TT$
Travel Time Index (TTI)	This represents the time required to arrive on time 95% of the time.	$TTI = \frac{Average\ TT}{Free\ Flow\ TT}$
Planning Time Index (PTI)	This represents the average extra time needed to travel during peak hour compared to no-traffic condition.	$PTI = \frac{95th\ Percentile\ TT}{Free\ FlowTT}$
Buffer Time (BT)	This represents the additional time above the ATT the traveler needs to consider to be on time 95% of the time.	$BT = 95th\ Percentile\ TT - Average\ TT$
Buffer Time Index (BTI)	This represent the percentage of extra time above the ATT the traveler needs to consider to be on time 95% of the time.	$BTI = \frac{BT}{Average\ TT} * 100$

Note: i represents road link from i = 1 to n and j represent the hour of the day from j = 0 to j = 23.

A before-and-after study design was employed to assess if there is an improvement in travel time measure of the before, during, and after phases of each transportation project. Road links within a one-mile radius of a transportation project were analyzed for a change in travel time measure during and after the completion of the project. Table 3 describes the study's design.

Table 3. Study Design for Before-After Analysis



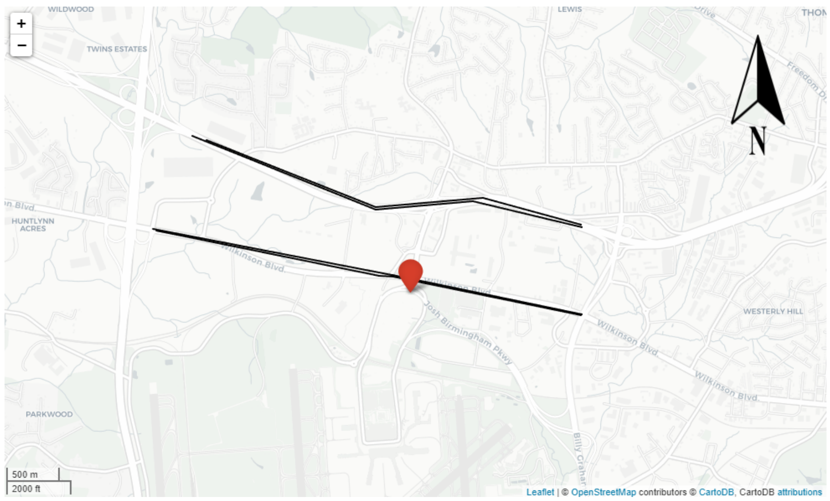
2.4 Results

This section describes the results from evaluating the impact of transportation projects on TTR measures of the road links within an airport's vicinity. Here, road connectivity projects, expansion of airport parking lot, staging, and parking grounds for ride-sharing vehicles are of interest.

2.4.1 Josh Birmingham Pkwy Road Connectivity

The CLT constructed a new entrance connecting the Little Rock Rd exit off of I-85 to N Josh Birmingham Pkwy This new entrance and exit road provide more options for airport users to connect to Wilkinson Blvd, I-85, and I-77. Figure 4 shows the location of the connectivity project and the selected road links within a one-mile radius of the construction project.

Figure 4. Location of the Josh Birmingham Pkwy Road Connectivity Project and the Selected Road Links for Analysis



Exploratory data analytics were carried out to visualize the trend of random road links within the vicinity of the Josh Birmingham Pkwy road connectivity project. Due to the length of the project, six months of travel time data before and after the Josh Birmingham Pkwy road connectivity project was collected for visual inspection to understand the pattern and check for the presence of any external validity threat in the data. The PT, as shown in Figure 5, represents the daily travel time of the most congested hour for a weekday—Friday. These distributions compare the PT on a weekday and a weekend before, during, and after connectivity project. There is clear evidence of a change in the level between the PT of a weekday before and after the connectivity project. However, the PT of a weekend remained stable, and there is no clear change between the before and after periods. In addition, there was a gradual increase in PT between January and July 2014 after which there is a decline in PT during the construction. This pattern, however, is absent for weekend PT implying that the travel time of the most congested hour increased during the construction between January and July 2014.

Figure 5. PT Before, During, and After the Josh Birmingham Pkwy Road Connectivity Project on Road Link I85S2 on a Weekday vs. Weekend

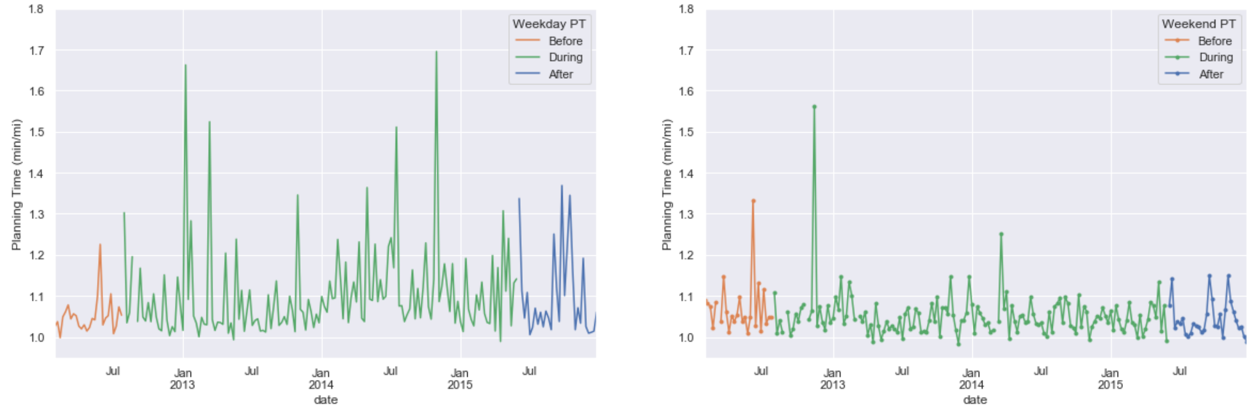


Figure 6 shows the distribution of ATT before, during, and after the Josh Birmingham Pkwy road connectivity project on I-85S for a weekday versus weekend. Unlike the pattern observed in the PT during the weekday, the weekday pattern of ATT seems to be slightly different. In January 2014, there was sudden increase in ATT followed by a gradual decrease in ATT until July 2014. A more stable variation of ATT is observed on road link I85S2 during the weekend when compared to the weekday variation.

Figure 6. ATT Before, During and After the Josh Birmingham Pkwy Road Connectivity Project on Road Link I85S2 on a Weekend vs. Weekend

Table 4 summarizes TTR measures before, during, and after the Josh Birmingham Pkwy road connectivity project. Ten road links within a one-mile radius of the Josh Birmingham Pkwy road connectivity project were selected. Variations in the ATT on the road links within the vicinity of Josh Birmingham Pkwy before, during, and after its construction can be observed. To elaborate on the interpretation of Table 4, an example road link I85N1 is used. The ATT of 0.978 minutes/mile increased to 0.983 minutes/mile during the construction but decreased to 1.109 minutes/mile after the connectivity project is completed. The PTI (1.146) decreased during the connectivity project construction but increased after its completion. From the table, WKB1 has the highest PTI of 5.388 during the connectivity project construction, meaning that air travelers will spend almost five and a half times longer traveling as the free-flow travel time on this link to get to the airport.

Table 4. TTR Measures on Road Links Surrounding the Josh Birmingham Pkwy Road Connectivity Project

Link ID	Length	Stage	ATT	PT	BT	BTI	TTI	PTI
I85N1	1.15	Before	0.978	1.070	0.092	9.380	1.048	1.146
		During	0.983	1.070	0.087	8.894	1.048	1.141
		After	0.969	1.060	0.092	9.461	1.050	1.149
I85N2	0.657	Before	1.049	1.157	0.108	10.278	1.054	1.163
		During	1.056	1.164	0.109	10.304	1.053	1.162
		After	1.042	1.157	0.114	10.976	1.056	1.172
WKB1	1.119	During	2.834	7.897	5.063	178.669	1.934	5.388
		After	2.802	7.587	4.785	170.809	1.751	4.743
WKB2	1.415	During	1.959	3.943	1.984	101.308	1.467	2.952
		After	1.976	3.745	1.769	89.541	1.425	2.701
I85S1	0.588	Before	1.143	1.288	0.144	12.611	1.059	1.192
		During	1.145	1.273	0.127	11.108	1.056	1.173
		After	1.121	1.229	0.108	9.605	1.049	1.150
WKB3	1.114	During	2.193	4.363	2.170	98.956	1.499	2.982
		After	2.487	5.557	3.069	123.411	1.548	3.458
WKB4	1.327	During	2.159	4.297	2.139	99.066	1.474	2.933
		After	1.898	3.037	1.139	59.973	1.300	2.080
I85S2	1.059	Before	0.985	1.062	0.077	7.803	1.043	1.125
		During	0.990	1.076	0.087	8.769	1.048	1.140
		After	0.979	1.061	0.082	8.396	1.048	1.136
I85S3	0.625	Before	0.889	1.000	0.111	12.428	1.060	1.192
		During	0.891	0.990	0.099	11.078	1.056	1.173
		After	0.872	0.956	0.084	9.601	1.050	1.151
I85N3	0.561	Before	0.881	0.967	0.086	9.775	1.050	1.152
		During	0.886	0.969	0.083	9.346	1.050	1.148
		After	0.873	0.957	0.084	9.593	1.051	1.152

Note: ATT, PT, and BT values are given in minutes/mile and the lengths of links are provided in miles.

The change in TTR measures during and after the connectivity project compared to before the connectivity project are presented in Table 5. There are missing data on Wilkinson Blvd before the connectivity project, which explains why they have no value for the before-during and before-after comparison. There is a reduction in all TTR measures on link I85S1 during and after the project. While there was a reduction in the ATT of all links, other TTR measures seem to have increased. There is a decrease in BT on most road links, and an increase was observed in TTI on most road links. In order to see a clear pattern of the changes after the connectivity project, a chart showing the percentage change in TTR measures was made, as shown in Figure 7.

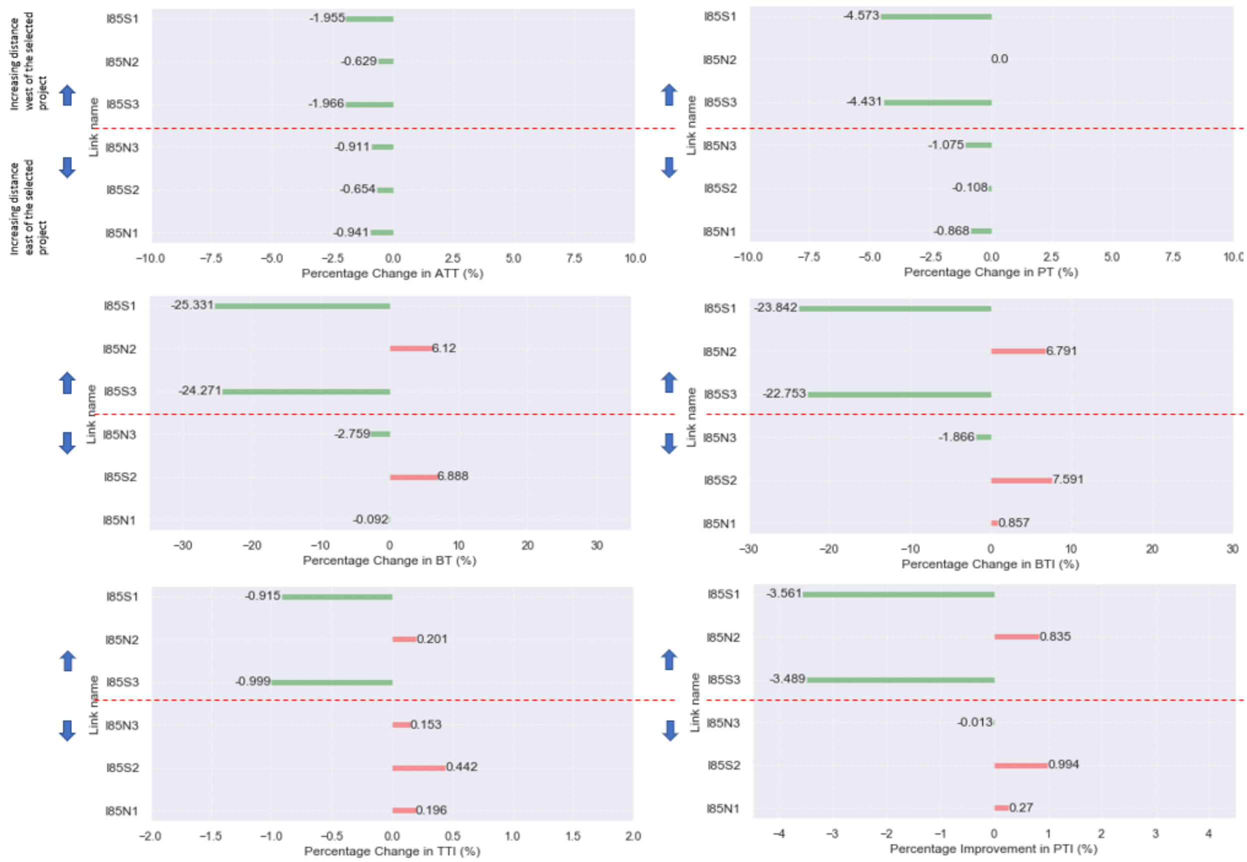
Table 5. Comparison of TTR Measure for Before-During and Before-After Josh Birmingham Pkwy Road Connectivity Project

Link ID	ATT		PT		BT		BTI		TTI		BTI	
	Before – During	Before –After	Before–During	Before –After	Before–During	Before–After	Before–During	Before–After	Before–During	Before–After	Before–During	Befor e–After
I85N1	0.514	-0.941	0.068	-0.868	-4.691	-0.092	-5.178	0.857	0.048	0.196	-0.396	0.270
I85N2	0.634	-0.629	0.658	0.0000	0.887	6.120	0.251	6.791	-0.066	0.201	-0.043	0.835
WKB1	-	-	-	-	-	-	-	-	-	-	-	-
WKB2	-	-	-	-	-	-	-	-	-	-	-	-
I85S1	0.176	-1.955	-1.161	-4.573	-11.765	-25.331	-11.921	-23.842	-0.295	-0.915	-1.626	-3.561
WKB3	-	-	-	-	-	-	-	-	-	-	-	-
WKB4	-	-	-	-	-	-	-	-	-	-	-	-
I85S2	0.474	-0.654	1.374	-0.108	12.910	6.888	12.377	7.591	0.474	0.442	1.374	0.994
I85S3	0.195	-1.966	-1.009	-4.431	-10.692	-24.271	-10.866	-22.753	-0.373	-0.999	-1.569	-3.489
I85N3	0.547	-0.911	0.154	-1.075	-3.866	-2.759	-4.389	-1.866	0.016	0.153	-0.375	-0.013

Figure 7 shows the road links in order of increasing distance from the redline to the west and east of the Josh Birmingham Pkwy road connectivity project. The TTR measures within the construction are shown for different road links. For the Josh Birmingham Pkwy road connectivity project, the travel time information for all road links on Wilkinson Blvd before the start of the project was missing. Here, the road links with a red color show an increase in TTR measures, while the green color indicates a reduction in TTR measures after the Josh Birmingham Pkwy road connectivity project. The ATT reduced on all links on I-85 (Figure 5). Although the change in ATT is not considerably high for most links, it is relatively high for some when compared with the ATT values obtainable on these links. The PT on all road links is reduced as well. A reduction of up to 4 percent of PT was achieved on a few links on 1-85S. While most road links on I-85S show considerable reduction in most TTR measures, there is an increase in the TTR measures on most road links on I-85N. The change pattern in BT and BTI across all links are similar and thus can be used interchangeably in measuring road connectivity's impact. While the change pattern in TTI and PTI looks similar, the figure shows different percentage changes in these measures. Road link I85S3 saw a reduction in TTR given the connectivity of Josh Birmingham Pkwy

While many of the road links are on I-85, it would be interesting to see how the links on Wilkinson Blvd after the project compare with those before. The assessment of Little Rock Rd's connectivity provides insights on how the traffic changed due to the new entrance's construction.

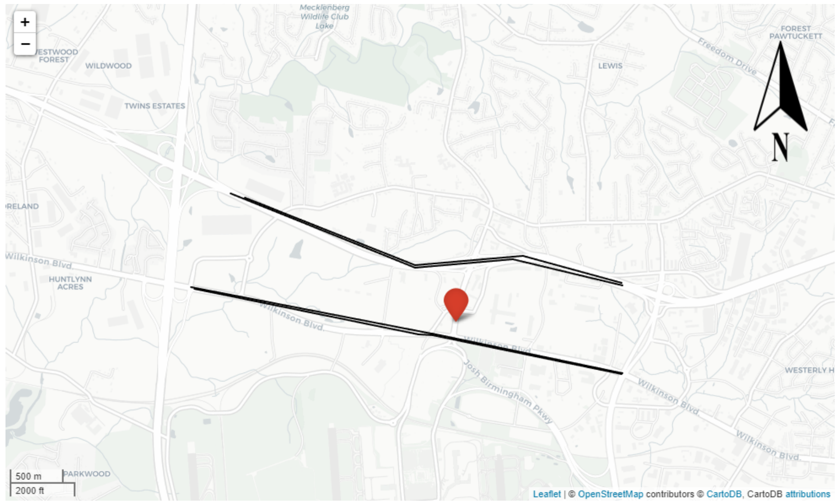
Figure 7. Change in TTR Measure of Road Links After the Josh Birmingham Pkwy Road Connectivity Project



2.4.2 Little Rock Rd Connectivity

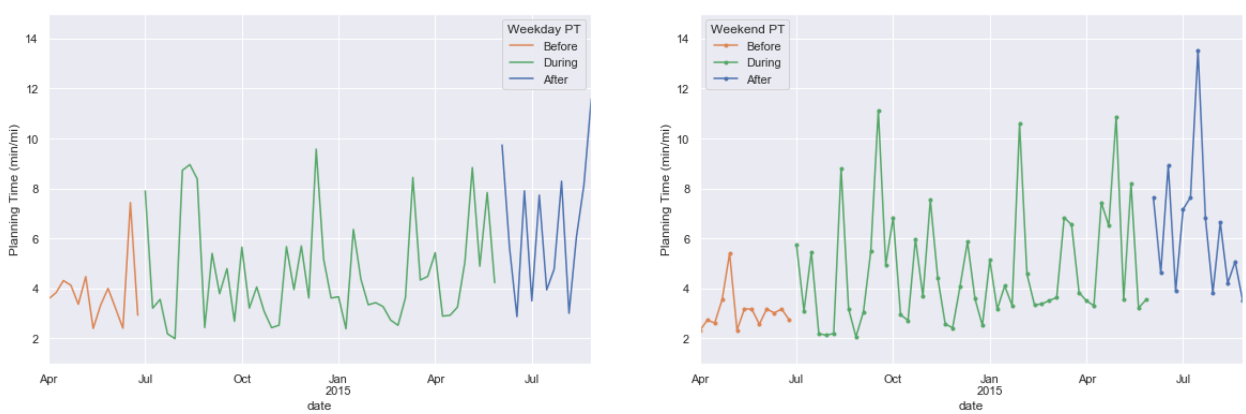
One part of the new airport entrance project was to connect Little Rock Rd to Josh Birmingham Pkwy This connectivity was designed to create easier access to the airport from I-85. After this connectivity, the usage of the Wilkinson Blvd/Josh Birmingham Pkwy intersection was expected to increase because airport users could connect to the entrance through Little Rock Rd from I-85. Figure 8 shows the location of the project and the surrounding road network within a one-mile radius of the construction.

Figure 8. Location of Little Rock Rd Connectivity Project around the Airport Access



The data were explored for different road links to observe the travel time distribution between April to June 2013; July 2014 to May 2015; and June 2015 to August 2015 before, during, and after the road connectivity project periods. Figure 9 compares the PT on road link WKB3 on a weekday with the weekend. The distribution reflects the road connectivity project's before, during, and after periods for weekdays and weekends. An inconsistent variation of the PT after the project might be a result of the variation of the road's use. Perhaps, not many travelers are aware of the new connectivity of Little Rock Rd The overall trend for WKB3 shows an increase in PT over time for both the weekday and weekend. However, there was a fast decrease in PT during the weekend after the project was completed.

Figure 9. PT Before, During, and After Little Rock Rd Connectivity Project on Road Link WKB3 for a Weekday vs. Weekday



Similar to what was observed on WKB3 for PT, Figure 10 shows that ATT increased from April, before the start of the project, until after the Little Rock Rd connectivity project's completion. While there was an overall increase in ATT after the project was completed compared to before, the increase was higher during the weekend. The ATT trend for both the weekend and weekday increased from April, before the start of the connectivity project until after the Little Rock Rd connectivity project's completion resulting in an increase in travel time during and after the project on this road link. This might be the result of the proximity of the road link to the airport's entrance. Inspection of the trends also showed the introduction of a signal light at the intersection leading to the airport's entrance which might result in a delay on the road links after and during the connectivity project in addition to the effect of the work zone during the construction.

Figure 10. ATT Before, During, and After the Little Rock Rd Connectivity Project on Road Link WKB3 for a Weekday vs. Weekend

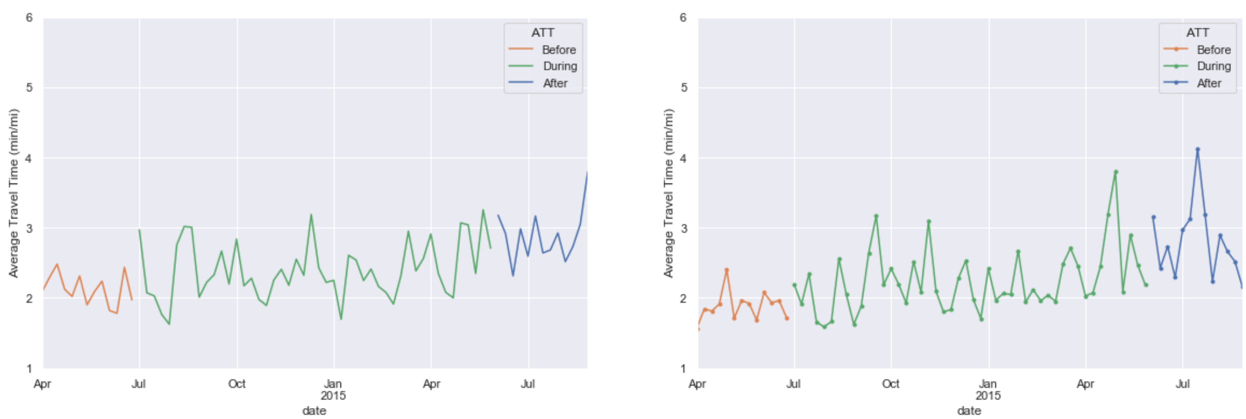


Table 6 shows the TTR measures of road links before, during, and after the Little Rock Rd connectivity project. Ten road links with different lengths were examined. Variations in the ATT on the road links within the vicinity of Little Rock Rd were observed before, during, and after construction. To elaborate on Table 6, an example road link I85N1 was used. The ATT (0.988 minutes/mile before the connectivity of Little Rock Rd) decreased during and after the connectivity project's completion to 0.976 minutes/mile and 0.965 minutes/mile, respectively. The PT = 1.071 minutes on link I85N1 before the connectivity project. An additional 0.083 minutes over the ATT was required for the unexpected delay on the road link. This implies that travelers should plan an extra 8.4 percent time beyond the ATT, equivalent to the BT of the road link.

Table 7 shows the percentage change in TTR measures during and after the connectivity compared to the period before. The negative numbers indicate a decrease in TTR measures compared to the before period while the positive numbers indicate an increase. For links I85N1 and I85N2, while it seems as if there is an improvement in ATT, the BT, BTI, TTI, and PTI increased compared to the before scenario. There was a higher increment in all TTR measures on link WKB3 when compared to the change experienced on other links. The BT after the construction on link WKB4 was considerably higher (153.8%) than in the before period. While there was a change in the TTR measure of the before period compared to the after and during periods, the pattern varied across different reliability measures. It should be noted that there was an increase in BT, BTI, and PTI for most of the road links during the implementation of the project. However, some road links experienced a reduction in travel time after the connectivity project's completion.

Table 6. TTR Measures on Road Links Surrounding Little Rock Rd Connectivity Project

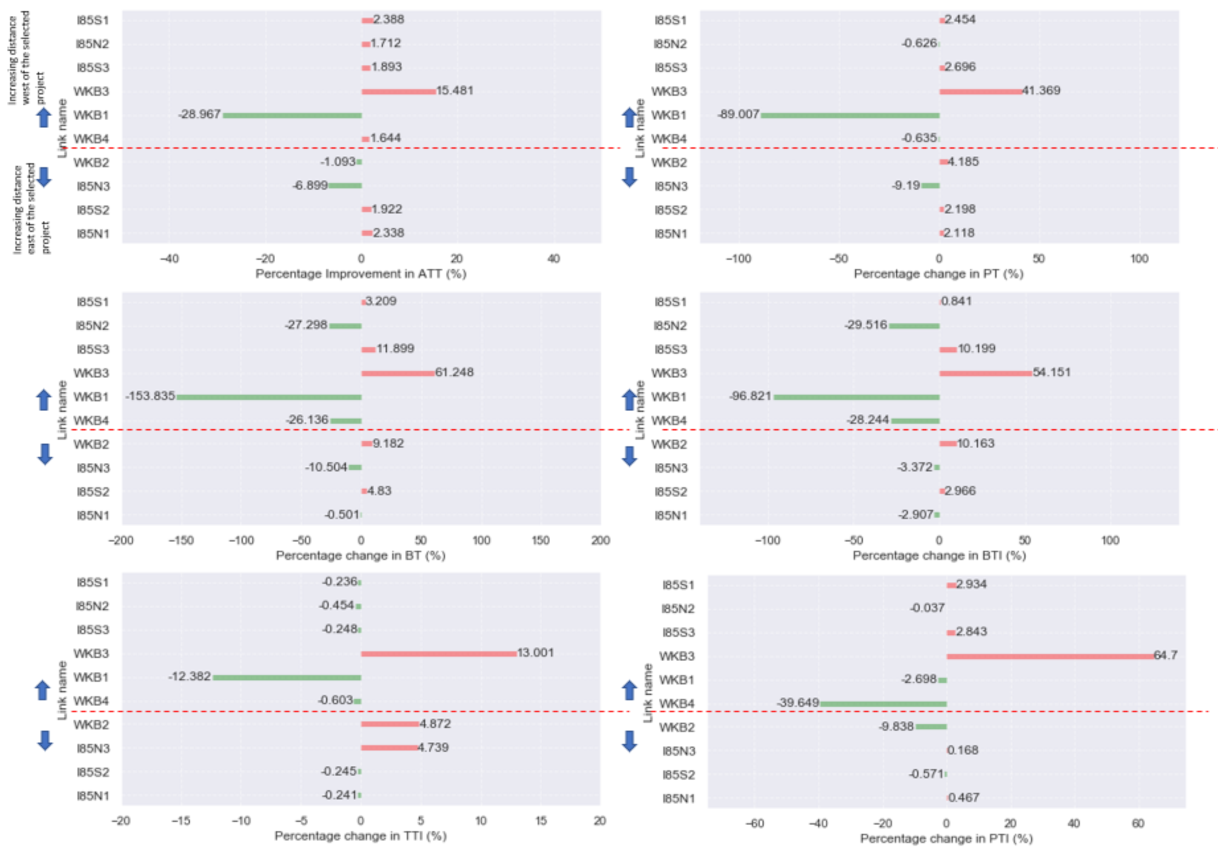
Link ID	Length	Stage	Average TT	PT	BT	BTI	TTI	PTI
I85N1	1.150	Before	0.988	1.071	0.083	8.410	1.044	1.132
		During	0.976	1.067	0.090	9.244	1.049	1.146
		After	0.965	1.048	0.083	8.654	1.047	1.137
I85N2	0.657	Before	1.056	1.167	0.111	10.483	1.050	1.160
		During	1.051	1.165	0.114	10.885	1.053	1.168
		After	1.036	1.141	0.105	10.172	1.052	1.160
WKB1	1.119	Before	2.766	7.587	4.821	174.261	1.933	5.300
		During	2.914	8.460	5.547	190.369	1.918	5.569
		After	2.957	8.284	5.327	180.138	1.841	5.157
WKB2	1.415	Before	2.002	4.116	2.114	105.620	1.520	3.126
		During	2.011	4.257	2.245	111.633	1.498	3.170
		After	2.024	3.944	1.920	94.885	1.446	2.818
I85S1	0.588	Before	1.144	1.246	0.102	8.936	1.047	1.141
		During	1.141	1.276	0.135	11.835	1.059	1.184
		After	1.125	1.254	0.129	11.459	1.054	1.174
WKB3	1.114	Before	2.104	4.052	1.948	92.613	1.465	2.821
		During	2.343	5.089	2.746	117.238	1.572	3.415
		After	2.713	7.658	4.945	182.283	1.646	4.646
WKB4	1.327	Before	2.261	5.205	2.945	130.232	1.508	3.471
		During	2.223	4.496	2.273	102.240	1.492	3.017
		After	1.911	3.052	1.141	59.710	1.312	2.095
I85S2	1.059	Before	0.995	1.081	0.087	8.718	1.046	1.137
		During	0.989	1.076	0.087	8.815	1.054	1.147
		After	0.976	1.052	0.076	7.829	1.049	1.131
I85S3	0.625	Before	0.890	0.968	0.078	8.766	1.050	1.142
		During	0.887	0.992	0.105	11.813	1.060	1.185
		After	0.875	0.974	0.099	11.354	1.054	1.174
I85N3	0.561	Before	0.890	0.969	0.078	8.794	1.046	1.138
		During	0.880	0.963	0.083	9.393	1.050	1.149
		After	0.869	0.945	0.076	8.720	1.048	1.140

Table 7. Comparison of TTR Measure for Before-During and Before-After Little Rock Rd Connectivity Project

Link ID	Average ATT %		PT %		BT %		BTI %		TTI %		PTI %	
	Before – During	Before –After	Before – During	Before –After	Before – During	Before –After	Before – During	Before –After	Before– During	Before –After	Before – During	Before –After
I85N1	-1.150	-2.338	-0.389	-2.118	8.660	0.501	9.924	2.907	0.513	0.241	1.287	0.467
I85N2	-0.507	-1.922	-0.145	-2.198	3.310	-4.830	3.837	-2.966	0.327	0.245	0.692	-0.037
WKB1	5.324	6.899	11.510	9.190	15.060	10.504	9.243	3.372	-0.758	-4.739	5.071	-2.698
WKB2	0.481	1.093	3.419	-4.185	6.201	-9.182	5.693	-10.163	-1.466	-4.872	1.415	-9.838
I85S1	-0.266	-1.644	2.389	0.635	32.101	26.136	32.453	28.244	1.098	0.603	3.789	2.934
WKB3	11.364	28.967	25.602	89.007	40.975	153.835	26.589	96.821	7.339	12.382	21.062	64.700
WKB4	-1.685	-15.481	-13.638	-41.369	-22.816	-61.248	-21.494	-54.151	-1.071	-13.001	-13.099	-39.649
I85S2	-0.525	-1.893	-0.437	-2.696	0.574	-11.899	1.105	-10.199	0.753	0.248	0.842	-0.571
I85S3	-0.313	-1.712	2.479	0.626	34.336	27.298	34.758	29.516	0.957	0.454	3.785	2.843
I85N3	-1.158	-2.388	-0.613	-2.454	5.581	-3.209	6.818	-0.841	0.419	0.236	0.972	0.168

Figure 11 shows the road links in order of increasing distance from the red line to the west and east of the Little Rock Rd connectivity project. The TTR measures within the road connectivity project are shown for different road links. The road links in red indicate an increase in TTR measures, while the road links in green indicate a reduction in TTR measures after the implementation of the Little Rock Rd connectivity project. The figure shows that for all TTR measures, road link WKB4 experienced the highest gain in travel time, while WKB3 has the most reduction in TTR measures. The PTI for some road links did not change so much after the project compared to before the projects were implemented. While some of these road links were reduced in terms of BTI, there was an increase in measures such as PT and ATT. This implies that the additional time needed to ensure on-time arrival at the airport decreased while other measures, such as ATT, increased on the road link. There is a clear pattern of reduced impact as the distance from the connectivity project decreased. There is a notable reduction in BTI on the closest road links west of the connectivity project on Wilkinson Blvd However, BTI increased east of the connectivity project on Wilkinson Blvd The change in BT and BTI are similar and, hence, both reliability measures can be used interchangeably in assessing the impact of road connectivity projects on TTR. Similarly, the change observed on all road links across PT and ATT are similar.

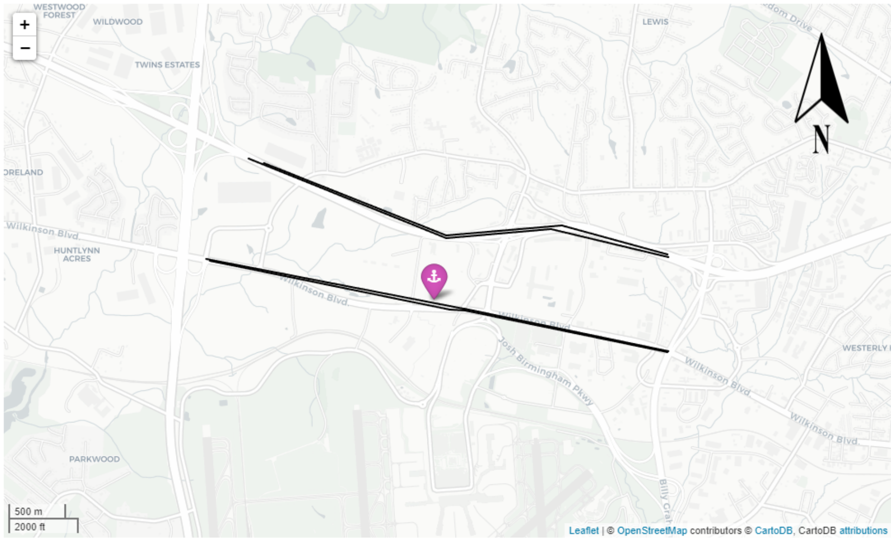
Figure 11. Percentage Change in TTR Measure of Road Links after the Little Rock Rd Connectivity Project



2.4.3 Impact of the Construction of The Parking Spot CLT Parking Lot on TTR

The Parking Spot started its operation in 2018 and offers amenities that make airport parking more convenient, including shuttle service to the terminal, 24-hr. parking service, covered and uncovered parking, electric vehicle (EV) charging, and many more, which are meant to attract CLT users. Figure 12 shows the location of the project and the surrounding road network within a one-mile radius of the construction.

Figure 12. Location of The Parking Spot around the Airport Access



To study the impact of the CLT parking lot on TTR on the surrounding road links, the distribution of PT was visualized for a weekday and weekend, as shown in Figure 13. PT increases during a weekday while the construction of the parking lot was ongoing. However, there seems to be little change in the PT during the weekend. A rapid decrease in PT was observed after the parking project's completion. However, the overall trend of PT increased considerably after the project was completed compared to the before period during the weekday. This is a reasonable finding as the road link is located on Wilkinson Blvd and more vehicles would need to access the airport via this road because due to the parking lot's convenience offers, hence an increase in PT on some of the road links.

Figure 13. PT Before, During, and After the Parking Lot Construction Project on Road Link WKB3 for a Weekday vs. Weekend

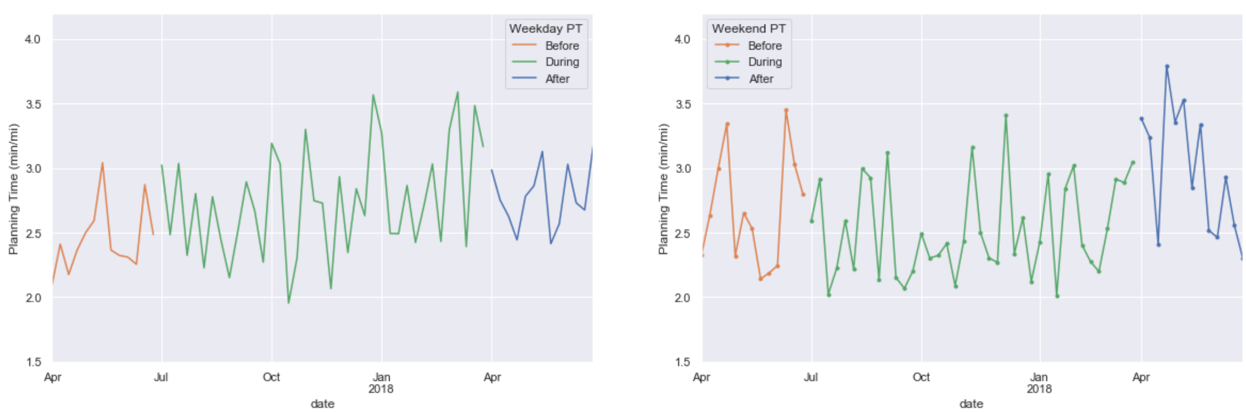


Figure 14 shows a slight increase in ATT during the weekday. However, the ATT change was drastic during the weekend, immediately after the parking lot's construction. The trend for ATT during both weekday and weekend can be seen increasing from April, before the start of the project, until after the parking project's completion. Thus, there is an increase in travel time during and after the project on this road link. This might be a result of its proximity to the entrance of the airport. The introduction of a signal light might have caused additional delay on the road links during and after the project in addition to the effect of the work zone during the construction.

Figure 14. ATT Before, During and After the Parking Lot Construction Project on Road Link WKB3 for a Weekday vs. Weekend

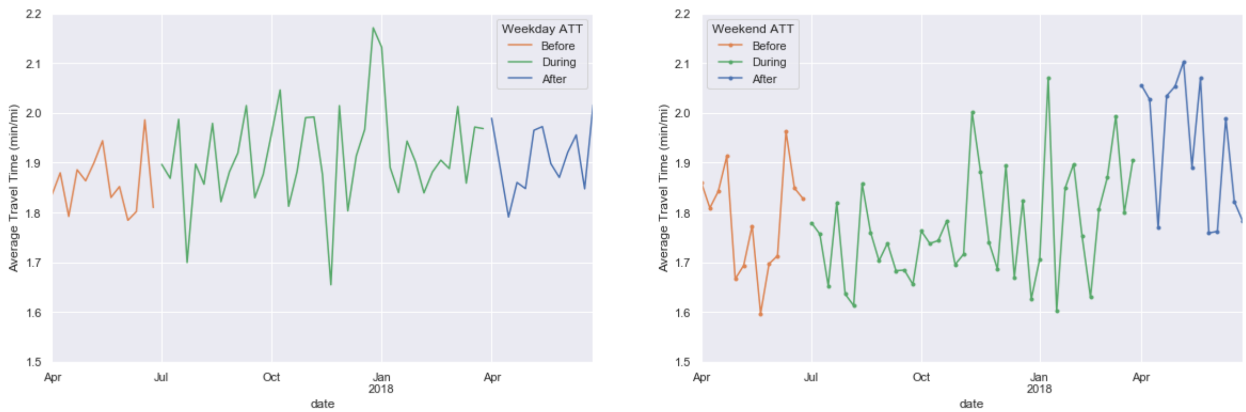


Table 8 shows the TTR measures of road links before, during, and after the construction of The Parking Spot lot on Wilkinson Blvd Ten road links within a one-mile radius of the project were selected. Variations in the ATT on the road links within the vicinity of the parking lot before, during, and after its construction was observed. The percentage change in all the TTR measures is shown in Table 9.

Table 9 also shows the percentage change in TTR measures during and after the project compared to the before period. The negative numbers indicate a decrease in TTR measures compared to the before period, while the positive numbers indicate an increase. There is an increase in PTI after the parking lot construction project's completion for most of the links within its surroundings.

Figure 15 shows the percentage change in ATT, PT, BT, BTI, TTI, and PTI for all road links within a one-mile proximity to the CLT Parking Lot construction project. Road links with red indicate an increase in TTR measures, while road links in green indicate a reduction after the implementation of the parking project. For most of the TTR measures, only road link 185S1 experienced a reduction in BT, BTI and PTI, while an increase was observed on other road links. The ATT for some road links decreased; however, these links experienced an increase in PT, BT, BTI, TTI, and PTI. This result is as expected since the construction of a parking lot means more vehicles will make use of the surrounding roads. The increase in TTR measures on most links might be associated with an increase in demand resulting from the parking lot. The change in BT and BTI are similar in terms of the magnitude of change. Hence, either of the two reliability measures can be used in assessing the impact of the parking lot's expansion on TTR within airport access links. As expected, and shown in Figure 15, the impact reduces as we move farther north and south of the red line.

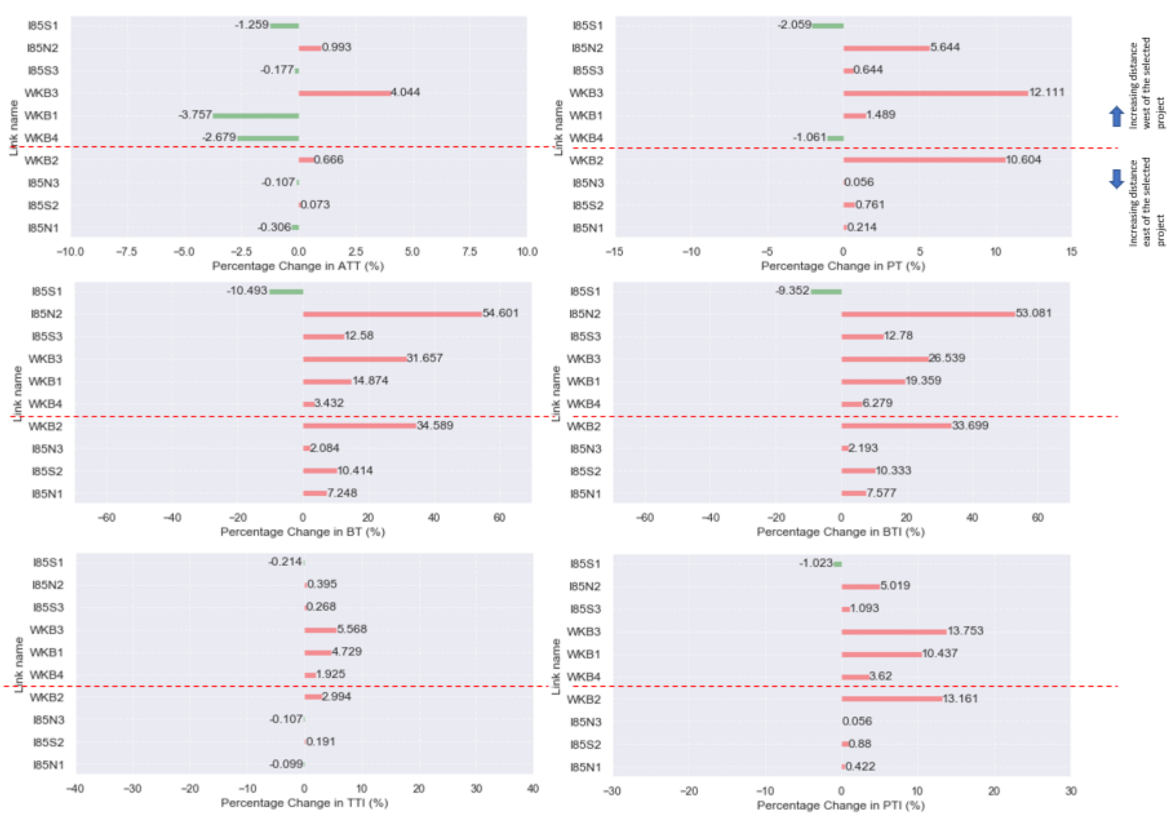
Table 8. TTR Measures on Road Links Surrounding the Parking Spot CLT Parking Lot on Wilkinson Blvd

Link ID	Length	Stage	ATT	PT	BT	BTI	TTI	PTI
I85N1	1.15	Before	1.017	1.017	0.070	7.388	1.043	1.121
		During	0.949	1.026	0.077	8.153	1.045	1.130
		After	0.944	1.020	0.075	7.948	1.042	1.125
I85N2	0.657	Before	1.060	1.060	0.092	9.500	1.051	1.150
		During	0.971	1.071	0.100	10.292	1.050	1.158
		After	0.978	1.120	0.142	14.543	1.055	1.208
WKB1	1.119	Before	2.647	2.647	0.745	39.188	1.244	1.731
		During	1.861	2.726	0.865	46.465	1.280	1.874
		After	1.830	2.686	0.856	46.774	1.302	1.912
WKB2	1.415	Before	2.142	2.142	0.628	41.433	1.211	1.713
		During	1.499	2.189	0.689	45.959	1.223	1.785
		After	1.525	2.369	0.845	55.396	1.247	1.938
I85S1	0.588	Before	1.068	1.068	0.093	9.492	1.051	1.150
		During	0.968	1.053	0.085	8.773	1.050	1.142
		After	0.963	1.046	0.083	8.605	1.048	1.138
WKB3	1.114	Before	2.603	2.603	0.760	41.272	1.222	1.726
		During	1.857	2.751	0.894	48.155	1.262	1.870
		After	1.917	2.918	1.001	52.226	1.290	1.963
WKB4	1.327	Before	2.084	2.084	0.552	36.010	1.179	1.604
		During	1.518	2.063	0.545	35.892	1.192	1.620
		After	1.491	2.062	0.571	38.271	1.202	1.662
I85S2	1.059	Before	0.993	0.993	0.066	7.132	1.043	1.118
		During	0.926	0.995	0.070	7.560	1.043	1.122
		After	0.928	1.001	0.073	7.869	1.045	1.128
I85S3	0.625	Before	1.002	1.002	0.064	6.883	1.037	1.109
		During	0.934	0.998	0.064	6.876	1.037	1.108
		After	0.935	1.008	0.073	7.763	1.040	1.121
I85N3	0.561	Before	1.025	1.025	0.076	8.017	1.040	1.124
		During	0.950	1.025	0.075	7.863	1.040	1.122
		After	0.948	1.026	0.078	8.193	1.039	1.124

Table 9. Comparison of TTR Measure for Before-During and Before-After the Construction of The Parking Spot CLT Parking Lot on Wilkinson Blvd

Link ID	ATT		PT		BT		BTI		TTI		PTI	
	Before – During	Before–After	Before–During	Before–After	Before–During	Before–After	Before–During	Before –After	Before–During	Before–After	Before–During	Before–After
I85N1	0.141	-0.306	0.855	0.214	10.517	7.248	10.361	7.577	0.120	-0.099	0.834	0.422
I85N2	0.292	0.993	1.017	5.644	8.647	54.601	8.330	53.081	-0.046	0.395	0.677	5.019
WKB1	-2.145	-3.757	2.971	1.489	16.026	14.874	18.570	19.359	2.884	4.729	8.263	10.437
WKB2	-1.004	0.666	2.164	10.604	9.809	34.589	10.923	33.699	0.993	2.994	4.225	13.161
I85S1	-0.707	-1.259	-1.359	-2.059	-8.235	-10.493	-7.582	-9.352	-0.026	-0.214	-0.683	-1.023
WKB3	0.773	4.044	5.683	12.111	17.577	31.657	16.675	26.539	3.308	5.568	8.341	13.753
WKB4	-0.927	-2.679	-1.013	-1.061	-1.251	3.432	-0.327	6.279	1.079	1.925	0.991	3.620
I85S2	-0.186	0.073	0.212	0.761	5.799	10.414	5.996	10.333	-0.068	0.191	0.331	0.880
I85S3	-0.314	-0.177	-0.320	0.644	-0.409	12.580	-0.096	12.780	-0.048	0.268	-0.054	1.093
I85N3	0.142	-0.107	0.000	0.056	-1.774	2.084	-1.913	2.193	-0.021	-0.107	-0.163	0.056

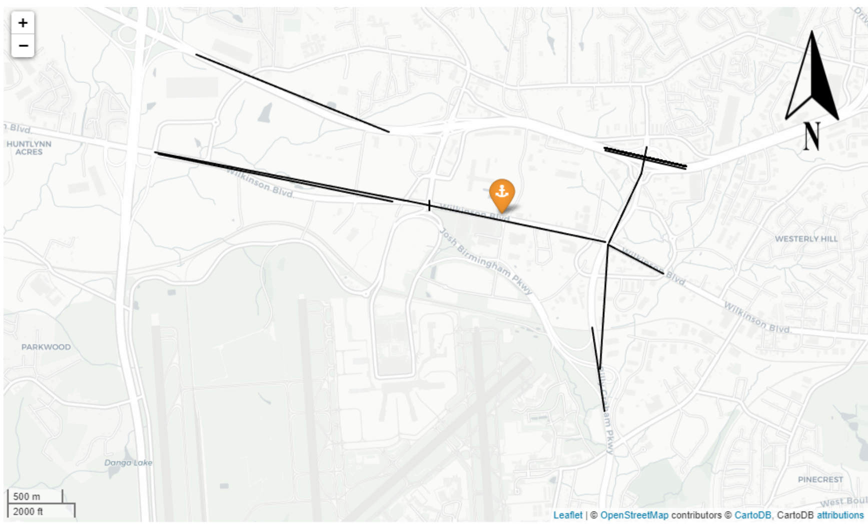
Figure 15. Change in TTR Measure of Road Links After the Parking Spot CLT Parking Lot on Wilkinson Blvd



2.4.4 Impact of Parking and Staging Area for Ridesharing Vehicles on TTR

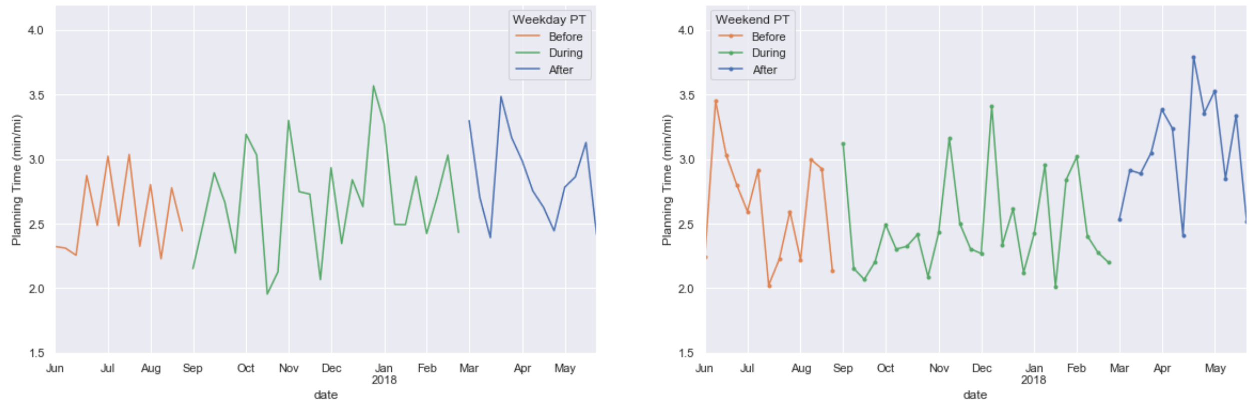
The parking and staging area for Uber and Lyft is a designated area within the airport's vicinity where drivers wait for ride requests, and vehicles outside of this lot will not receive requests from the airport. The parking and staging area was moved to this location in 2018 due to the airport's ongoing internal construction. This relocation is semi-permanent and will be in effect for the period of construction. Figure 16 shows the location of the project and the surrounding road network within a one-mile radius of the construction.

Figure 16. Location of the Parking and Staging Area for Ridesharing Vehicles



The visual exploration of PT and ATT before, during, and after the project on a road link on I-85S on a weekday is as shown in Figure 17. The trend line shows an upward trend in the PT over the years/months. Conversely, the ATT distribution appears to be stable over time. There is a level change in PT after the construction of parking and staging area for ridesharing vehicles. The decrease is in comparison with the PT during the project. The PT in the after period appears to be higher than the PT before the project.

Figure 17. PT Before, During, and After the Construction of Parking and Staging Area for Ridesharing Vehicles on road link I85N1 on a Weekday vs. Weekend



The weekend has a similar pattern, with higher PT and lower ATT compared to the weekday distribution. As opposed to what was observed in the weekday distribution, the ATT for the weekend after the construction of the parking and staging area for ride-sharing vehicles has increased. A change in level in the after period compared to during and before the project periods was observed in the ATT of a weekend. A more stable variation exists in the weekday data compared to the weekend data.

Figure 18. ATT Before, During, and After the Construction of Parking and Staging Area for Ridesharing Vehicles on Road Link I85N1 on a Weekday vs. Weekend

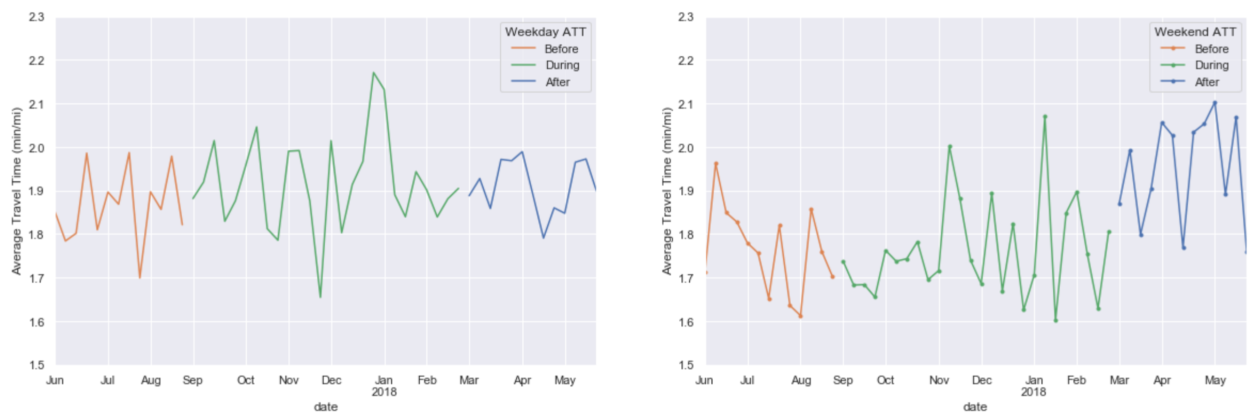


Table 10 shows the reliability measures of road links before, during, and after the construction of the staging and parking area for ridesharing vehicles. Here, ten road links with different lengths were examined. One can see variations in the ATT on the road links within the vicinity of the parking lot before, during, and after its construction. To elaborate the interpretation of Table 10 using an example road link "I85N1," the PT of 1.017 minutes/mile before the construction of the parking and staging area increased during the project to 1.026 and decreased after the construction to 1.019 minutes/mile. The PT value of 1.017 minutes/mile on link I85N1 represents the travel time of the worst day on the road link before the project. An additional time of 0.080 minutes/mile over the ATT was required for unexpected delay on the road link. In addition, this implies that travelers should plan an extra 7.39 percent time over the ATT which is equivalent to the BT of the road link.

Table 11 shows the percentage change in TTR measures during and after the project compared to the "before" scenario. A pattern is shown in the table, with negative numbers showing a decrease in TTR measures compared to the "before" scenario. However, positive numbers represent an increase in TTR measures compared to the "before" scenario. There is an increase in BT, BTI, TTI, and PTI after the parking and staging area construction project for most of the links within its surroundings.

Table 10. TTR Measures on Road Links Surrounding the Construction of Parking and Staging Area for Ridesharing Vehicles

Link ID	Length	Stage	ATT	PT	BT	BTI	TTI	PTI
I85N1	1.150	Before	0.948	1.017	0.070	7.388	1.043	1.121
		During	0.949	1.026	0.077	8.153	1.045	1.130
		After	0.944	1.019	0.075	7.924	1.043	1.126
I85N2	0.657	Before	0.968	1.061	0.091	9.500	1.051	1.150
		During	0.971	1.072	0.100	10.292	1.050	1.158
		After	0.977	1.119	0.142	14.450	1.056	1.208
BGPk4	0.704	Before	1.646	2.308	0.662	40.223	1.264	1.772
		During	1.611	2.230	0.619	38.482	1.260	1.744
		After	1.598	2.264	0.666	41.636	1.271	1.801
BGPk2	0.431	Before	2.074	3.441	1.369	66.011	1.396	2.318
		During	2.046	3.397	1.350	65.989	1.400	2.323
		After	2.026	3.450	1.427	70.431	1.407	2.398
WKB8	0.356	Before	1.461	1.826	0.365	24.912	1.163	1.453
		During	1.396	1.770	0.374	26.862	1.146	1.454
		After	1.354	1.713	0.360	26.609	1.147	1.452
WKB1	1.119	Before	1.906	2.679	0.773	40.551	1.246	1.751
		During	1.862	2.734	0.870	46.736	1.281	1.879
		After	1.828	2.679	0.851	46.497	1.304	1.910
WKB2	1.415	Before	1.514	2.142	0.628	41.433	1.211	1.713
		During	1.500	2.189	0.689	45.959	1.223	1.785
		After	1.529	2.342	0.813	53.144	1.243	1.904
BoSt6	0.298	Before	3.483	7.483	4.000	114.808	1.635	3.512
		During	3.725	8.557	4.832	129.721	1.734	3.984
		After	3.745	8.557	4.812	128.418	1.777	4.058
BGPk7	0.418	Before	1.701	2.821	1.120	65.786	1.329	2.203
		During	1.656	2.670	1.014	61.169	1.319	2.126
		After	1.665	2.596	0.931	55.896	1.332	2.076
WKB3	1.114	Before	1.841	2.595	0.754	40.947	1.221	1.721
		During	1.856	2.750	0.894	48.166	1.262	1.870
		After	1.913	2.908	0.995	52.002	1.291	1.963
WKB4	1.327	Before	1.531	2.079	0.549	35.856	1.178	1.600
		During	1.518	2.059	0.541	35.660	1.192	1.616
		After	1.491	2.072	0.581	38.960	1.211	1.683
WKB5	0.348	Before	1.463	1.842	0.382	26.060	1.156	1.457
		During	1.451	1.833	0.385	26.442	1.148	1.451
		After	1.408	1.830	0.422	29.943	1.167	1.516
I85S2	1.059	Before	0.927	0.993	0.066	7.132	1.043	1.118
		During	0.925	0.996	0.070	7.585	1.043	1.122
		After	0.927	1.002	0.075	8.072	1.044	1.129
I85S3	0.625	Before	0.938	1.002	0.064	6.883	1.037	1.109
		During	0.934	0.998	0.064	6.870	1.037	1.108
		After	0.934	1.013	0.077	8.254	1.040	1.125
I85S4	0.468	Before	0.968	1.060	0.094	9.628	1.049	1.150
		During	0.962	1.047	0.085	8.916	1.046	1.140
		After	0.955	1.032	0.077	8.126	1.044	1.128
BGPk1	0.468	Before	1.389	1.865	0.479	34.417	1.226	1.648
		During	1.357	1.814	0.457	33.654	1.222	1.633
		After	1.359	1.823	0.464	34.113	1.239	1.661
BGPk9	0.153	Before	2.451	4.791	2.340	95.549	1.500	2.934

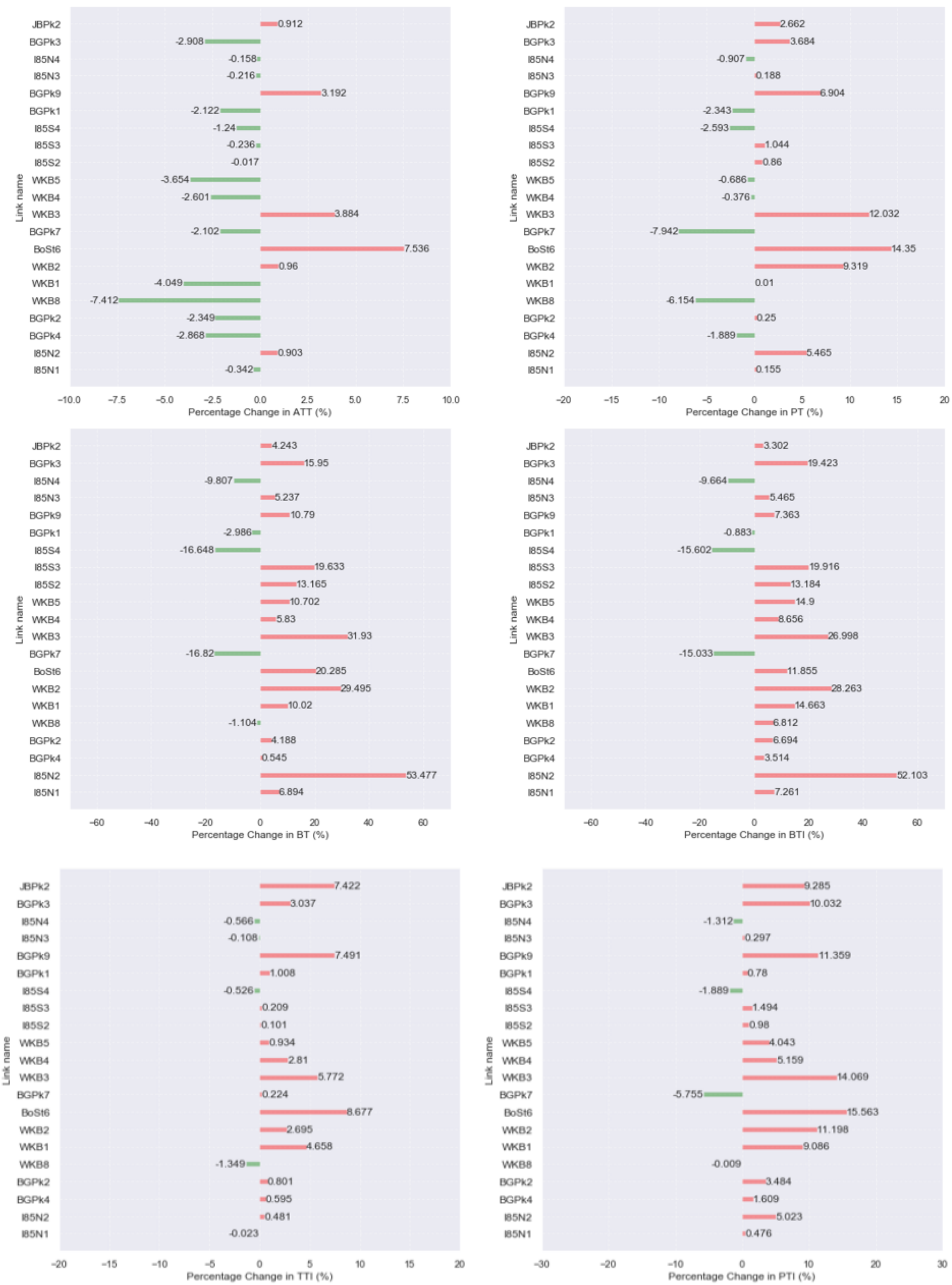
Link ID	Length	Stage	ATT	PT	BT	BTI	TTI	PTI
		During	2.431	4.595	2.163	89.110	1.549	2.929
		After	2.529	5.124	2.595	102.585	1.613	3.267
I85N3	0.561	Before	0.948	1.025	0.077	8.017	1.040	1.124
		During	0.950	1.025	0.075	7.863	1.040	1.122
		After	0.947	1.027	0.080	8.455	1.039	1.127
I85N4	0.453	Before	0.936	1.013	0.079	8.420	1.041	1.129
		During	0.936	1.004	0.068	7.321	1.038	1.114
		After	0.934	1.004	0.071	7.606	1.036	1.114
BGPk3	0.150	Before	2.467	3.787	1.327	53.739	1.422	2.187
		During	2.467	3.973	1.507	60.981	1.434	2.308
		After	2.393	3.927	1.533	64.177	1.465	2.406
JBPk2	0.053	Before	3.830	8.057	4.245	110.708	1.844	3.884
		During	3.868	8.491	4.623	119.755	1.906	4.189
		After	3.868	8.283	4.415	114.363	1.980	4.245

Table 11. Comparison of TTR Measure for Before-During and Before-After the Construction of Parking and Staging Area for Ridesharing Vehicles

Link ID	ATT		PT		BT		BTI		TTI		PTI	
	Before – During	Before –After	Before– During	Before –After	Before– During	Before– After	Before– During	Before– After	Before– During	Before –After	Before– During	Before– After
I85N1	0.141	-0.342	0.855	0.155	10.517	6.894	10.361	7.261	0.120	-0.023	0.834	0.476
I85N2	0.292	0.903	1.017	5.465	8.647	53.477	8.330	52.103	-0.046	0.481	0.677	5.023
BGPk4	-2.147	-2.868	-3.362	-1.889	-6.383	0.545	-4.329	3.514	-0.335	0.595	-1.573	1.609
BGPk2	-1.319	-2.349	-1.333	0.250	-1.353	4.188	-0.034	6.694	0.247	0.801	0.234	3.484
WKB8	-4.567	-7.412	-3.077	-6.154	2.906	-1.104	7.831	6.812	-1.447	-1.349	0.092	-0.009
WKB1	-2.269	-4.049	2.032	0.010	12.639	10.020	15.254	14.663	2.808	4.658	7.333	9.086
WKB2	-1.004	0.960	2.164	9.319	9.809	29.495	10.923	28.263	0.993	2.695	4.225	11.198
BoSt6	6.927	7.536	14.350	14.350	20.815	20.285	12.989	11.855	6.091	8.677	13.456	15.563
BGPk7	-2.595	-2.102	-5.307	-7.942	-9.431	-16.820	-7.018	-15.033	-0.739	0.224	-3.504	-5.755
WKB3	0.813	3.884	5.976	12.032	18.586	31.930	17.630	26.998	3.363	5.772	8.657	14.069
WKB4	-0.859	-2.601	-1.003	-0.376	-1.403	5.830	-0.549	8.656	1.143	2.810	0.996	5.159
WKB5	-0.713	-3.654	-0.412	-0.686	0.744	10.702	1.467	14.900	-0.713	0.934	-0.412	4.043
I85S2	-0.173	-0.017	0.249	0.860	6.166	13.165	6.351	13.184	-0.055	0.101	0.367	0.980
I85S3	-0.303	-0.236	-0.314	1.044	-0.484	19.633	-0.182	19.916	-0.036	0.209	-0.048	1.494
I85S4	-0.604	-1.240	-1.249	-2.593	-7.956	-16.648	-7.397	-15.602	-0.274	-0.526	-0.921	-1.889
BGPk1	-2.208	-2.122	-2.763	-2.343	-4.377	-2.986	-2.218	-0.883	-0.374	1.008	-0.940	0.780
BGPk9	-0.915	3.192	-4.178	6.904	-7.592	10.790	-6.739	7.363	3.214	7.491	-0.185	11.359
I85N3	0.142	-0.216	0.000	0.188	-1.774	5.237	-1.913	5.465	-0.021	-0.108	-0.163	0.297
I85N4	0.108	-0.158	-0.907	-0.907	-12.962	-9.807	-13.056	-9.664	-0.301	-0.566	-1.312	-1.312
BGPk3	0.159	-2.908	4.877	3.684	13.656	15.950	13.475	19.423	0.805	3.037	5.553	10.032
JBPk2	0.979	0.912	5.314	2.662	9.231	4.243	8.172	3.302	3.407	7.422	7.847	9.285

The effect observed in the percentage change of TTR measures after the construction of the parking and staging area for ridesharing vehicles is similar to that observed after the completion of The Parking Spot project. Figure 19 reveals a reduction in ATT on most of the road links. However, the BT, BTI, TTP, and PTI on most road links increased substantively.

Figure 19. Percentage Change in TTR Measure of Road Links after the Construction of Parking and Staging Area for Ridesharing Vehicles



3. Evaluation of the Effectiveness of Conventional & Unconventional Intersection Designs

3.1 Background

Today's traffic volumes and travel demands often lead to safety problems that are too complex for conventional intersection designs to handle adequately. This problem is critical near highway junctions, where congestion can raise concerns about the safety of the drivers along with that of pedestrians and bicyclists. Sometimes, a development project can also change the traffic conditions at the intersections within its vicinity. Such developments or infrastructure improvements can increase vehicular traffic near park-and-ride facilities. Contrarily, it can also increase the number of non-motorist users (Kodupuganti et al., 2022). A simulation-based study also showed a quantifiable decrease in operational performance due to school buses on the coordinated signalized arterial corridor (Dumitru & Pulugurtha, 2021). Subsequently, more practitioners are considering various innovative treatments as they strive for solutions to address these complex problems. Quadrant roadway intersections, restricted crossing U-turns or super street medians (RCUT), mini roundabouts, bowties, jug handles, split intersections, and continuous flow intersections (CFI) are examples of unconventional intersection designs that can improve traffic in specific scenarios. They can separate the conflict points and, hence, decrease the risk of a crash. Depending on the traffic conditions, a suitable unconventional intersection design can help resolve traffic more efficiently than conventional designs. Other benefits include higher capacities, lower costs, and better bicyclist and pedestrian movement.

Operational, safety, psychological, and other studies conducted previously influenced practitioners to use unconventional intersection designs. They found a significant difference in intersection performance between conventional and unconventional intersection designs. These studies have compared various performance parameters such as travel time, delay, speed, number of conflicts, conflict intensity, travel distance, etc. (Reid et al., 2001). Protected intersection design, through evaluations using Vissim, was observed to effectively reduce bicycle-related conflicts while not having adverse effects on operational performance (Preston & Pulugurtha, 2021). However, not all intersection designs are applicable to every traffic condition and intersection (Abo-Bakr et al., 2022; Mane & Pulugurtha, 2020). For example, some unconventional intersection designs increase the number of stops, and, still, we can achieve better overall intersection performance.

These designs can help decrease delay and travel time around the network by encouraging traffic from freeways to enter the network around the airport and improving accessibility. They even perform better in the three-legged intersections, as some of the unconventional intersection designs can be partially implemented. The average delay and number of stops per vehicle was used to compare the intersection performance in this study. Highway Capacity Manual (HCM) was used to assess the LOS based on the delay (HCM, 2010).

3.2 Literature Review

This section presents an overview of past research on different alternative intersection designs used in this study. Furthermore, the limitations of past research are also presented.

3.2.1 Continuous Flow Intersection (CFI)

Francisco Mier of El Cajon, California, holds U.S. patent #5049000 for CFI. The major innovation of this design is that through and left-turning traffic moves simultaneously at the main intersection, requiring protected left-turns with a two-phase signal. The CFI supports high traffic flow with a large volume of left turns. The CFI accomplishes this by moving left-turning traffic to the left side of a highway before the main intersection. Left turns can then be made simultaneously as the opposing through movement. This eliminates the need for separate left-turn signal phasing and reduces the potential conflict points between left-turning and the through traffic. Because CFI left-turn movements begin well before the road junction, signing and marking requirements differ from conventional intersections (Inman, 2009). These unconventional intersections perform better in terms of delay, fuel consumption, fewer pollutants, queue length, etc. in special traffic conditions than the conventional ones. CFI is better in terms of keeping traffic moving (Hughes, 2010). Goldblatt et al. (1994) conducted travel time analyses of CFI relative to conventional designs and found great time savings, particularly at high volume levels.

3.2.2 Restricted Crossing U-turn (RCUT) Intersection

An RCUT intersection is also known as the J-turn intersection or super street. It prohibits left-turns and through movements from side-street approaches, which are permitted in conventional designs. It accommodates left turns by providing a right turn from the main intersection and requiring them to take a U-turn at a median opening. RCUT intersections are of three types: signal-controlled, stop-controlled, and merge-controlled. A stop-controlled and signal-controlled RCUT intersection was considered for evaluation in this study. In the case of a narrow median, a "loon" must be provided to accommodate truck turns. A safety evaluation of two-way stop-controlled intersections converted to signalized and unsignalized RCUT intersection designs showed a significant reduction in total, fatal, and injury crashes (FI) (Mishra & Pulugurtha, 2022).

A distance of 660 ft ±100 ft is suggested between the main intersection and the U-turn crossover for an RCUT intersection. This is based partly on the deceleration length required for the major street with a posted speed limit of 45 mph. The same spacing should be 400 ft to 600 ft as per the AASHTO recommendation (Bared, 2009).

3.2.3 Mini-roundabout

The mini-roundabout is a type of roundabout characterized by a small diameter and fully traversable central island and splitter islands. They are a design option in areas with constraints on land acquisition, speeds, and the use of large roundabouts with raised central islands. The mini-roundabout features a much smaller inscribed diameter, on the order of 45 ft to 90 ft, and a relatively small circular central island (e.g., 16 ft to 45 ft diameter) that is traversable. A recent study revealed the safety benefits of converting a two-way stop-controlled and all-way stop-controlled intersection to a mini-roundabout (Mishra et al., 2022).

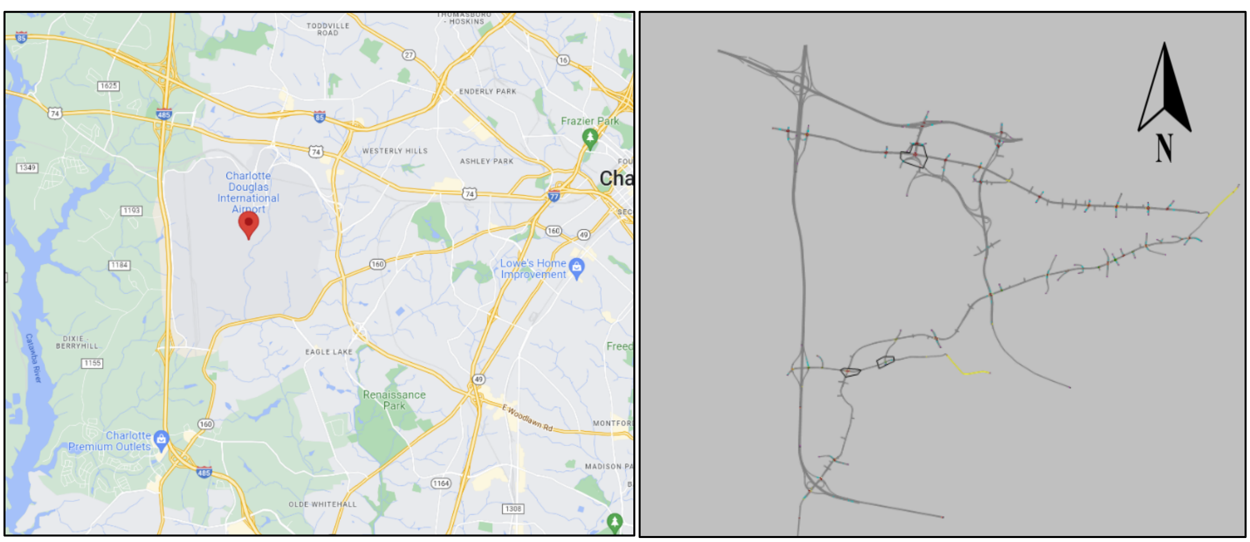
3.3 Methodology

This section presents the methodology adopted to check the effectiveness of conventional and unconventional alternatives for relocating or closing the existing roads and for the new inbound/outbound access routes.

3.3.1 Study Area and Data Collection

The road network surrounding the CLT was considered the study area. CLT is planning to expand its capacity by constructing a new terminal which will need to shift the existing West Blvd The redesign will need to consider the existing West Blvd, Byrum Dr, and Steele Creek intersection. The Wilkinson Blvd & N. Josh Birmingham Pkwy intersection was also considered for improvement to increase accessibility to the airport by providing new inbound/outbound routes. Traffic volume, turning movement counts, and signal data were obtained from the city of Charlotte Department of Transportation (CDOT). Speed data for the selected links were extracted from a private data source. The evening peak period from 5:00 PM to 6:00 PM on the weekday was considered for the analysis.

Figure 20. Study Area and Vissim Model



3.3.2 Data Processing

The "volume balancing macro-worksheet" developed by the Wisconsin Department of Transportation (WSDOT, 2018) was used for traffic volume balancing. This tool uses a mechanism of equal distribution of volumes for consecutive intersections based on the difference in the number of vehicles and a maximum of 1,000 iterations to adjust the balanced traffic volumes.

3.3.3 Preparing the Network

A microsimulation platform was used to build the existing road network. Road links per current dimensions, speed limit, and characteristics such as the number of lanes, left/right turning lanes, etc. were created in Vissim using satellite images and street-view in Google Earth and Google Maps. Figure 20 shows the network prepared in Vissim. Nearby intersections were also modeled to observe the corridor's operational performance change.

3.3.4 Building and Modeling the Environment

A built-in simulation platform capable of replicating the existing road and traffic conditions is required to study and compare different hypothetical scenarios. A weekday was selected and checked with historical weather data and local events record to avoid any external effects on traffic conditions due to weather (precipitation, fog, etc.), special events (e.g., football games), and holidays. Speed distributions of the selected day were analyzed from the speed dataset, which consisted of speed data at 5-minute intervals. The speed distributions obtained for different road facilities were input into Vissim software.

The start and end sections of the considered network were extended for vehicle input to ensure stable flow. Further, the simulation time at both the starting and end times was increased by 600 seconds. The total simulation time is 4,800 seconds. The assessment did not consider the start and end of 600 seconds each. Outputs were generated for the in-between 3,600 seconds. Simulation runs were carried out using five different random seeds. The average values of these runs were considered for calibration and validation. Defining the model parameters followed this task. The simulation runs were conducted with all the data collection points as per the data requirement.

3.3.5 Calibrating and Validating the Simulation Model

Calibration and validation of the simulation model is an essential process to verify whether the simulation model is capable of replicating observed behaviors in varying traffic conditions. The simulation model was developed and calibrated for different road facilities using observed travel time and traffic volume. Practically, capturing the simulation parameters, such as time headway, space headway, lateral space between vehicles, etc. is expensive using instrumented vehicles. Further, capturing these parameters over a wide range of traffic flow conditions is not feasible in many cases. The driving behavior parameters available in car-following models were adjusted for the Wiedemann 74 (used for urban arterials). These calibration parameters were adjusted on a trial-and-error basis until the simulated and observed speeds were almost equal (less than a 10 percent difference). The validation was carried out using the Mean Absolute Percentage Error (MAPE) between the simulated speed and the field observed speed. The functional form of MAPE is shown as follows:

$$MAPE = \frac{|TT_{Field} - TT_{Simulated}|}{TT_{Field}}$$

where TT_{Field} is the average speed from the field, and $TT_{Simulated}$ is the average speed from the simulation.

3.3.6 Unconventional Intersection Designs for the West Blvd, Byrum Dr, and Steele Creek Rd Intersection

As a part of the project, the existing West Blvd was proposed to be relocated. So, the existing southbound traffic was redirected to come from the westbound direction, making West Blvd, Byrum Dr, and Steele Creek Rd intersection a three-legged intersection. The southbound traffic volumes were added to the existing westbound traffic. The new traffic volumes are shown in Table 12, along with the projected traffic volumes. A rate of increase of three percent is considered for the projection of traffic volume. Figure 21 shows the turning movement count for the West Blvd, Byrum Dr, and Steele Creek Rd intersection, and Byrum Dr and Piney Top Dr intersection. Also, Table 12 shows the projected traffic volume for the West Blvd, Steele Creek Rd, and Byrum Dr intersection. New intersection design properties, such as the number of lanes, crossover control type, storage length, etc. for the new traffic volumes are shown in Table 13. Required signals were designed using Webster's method. Figure 22 shows the new signalized, CFI, RCUT, and signalized RCUT intersection designs.

Figure 21. Intersections Under Consideration Due to the Relocation of West Blvd

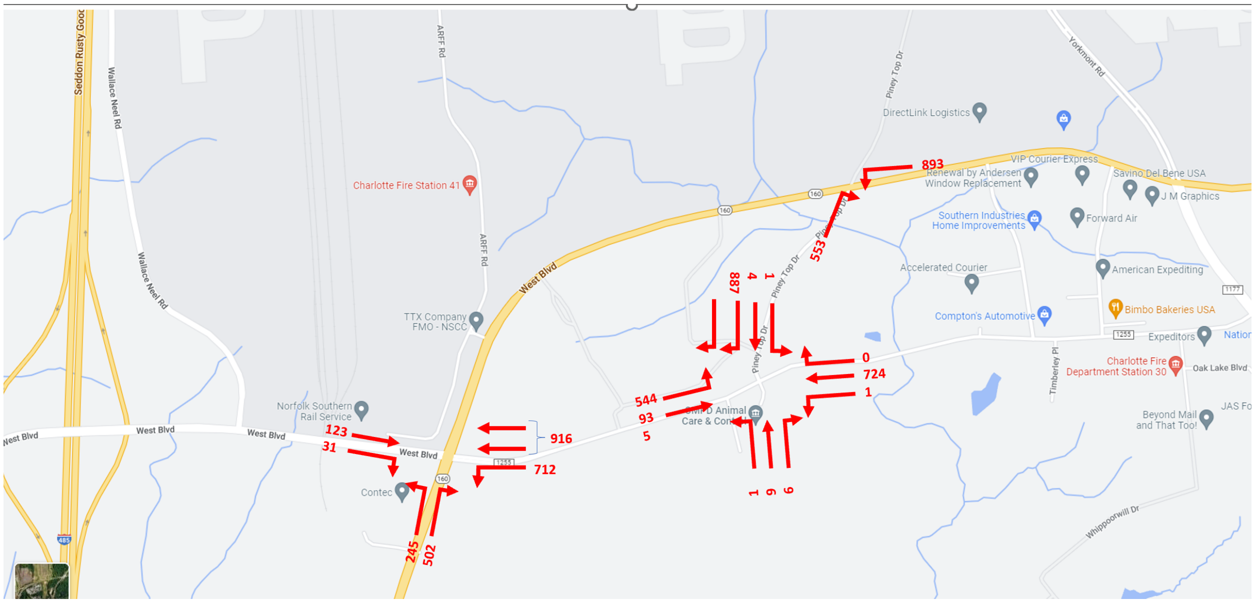


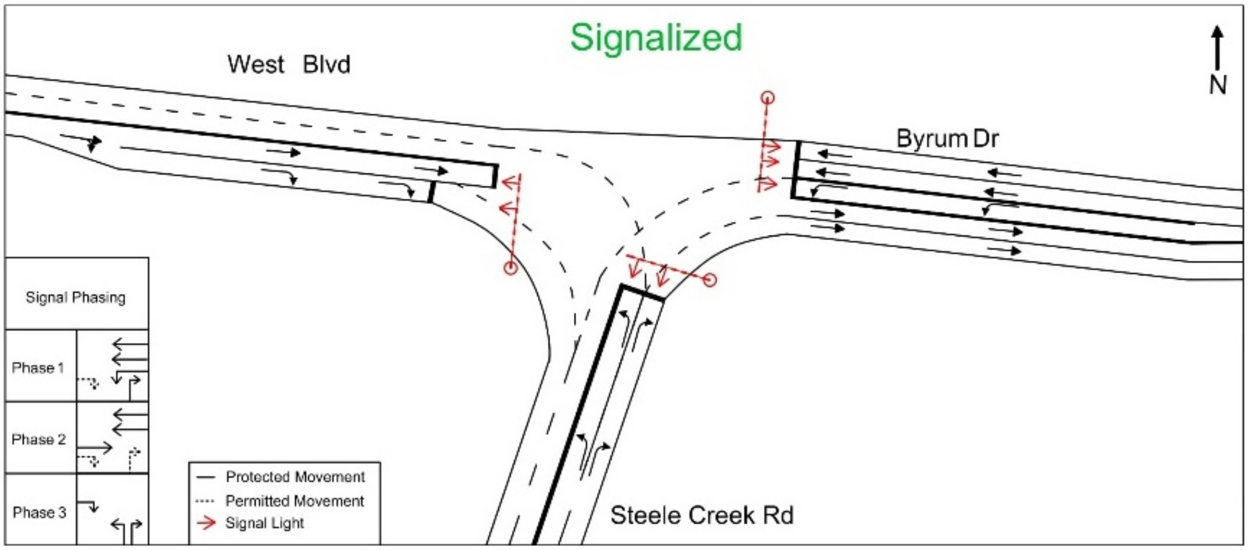
Table 12. Projected Traffic Volume at West Blvd, Byrum Dr, and Steele Creek Rd Intersection

Year	NBL	NBR	EBT	EBR	WBL	WBT
2019	245	502	123	31	712	916
2024	284	582	143	36	825	1,062
2029	329	675	165	42	957	1,231
2034	382	782	192	48	1,109	1,427
2039	442	907	222	56	1,286	1,654
2044	513	1,051	258	65	1,491	1,918

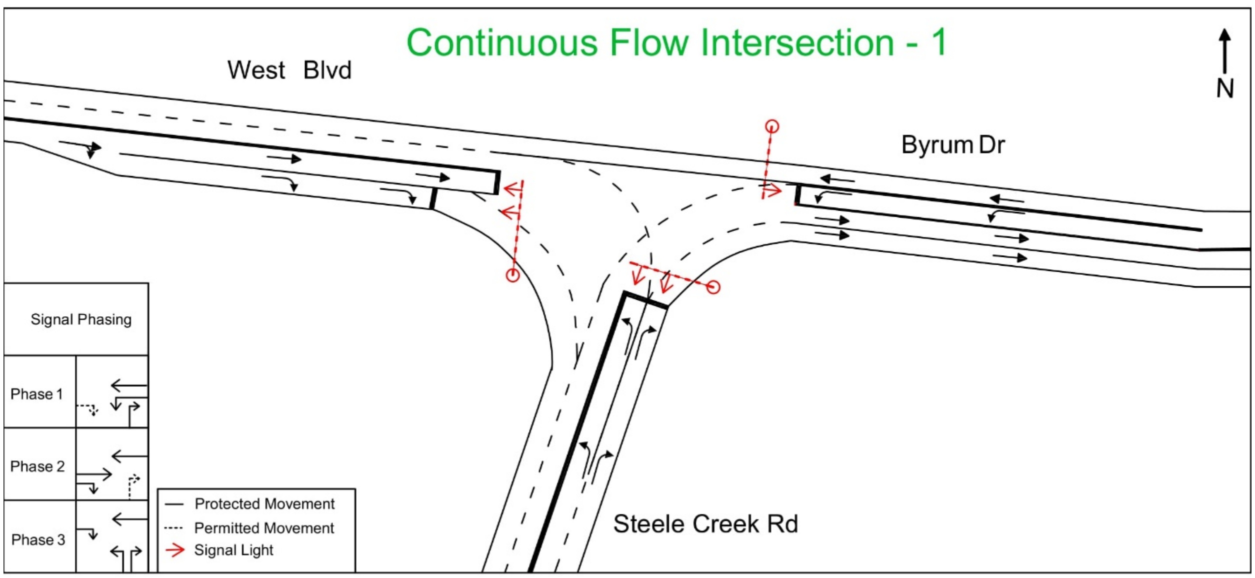
Table 13. Selected Intersection Design Configurations

Design Type	Number of lanes						Type of crossover	Storage length (ft)
	NBL	NBR	EBT	EBR	WBL	WBT		
Signalized	1	1	1	1	1	2	-	-
CFI-1	1	1	1	1	1	2	Signalized	285
CFI-2	1	1	1	1	1	2	Signalized	285
RCUT	1	1	1	1	1	2	Unsignalized	285
RCUT Signalized	1	1	1	1	1	2	Signalized	285

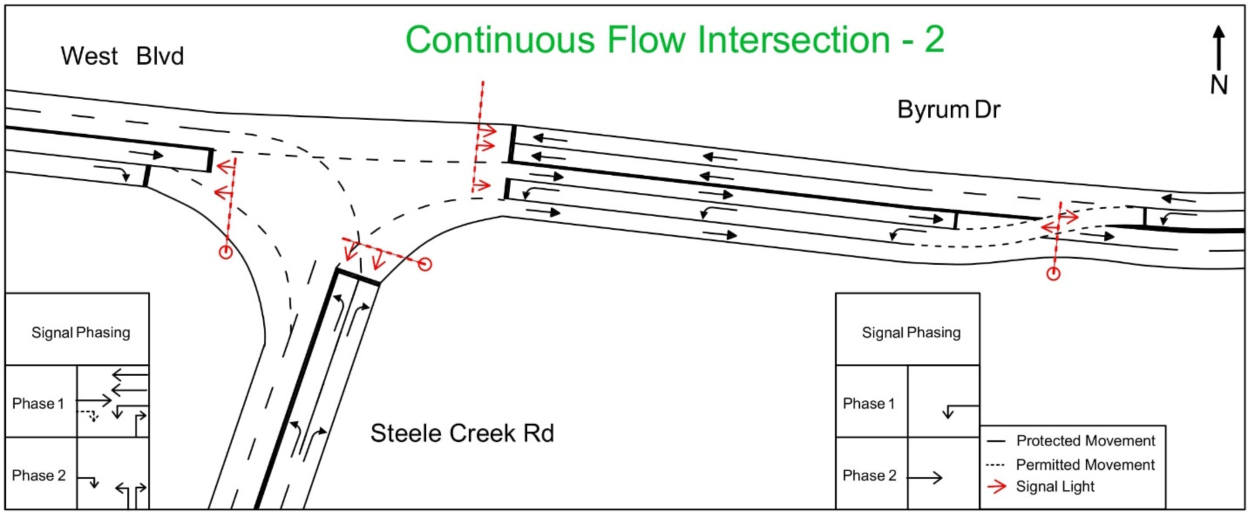
Figure 22. (a) Signalized, (b) CFI – 1, (c) CFI – 2, (d) RCUT, (e) RCUT – Signalized, (f) Mini-roundabout



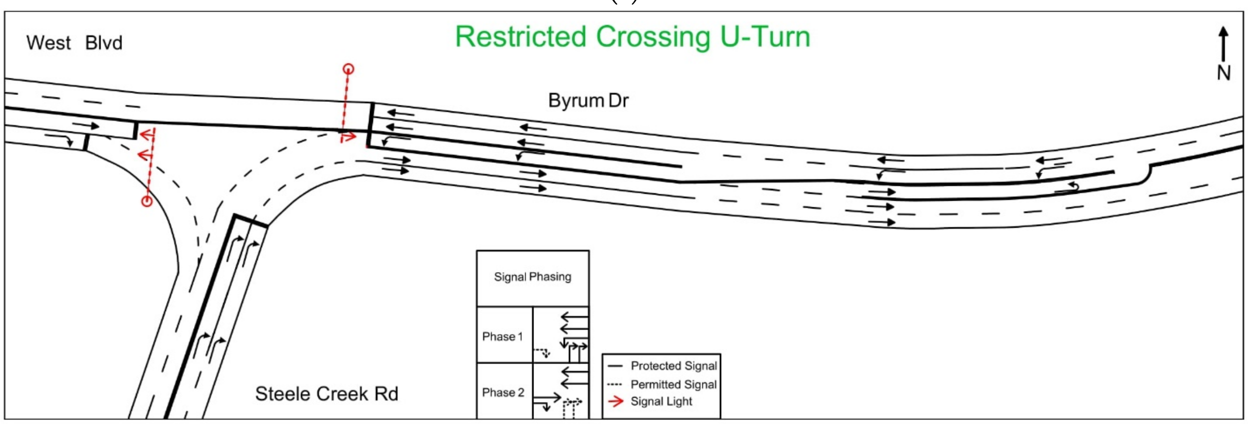
(a)



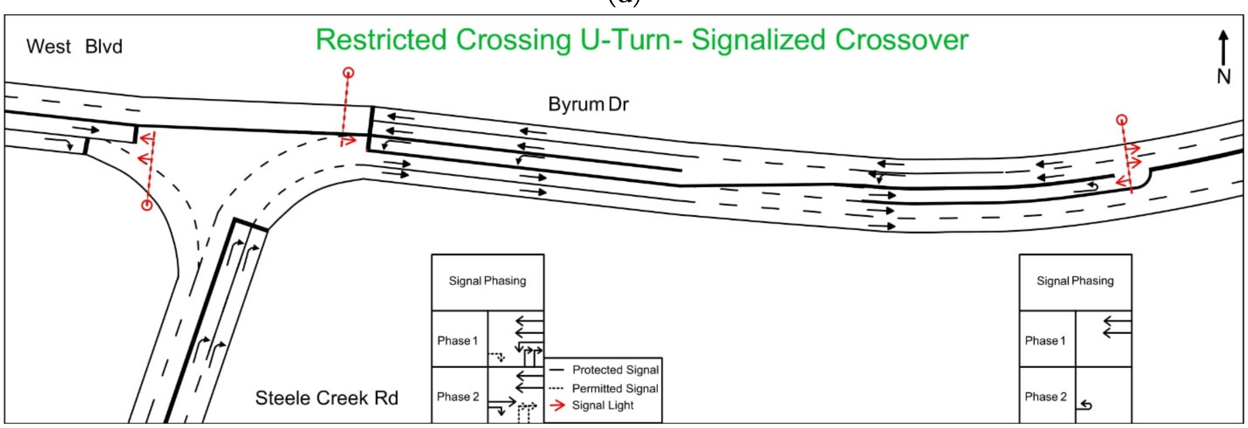
(b)


Continuous Flow Intersection - 2
West Blvd
Byrum Dr
N
Steele Creek Rd
Signal Phasing
Phase 1
Phase 2
Signal Phasing
Phase 1
Phase 2
Protected Movement
Permitted Movement
Signal Light

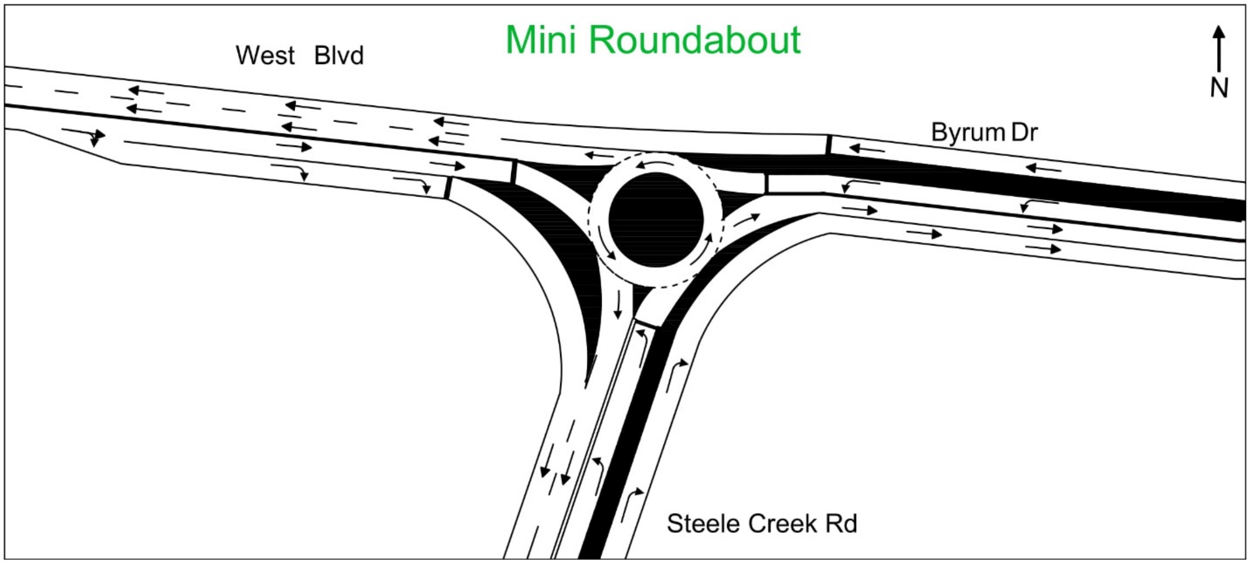
(c)


Restricted Crossing U-Turn
West Blvd
Byrum Dr
N
Steele Creek Rd
Signal Phasing
Phase 1
Phase 2
Protected Signal
Permitted Signal
Signal Light

(d)


Restricted Crossing U-Turn- Signalized Crossover
West Blvd
Byrum Dr
N
Steele Creek Rd
Signal Phasing
Phase 1
Phase 2
Protected Signal
Permitted Signal
Signal Light
Signal Phasing
Phase 1
Phase 2

(e)



(f)

Figure 23. Byrum Dr & Piney Top Dr Intersection Design

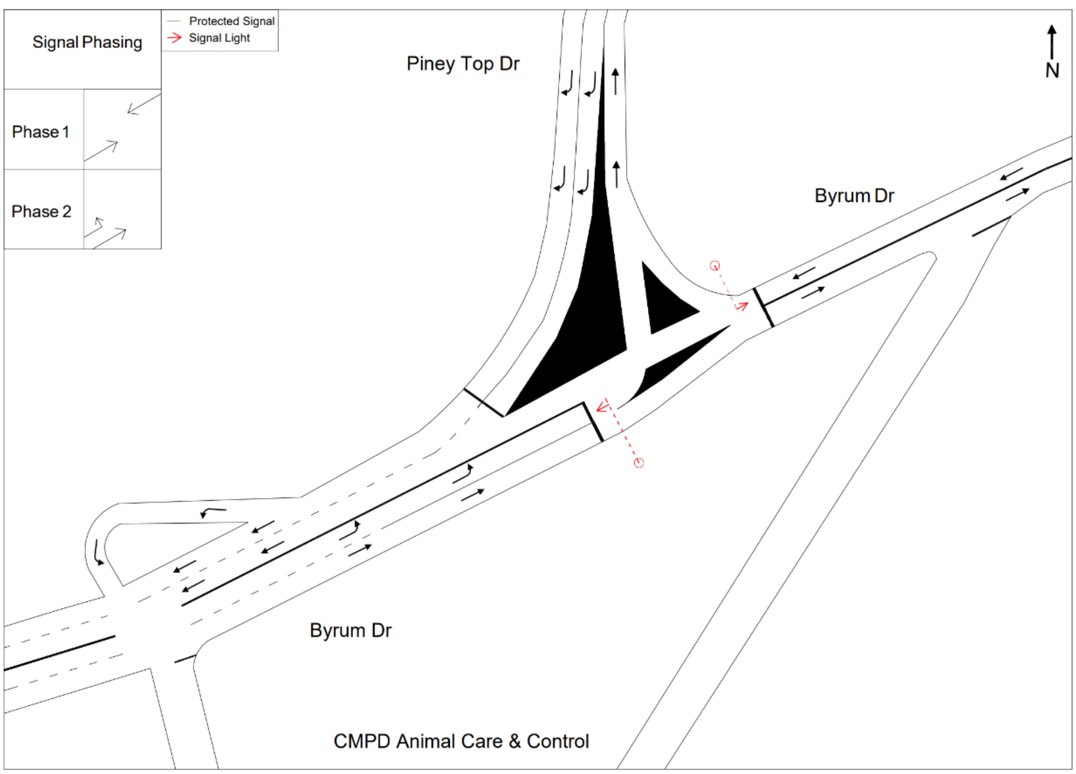


Figure 23 shows the proposed design for the Byrum Dr and Piney Top Dr intersection. The existing southbound approach, where the traffic to and from CMPD Animal Hospital merges at the intersection, is proposed to be relocated and connected to the east approach of the intersection only. This will decrease the green time dedicated to the traffic from the CMPD Animal Hospital and, hence, will improve the capacity of the proposed signalized intersection.

3.3.7 New Inbound/Outbound Access Routes from the Nearby Major Roads

The majority of the traffic uses the Wilkinson Blvd and N. Josh Birmingham Pkwy intersection to access the airport. Some traffic also uses Josh Birmingham Pkwy from the Billy Graham Pkwy to access the airport. Figure 24 shows the various routes used by the different areas of Charlotte. Figure 25 shows the turning movement count for the Wilkinson Blvd and N. Josh Birmingham Pkwy intersection. Looking at the traffic volume and the number of existing lanes, many of the alternative intersection designs do not provide safe movement and do not fit the criteria of using the intersection design at this particular location. Only CFI design is checked for performance.

Various bridge designs were considered for evaluating the performance and effectiveness in reducing travel time. For smooth entry and exit from and to the airport, the performance of the inbound and outbound bridge from the airport and from the N. Josh Birmingham Pkwy was considered. To reduce the travel time of the traffic coming from I-85, a direct ramp from I-85 to the airport was considered as an alternative. A slight modification of the entry-exit ramp, where the left-turning bridge approach from Wilkinson Blvd to the airport is eliminated, and instead, the left-turning traffic from the N. Josh Birmingham Pkwy to Wilkinson Blvd was also considered. This is named the north-south overpass. Figure 25 shows all four alternatives considered for evaluation in this study.

Figure 24. Selection of Routs from Different Parts of Charlotte City

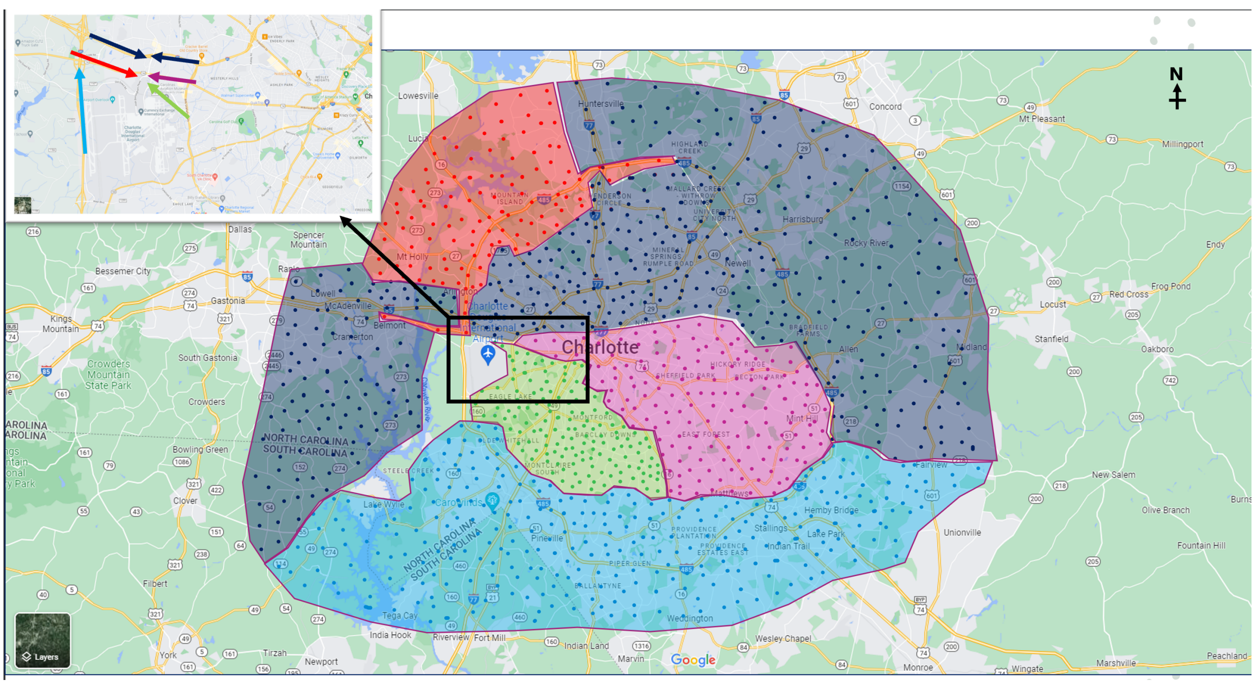
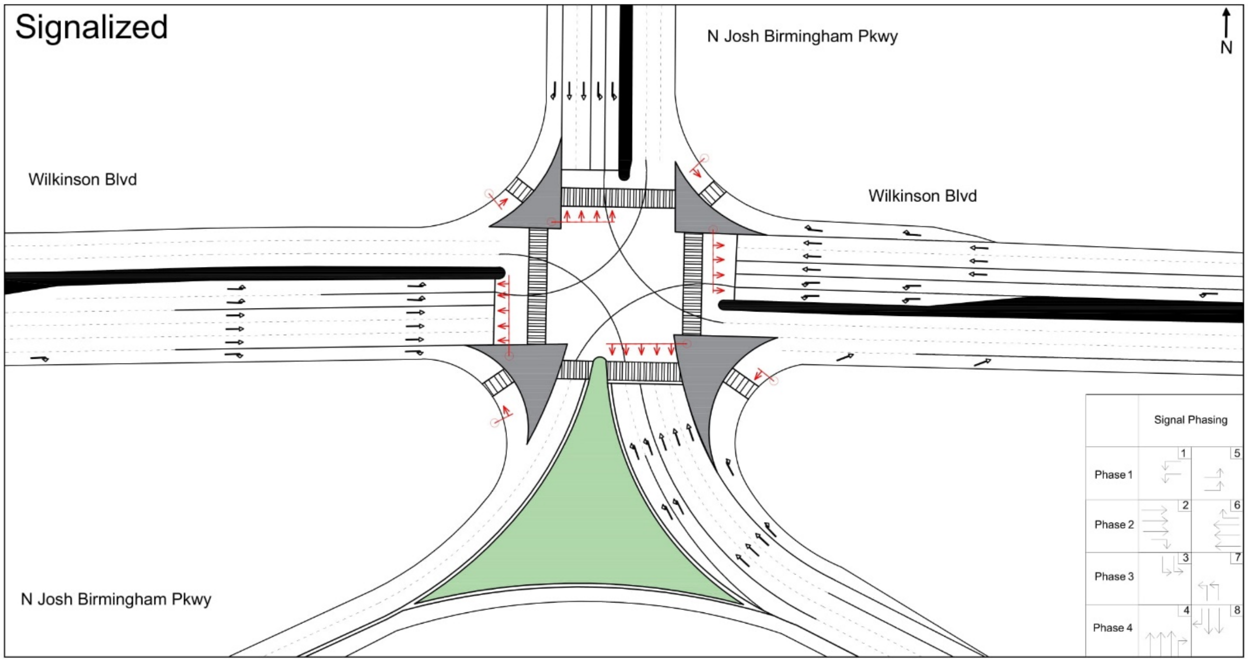
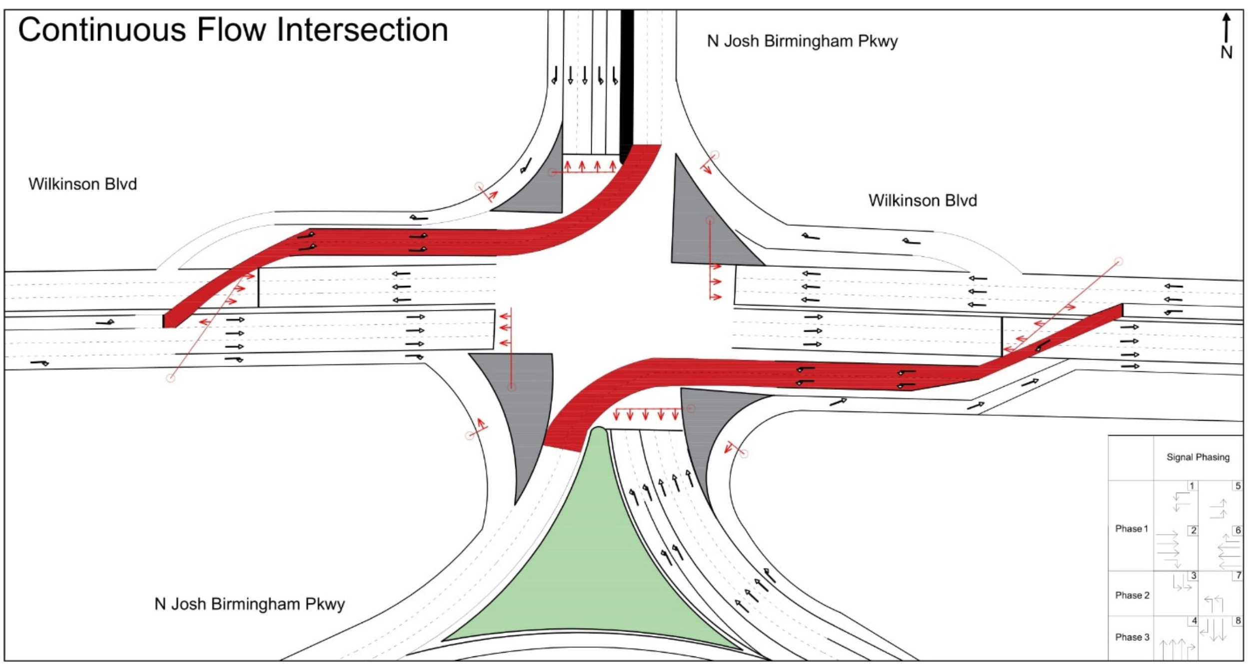


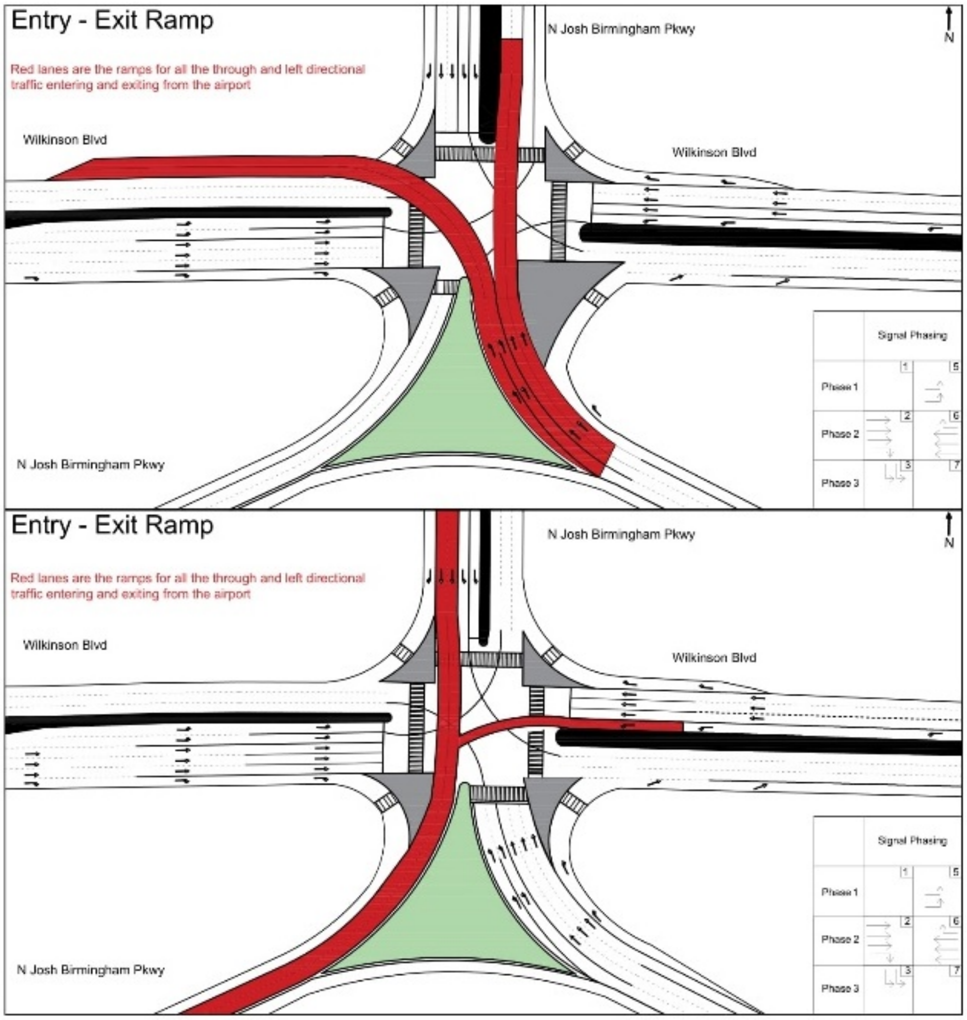
Figure 25. (a) Current Intersection, (b) CFI, (c) Entry-Exit Bridge, (d) N – S approach, (e) Direct ramp from I-85



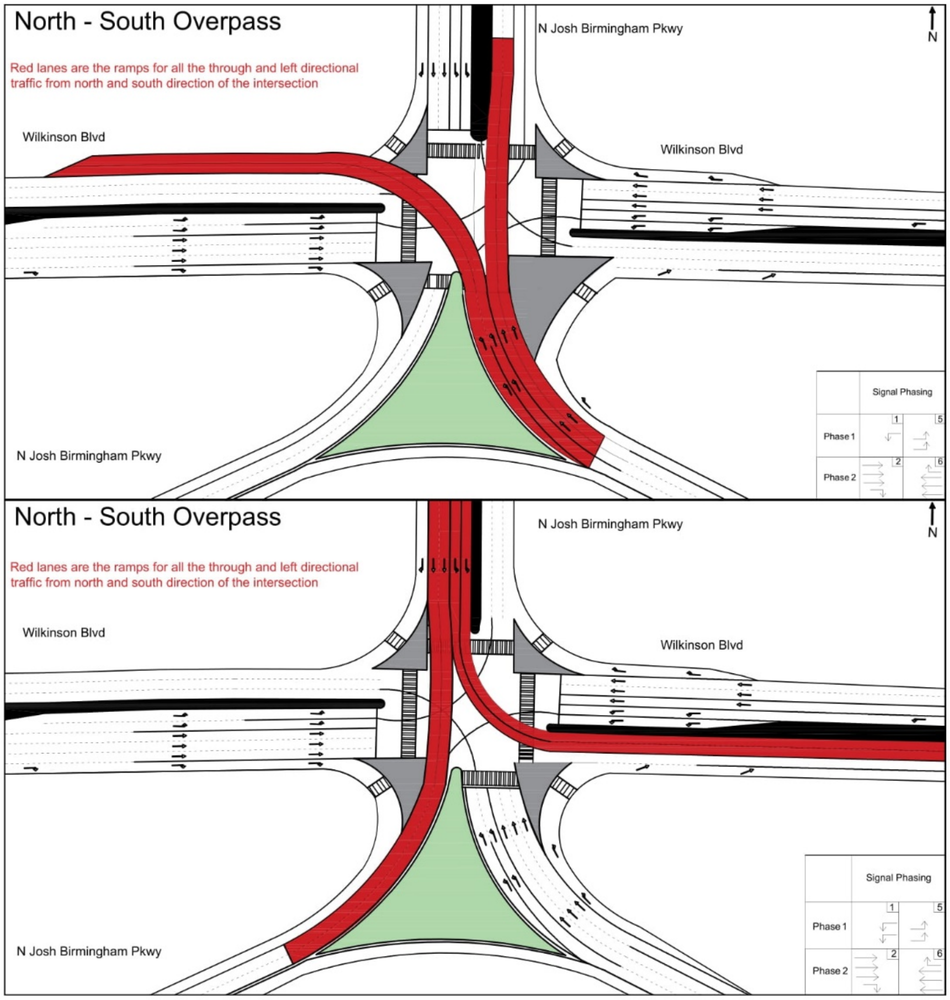
(a)



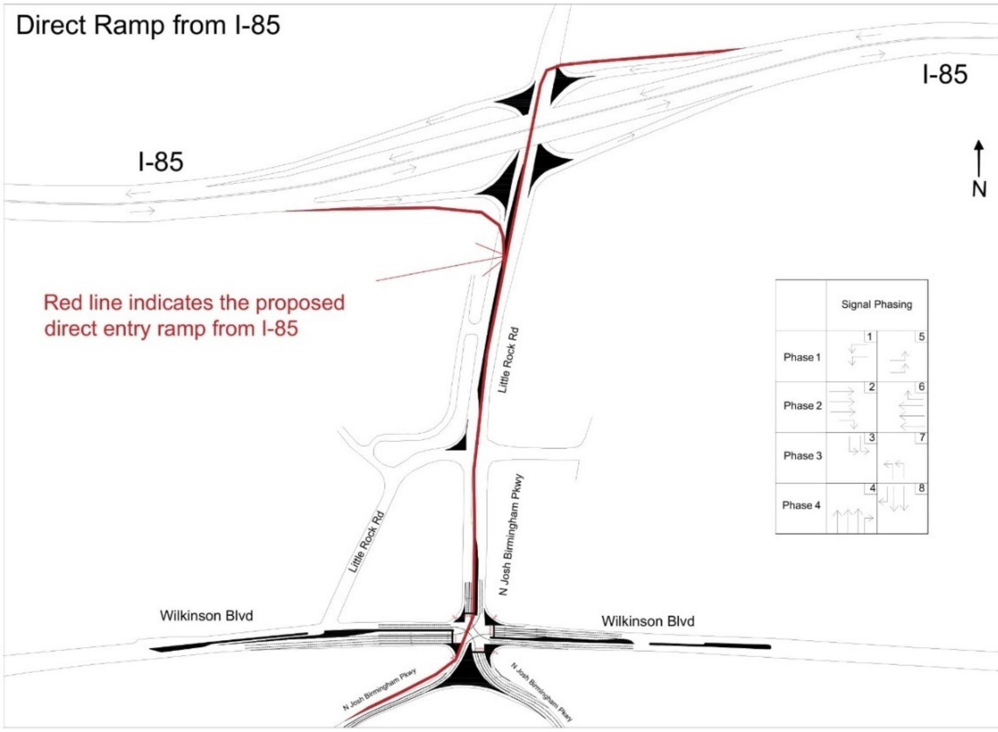
(b)


Entry - Exit Ramp
Red lanes are the ramps for all the through and left directional traffic entering and exiting from the airport
N Josh Birmingham Pkwy
N
Wilkinson Blvd
Wilkinson Blvd
N Josh Birmingham Pkwy
Signal Phasing
Phase 1
Phase 2
Phase 3
Entry - Exit Ramp
Red lanes are the ramps for all the through and left directional traffic entering and exiting from the airport
N Josh Birmingham Pkwy
N
Wilkinson Blvd
Wilkinson Blvd
N Josh Birmingham Pkwy
Signal Phasing
Phase 1
Phase 2
Phase 3

(c)


North - South Overpass
Red lanes are the ramps for all the through and left directional traffic from north and south direction of the intersection
N Josh Birmingham Pkwy
N
Wilkinson Blvd
Wilkinson Blvd
N Josh Birmingham Pkwy
Signal Phasing
Phase 1
Phase 2
1
5
2
6
North - South Overpass
Red lanes are the ramps for all the through and left directional traffic from north and south direction of the intersection
N Josh Birmingham Pkwy
N
Wilkinson Blvd
Wilkinson Blvd
N Josh Birmingham Pkwy
Signal Phasing
Phase 1
Phase 2
1
5
2
6

(d)



(e)

3.3.8 Capturing the Operational Performance

A yearly traffic growth rate of three percent was considered in this study, conducting simulation runs for the projected traffic volume every five years until the traffic volume reaches a 100 percent increase. Table 12 shows, as an example, the projected traffic volume for each year under consideration for the West Blvd, Byrum Dr, and Steele Creek Rd intersection. As stated previously, simulations were run using five random seed numbers, which are kept the same in every intersection design and alternative.

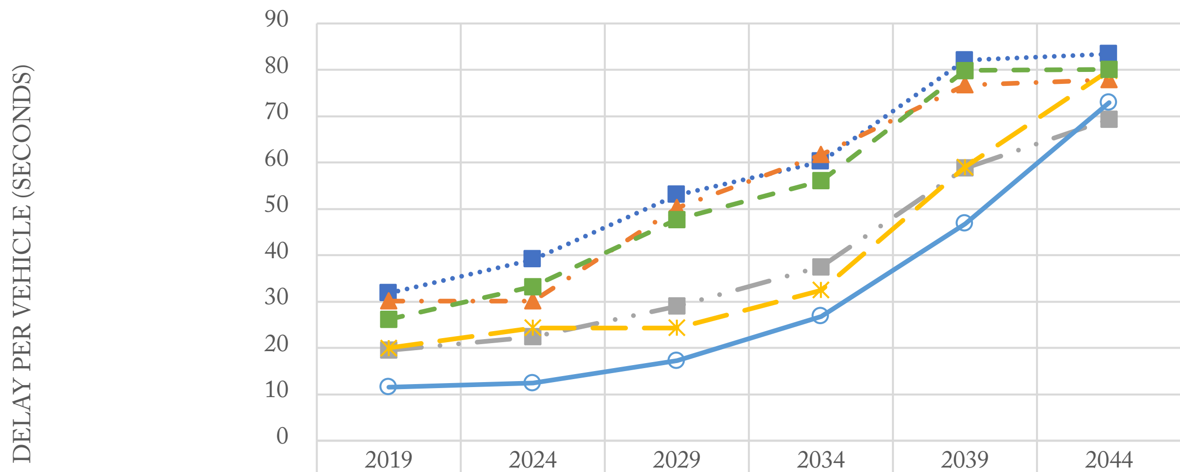
3.4 Results

The simulation results for all the designed intersections and alternatives are discussed in this section. The delay and number of stops are the two main measures considered for the comparison, as these measures indicate time saving and cost savings.

3.4.1 Effectiveness of Unconventional Intersection Designs for Relocating or Closing the Existing Roads

Figure 26 shows the average delay per vehicle for the projected traffic volumes of the West Blvd, Byrum Dr, and Steele Creek Rd intersection. Figure 27 shows the average number of stops per vehicle for the same intersection. RCUT (unsignalized) results in the lowest delay for almost all the projected traffic conditions. Hence, it is the most suitable design for this particular intersection even up to a 100 percent increase (year 2044), and after that, RCUT (signalized) or CFI can be used. As the traffic volume increases, the average delay per vehicle increased for all the considered types of designs.

Figure 26 Estimated Delay for West Blvd, Byrum Dr & Steele Creek Rd Intersection



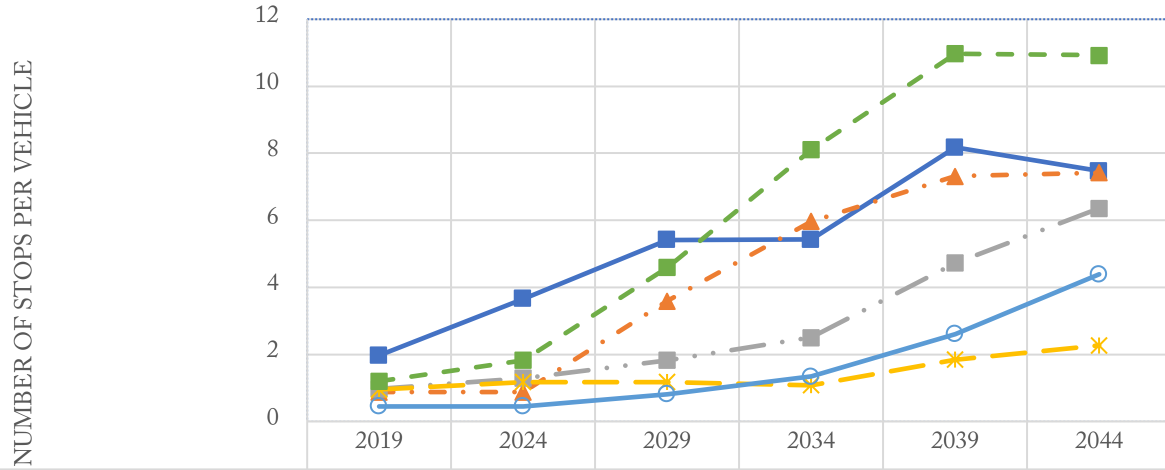
	2019	2024	2029	2034	2039	2044
Signalized	32	39	53	60	82	83
CFI-1	30	30	50	62	77	78
CFI-2	19	22	29	37	59	69
RCUT (Signalized)	20	24	24	32	59	80
RCUT (Unsignalized)	12	12	17	27	47	73
Mini Roundabout	26	33	48	56	80	80

YEAR

Figure 27 shows the estimated average number of stops for the projected traffic volumes of the West Blvd, Byrum Dr, and Steele Creek Rd intersection. For the initial years, the RCUT (unsignalized) resulted in a relatively smaller number of stops per vehicle. As the traffic increases, the RCUT (signalized) could result in a relatively smaller number of stops per vehicle. Conventional signalized intersections seem to result in the highest number of stops per vehicle. As the traffic volume increased, the average number of stops increased for all the considered types of designs.

The delay was converted into LOS based on HCM procedures for the unsignalized intersection to understand the serviceability of the intersections. The LOSs for the West Blvd, Byrum Dr, and Steele Creek Rd intersection are summarized in Table 14. For the signalized and RCUT (signalized) intersection designs, LOS is C for the initial traffic conditions while it is B for CFI and RCUT (unsignalized) designs. The LOS for the signalized intersection design deteriorated faster in the following years than the other types of intersection designs. RCUT (unsignalized) design performs better for this traffic condition. When traffic was increased by 100 percent, the LOS for the CFI, RCUT (unsignalized), and RCUT (signalized) deteriorated to E.

Figure 27 Estimated Average Number of Stops for West Blvd, Byrum Dr, and Steele Creek Rd Intersection



	2019	2024	2029	2034	2039	2044
Signalized	2.0	3.7	5.4	5.4	8.2	7.5
CFI-1	0.9	0.9	3.6	6.0	7.3	7.4
CFI-2	1.0	1.3	1.8	2.5	4.7	6.4
RCUT (Signalized)	1.0	1.2	1.2	1.1	1.8	2.3
RCUT (Unsignalized)	0.4	0.5	0.8	1.3	2.6	4.4
Mini Roundabout	1.2	1.8	4.6	8.1	11.0	10.9

YEAR

Table 14. Estimated LOS Results for West Blvd, Byrum Dr, and Steele Creek Rd Intersection

Year	2019	2024	2029	2034	2039	2044
Signalized	C	D	D	E	F	F
CFI-1	C	C	D	E	E	E
CFI-2	B	C	C	D	E	E
RCUT (Signalized)	C	C	C	C	E	E
RCUT (Unsignalized)	B	B	B	C	D	E
Mini Roundabout	C	C	D	E	E	F

The estimated average delay per vehicle (in seconds) and the average number of stops per vehicle for the Byrum Dr and Piney Top Dr intersection are shown in Figures 28 and 29. Table 15 summarizes the LOS results for the Byrum Dr and Piney Top Dr intersection. The new design serves at LOS B for the initial traffic conditions and could operate at LOS E as the traffic increases by 100 percent.

Figure 28. Estimated Delay for Byrum Dr & Piney Top Dr Intersection

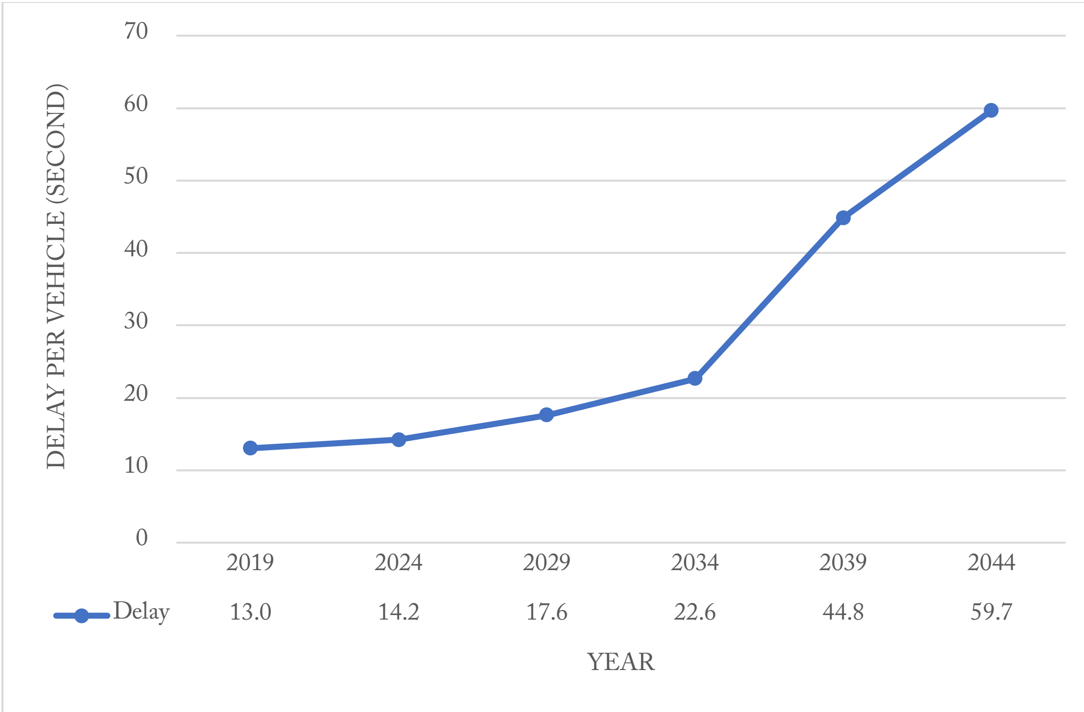


Figure 29. Estimated Number of Stops for Byrum Dr & Piney Top Dr Intersection

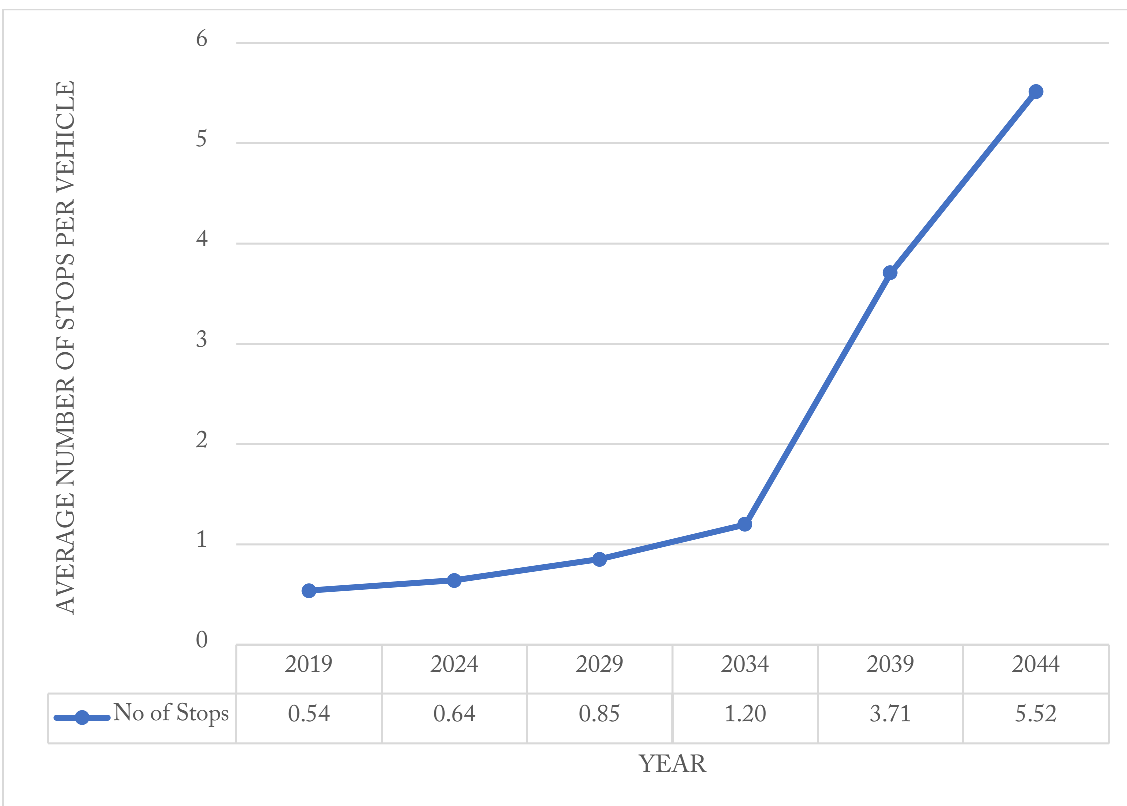


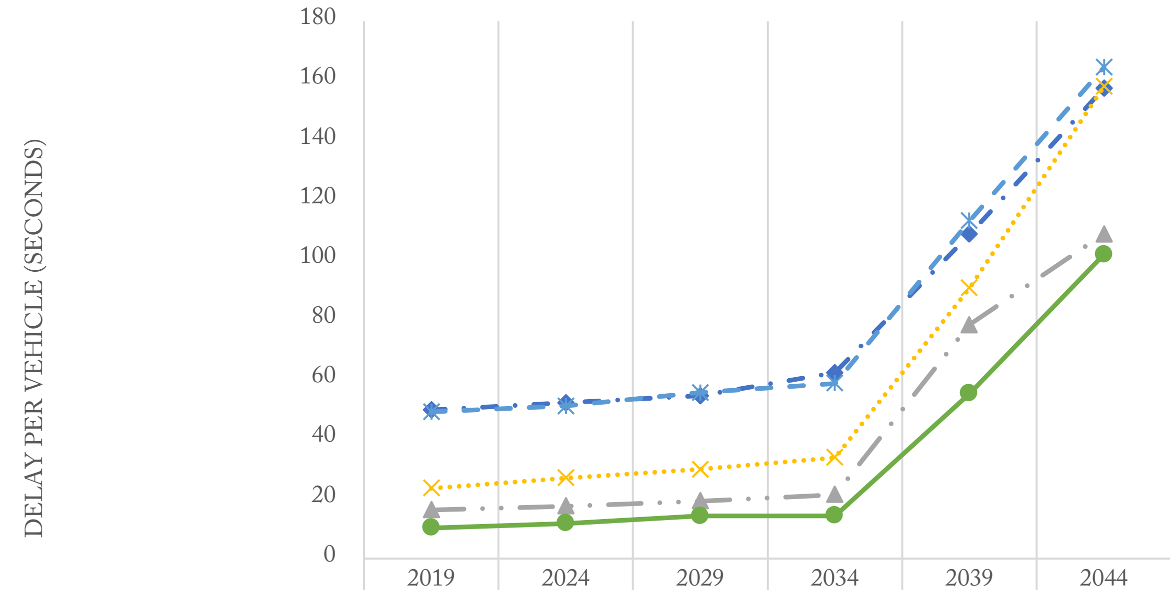
Table 15. Estimated LOS Based on the Delay for Byrum Dr & Piney Top Dr Intersection

Year	2019	2024	2029	2034	2039	2044
LOS	B	B	B	C	D	E

3.4.2 New Inbound/Outbound Access Routes from Major Roads to the Airport

Figure 29 shows the estimated average delay per vehicle for the projected traffic volumes of the Wilkinson Blvd and N. Josh Birmingham Pkwy intersection. Figure 31 shows the average number of stops per vehicle for the same intersection. Based on the delay results, the north-south overpass was the best suitable design for this particular intersection up to a 100 percent increase in traffic (year 2044). As the traffic volume increases, the average delay per vehicle increases for all the considered types of designs. The direct ramp from I-85 does not greatly change the intersection performance but decreases the travel time of the vehicles coming from the I-85 by more than 300 seconds.

Figure 30 Estimated Delay for Wilkinson Blvd & N Josh Birmingham Pkwy

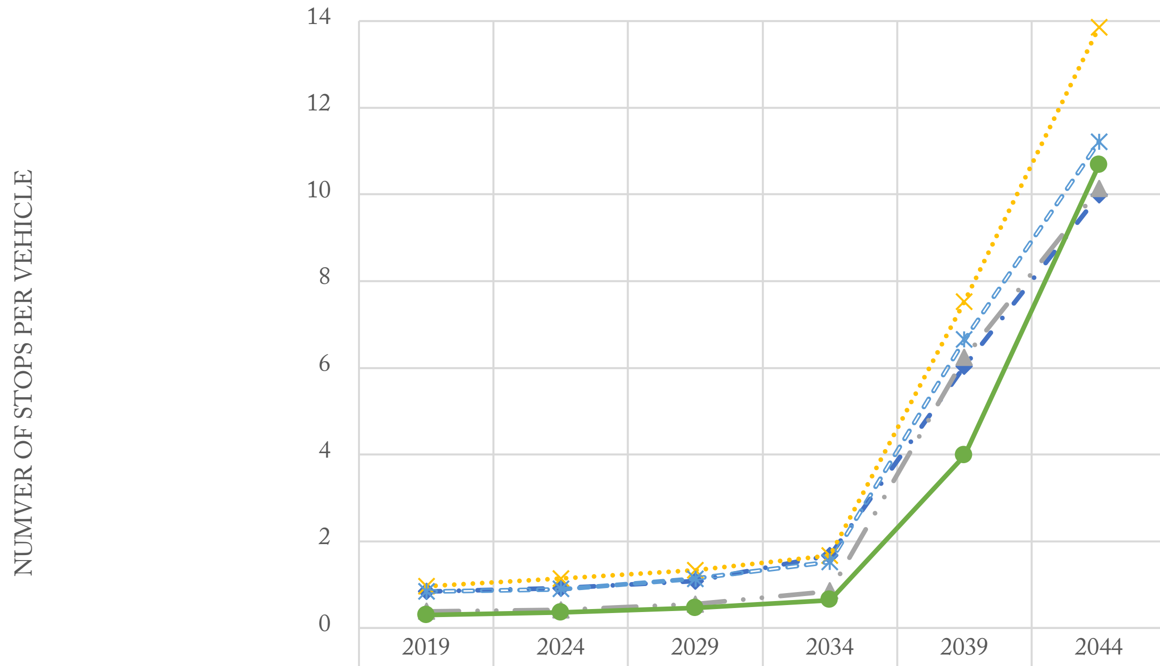


	2019	2024	2029	2034	2039	2044
Current Design (Signalized)	50	52	55	62	109	157
Entry - Exit Ramp	16	18	19	21	78	109
CFI	24	27	30	34	91	158
Direct Ramp form I-85	49	51	56	59	113	164
North-South Overpass	10	12	14	14	55	102

Figure 31 shows the estimated average number of stops for the projected traffic volumes of the Wilkinson Blvd and N. Josh Birmingham Pkwy intersection. For this intersection, the north-south overpass results in fewer stops per vehicle. As the traffic volume increases to 100 percent, the entry-exit ramp could result in a relatively fewer number of stops than the north-south overpass. CFI design results in the highest number of stops per vehicle. As the traffic volume increases, the average number of stops increases for all the considered types of alternative designs.

The LOSs for the Wilkinson Blvd and N. Josh Birmingham Pkwy intersection are summarized in Table 16. LOS is B for the entry-exit bridge and north-south overpass for the initial traffic conditions. At the same time, it is D for the current and direct ramp designs. The north-south overpass performs better at this traffic condition. When traffic increases by 100 percent, all alternative designs may operate at LOS F.

Figure 31 Estimated Average Number of Stops for Wilkinson Blvd and N. Josh Birmingham Pkwy



	2019	2024	2029	2034	2039	2044
Current Design (Signalized)	0.84	0.91	1.08	1.67	6.03	9.98
Entry - Exit Ramp	0.38	0.42	0.55	0.85	6.23	10.13
CFI	0.96	1.13	1.33	1.67	7.52	13.85
Direct Ramp form I-85	0.84	0.89	1.14	1.52	6.65	11.21
North-South Overpass	0.30	0.35	0.46	0.65	3.97	10.68

YEAR

Table 16. Estimated LOS Based on the Delay for Wilkinson Blvd & N Josh Birmingham Pkwy

Year	Current Design	Entry-Exit Bridge	CFI	Direct Ramp form I-85	North-South Overpass
2019	D	B	C	D	B
2024	D	B	C	D	B
2029	D	B	C	E	B
2034	E	C	C	E	B
2039	F	E	F	F	E
2044	F	F	F	F	F

4. Summary & Conclusions

4.1 Summary

The continued growth in air travel calls for expansion and construction efforts at many airports. The efficiency of a road network that surrounds large airports is discussed using the case of CLT. An assessment of how transportation projects impact link-level TTR was done using data analytics. A data mining technique was employed to process the data for possible trends and patterns. A before and after study design was used to assess the impact of these transportation projects on link-level TTR.

Future construction at CLT will affect the traffic conditions on its nearby roads. Roads and intersections near the airport may not be able to handle the induced traffic caused by the increased travel demand to and from the airport. Moreover, traffic volume will increase due to the population growth over time. This study aims to analyze the current traffic condition around CLT and suggest new suitable designs to effectively manage future traffic.

Two main intersections which require redesigning are the ones at West Blvd, Byrum Dr, and Steele Creek Rd and at Wilkinson Blvd and Josh Birmingham Pkwy The construction of the proposed airport terminal requires the existing West Blvd to be relocated. Hence, the traffic conditions at the intersection under consideration will change dramatically. The RCUT, CFI, mini-roundabout, and signalized designs were modeled and compared using delay and the number of stops as performance measures. The other intersection under consideration, Wilkinson Blvd and Josh Birmingham Pkwy, is the main intersection to the enter and exit the airport. Alternative designs were proposed to effectively handle the traffic situation and to improve the level of service.

4.2 Conclusions

The use of an outlier identification strategy has a significant impact on the average standard deviation of travel time. A boundary of the maximum between three standard deviations above the mean and 1.5 of the mean was used to exclude extreme values. On average, there is a reduction in the standard deviation by up to 30 percent for each project analyzed. Given the high impact of excluding extreme values, analysts need to exclude outliers after considering the length, time of outlier occurrence, and validity of "extreme" value in the face of the crash and extreme weather events.

For road connectivity projects, the construction of the Josh Birmingham Pkwy airport entrance/exit road and the connection of Little Rock Rd to the airport entrance were considered. The impact of these constructions on TTR measures decreased with an increase in distance to the construction site. The farther away from the airport, the lower the impact on TTR measures. The percentage change in BT and BTI for the surrounding road links due to the selected connectivity projects were similar and, hence, one of these measures can be used for analysis and modeling.

There was an expected increase in travel time on Wilkinson Blvd after the project was completed. However, a significant increase in TTR measures was not observed until Little Rock Rd was connected to the new entrance. This result is as expected, as the connectivity of Little Rock Rd to the new entrance attracted more demand from I-85 and I-77 interstates. Air travelers trying to access the airport would prefer to use the Little Rock Rd as it provides easier and faster access to the airport compared to the previously used route.

The effect of parking lots and staging areas for ride-sharing vehicles on TTR measures are similar. The result shows a shift in demand for road links after the construction of both the facilities. Most airports use predictive analytics to optimize car park occupancy and maximize revenue. Understanding how the demand and travel time change will help support airports in planning and allotting resources.

Different intersection designs and alternatives were selected based on the traffic conditions of the two major intersections: West Blvd, Byrum Dr, and Steele Creek Rd and Wilkinson Blvd and N. Josh Birmingham Pkwy These selected designs were implemented in the model prepared in the Vissim software, and the estimated average delay per vehicle and the number of stops per vehicle were compared for the different projected traffic volumes to find out the best design.

The results showed that RCUT (unsignalized) intersection decreased the intersection delay at West Blvd, Byrum Dr, and Steele Creek Rd considerably. The north-south overpass results in a minimum delay and number of stops at the Wilkinson Blvd & Josh Birmingham Pkwy intersection. These designs indicate relatively fewer stops with a considerable increase in traffic volume, but also a need to be reassessed and redesigned with evolving traffic conditions.

4.3 Limitations and Future Scope of Work

The study focuses on analyzing the variation in travel time within the airport vicinity. The analyses show how travel time varies with changes in connectivity and continuous construction of facilities such as parking lots and staging grounds for ride-sharing vehicles. At the same time, we expect the penetration of connected and automated vehicles (CAVs) with different levels of autonomy to affect traffic capacity and conditions. The potential effect of CAVs on airport users' travel behavior and travel-time performance measures should be studied in the future.

Selected unconventional intersection designs and access to the airport were explored in this study. The best possible design may have some limitations due to changes in traffic volumes or availability of the right-of-way. These intersection designs may not serve as expected if the traffic exceeds a certain limit or there are unexpected traffic conditions. Moreover, cost and land acquisition are important factors to be considered before the final decision. The performance of these designs with the penetration of CAVs should also be studied in the future.

Abbreviations and Acronyms

ATT	Average Travel Time
BT	Buffer Time
BTI	Buffer Time Index
CFI	Continuous Flow Intersection
CLT	Charlotte Douglas International Airport
FI	Fatal and Injury Crashes
GDP	Gross Domestic Product
GIS	Geographic Information System
HCM	Highway Capacity Manual
HPMS	Highway Performance Monitoring System
IATA	International Air Transport Association
LOS	Level of Service
MAPE	Mean Absolute Percentage Error
NPMRDS	National Performance Management Research Data Set
OWSC	One Way Stop-Controlled
PDO	Property Damage Only Crashes
RCUT	Restricted Crossing U-Turn
RITIS	Regional Integrated Transportation Information System
TTR	Travel Time Reliability
TWSC	Two Way Stop-Controlled
WSDOT	Wisconsin Department of Transportation

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