I-40 Pre-Feasibility Study

Regional Transportation Alliance

May 2021

AECOM

Acknowledgements

Thank you to the Regional Transportation Alliance and AECOM for their involvement and support in this pre-feasibility process, as well as their commitment to transit planning in the Triangle region.

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Executive Summary

The purpose of this study is to evaluate options for a dedicated transit facility along the I-40 corridor through the Triangle region. The goals of this project are to: 1) provide connections to the five future BRT routes and proposed commuter rail line, 2) identify a low-cost, near-term option for a transit priority facility, and 3) maintain a transit speed of 45 miles per hour (mph), regardless of travel conditions in adjacent mainline lanes on I-40.

The study area of interest is the I-40 corridor between the Martin Luther King (MLK)/NC 86 interchange in Chapel Hill through the Wilmington Street interchange in Raleigh (exits 266 to 299). This corridor is critical to transit because it would facilitate a high-frequency connection to the five planned Bus Rapid Transit (BRT) projects in the Triangle region via the Eubanks Road Park and Ride Lot in Chapel Hill and the soon to be completed Raleigh Union Station Bus Multimodal Facility.

This study is not meant as a substitute for a full feasibility report, but rather, as a preliminary review to screen potential alternative concepts and their application to this freeway. Transportation engineers, planners, and practitioners will find the report of special value in helping to identify appropriate dedicated alternative concepts for the I-40 corridor.

The project team applied a two-tier analysis to accomplish the goals and objectives of this study. Tier 1 identified transit priority alternative concepts and best practices and reviewed the alternative concepts to screen them for their ability to meet the goals of this study. The seven transit priority facility types were evaluated in the Tier 1 analysis included:

- Separated busways
- Freeway bus lanes
- Freeway HOV lanes
- Freeway HOT lanes
- Reversible Express lanes
- Dynamic Shoulder lanes
- Bus on Shoulder System (BOSS)

The results of the tier 1 analysis found that none of the transit priority facility types met all the criteria. As a result, the project team evaluated whether any of the transit priority facility types could be modified to meet the project goals. The result of this analysis found that moving the BOSS to the inside (left) shoulder would make it feasible for buses to travel at 45 mph and thus meeting the project goals. This new transit priority facility concept was called a Transit Priority Shoulder, which is defined as follows:

- Left shoulder would be modified or expanded to 14 feet wide to provide adequate room for buses to operate safely by providing a buffer between the median and general-purpose travel lanes.
- Buses can operate in the inside (left) shoulder at a maximum speed of 45 mph when traffic in the general-purpose travel lanes are moving at a reduced speed.

The tier 2 analysis involved a three-step approach to evaluating the transit priority shoulder concept for applicability to the I-40 corridor. Step 1 was to divide the 33-mile corridor into 8 segments based on the changes to the typical section (i.e. number of lanes, size of shoulders, and median barrier). Step 2 compared the existing pavement widths to the proposed pavement widths. Step 3 reviewed the pavement needs and right-of-way needs.

The results of the tier 2 analysis found that overall, no additional right-of-way was needed anywhere along the I-40 corridor. Existing pavement widths may be sufficient for the majority of the I-40 corridor if the general-purpose lanes are reduced from 12-feet to 11-feet. Two segments where this is not the case is the segment west of US 15-501 and the segment from NC 540 to Wade Avenue.

Based on these findings, the project team recommends that a full feasibility study be conducted on the transit priority shoulder. A full feasibility study would provide a detailed assessment and full understanding of infrastructure improvements and costs required to implement the alternative concept. It is recommended that the scope of the feasibility study include the following elements:

- Determine the design criteria through coordination with NCDOT, GoTriangle, CAMPO, and DCHC MPO
- Assess structures along the corridor to determine if modifications would be required
- Assess the cross section along the route for areas requiring additional pavement width
- Evaluate the depth of the shoulder pavement to determine if it is enough to handle regular use by buses
- Evaluate median barriers to determine if additional reinforcement is needed
- Identify utilities, signage, ITS infrastructure for relocations
- Develop a detailed cost estimate for the transit priority shoulder
- Identify possible minimum operable segment(s) and/or pilot projects

1 Introduction

The purpose of this study is to evaluate options for a dedicated transit facility along the I-40 corridor through the Triangle region. The study area of interest is the I-40 corridor between the Martin Luther King (MLK)/NC 86 interchange in Chapel Hill through the Wilmington Street interchange in Raleigh (exits 266 to 299). This corridor is critical to transit because it would facilitate a high-frequency connection to the five planned Bus Rapid Transit (BRT) projects in the Triangle region (described below) via the Eubanks Road Park and Ride Lot in Chapel Hill and the soon to be completed Raleigh Union Station Bus Multimodal Facility:

1. **North-South BRT Project, Chapel Hill:** AECOM is currently working with Chapel Hill to design a BRT line that would connect to the northern terminus of the proposed corridor at the MLK/NC 86 and I-40 interchange.
2. **Wake BRT: New Bern Avenue, Raleigh:** New Bern Avenue will connect downtown Raleigh with WakeMed and New Hope Road.
3. **Wake BRT: Western Boulevard, Raleigh:** The Wake BRT Western Boulevard Corridor project would intersect the proposed corridor along I-40, resulting in BRT between Cary and Raleigh.
4. **Wake BRT: Southern Corridor, Raleigh:** Wake BRT's Southern Corridor would intersect the proposed project at South Wilmington Street to connect downtown Raleigh with the North South Station and Purser Drive in Garner.
5. **Wake BRT: Northern Corridor, Raleigh:** The Northern Corridor will extend from downtown Raleigh north to Crabtree Boulevard along either Capital Boulevard or West Street.

Exhibit 1. *North-South Bus Rapid Transit.*

In addition to the BRT projects, the proposed project - with intermediate stops in West Raleigh, Morrisville, and RTP - could connect to the planned commuter rail line that would travel between Durham, Cary, and Raleigh. **Figure 1-1** shows the proposed I-40 corridor in relation to the five proposed BRT projects and the planned commuter rail project in the Triangle region.

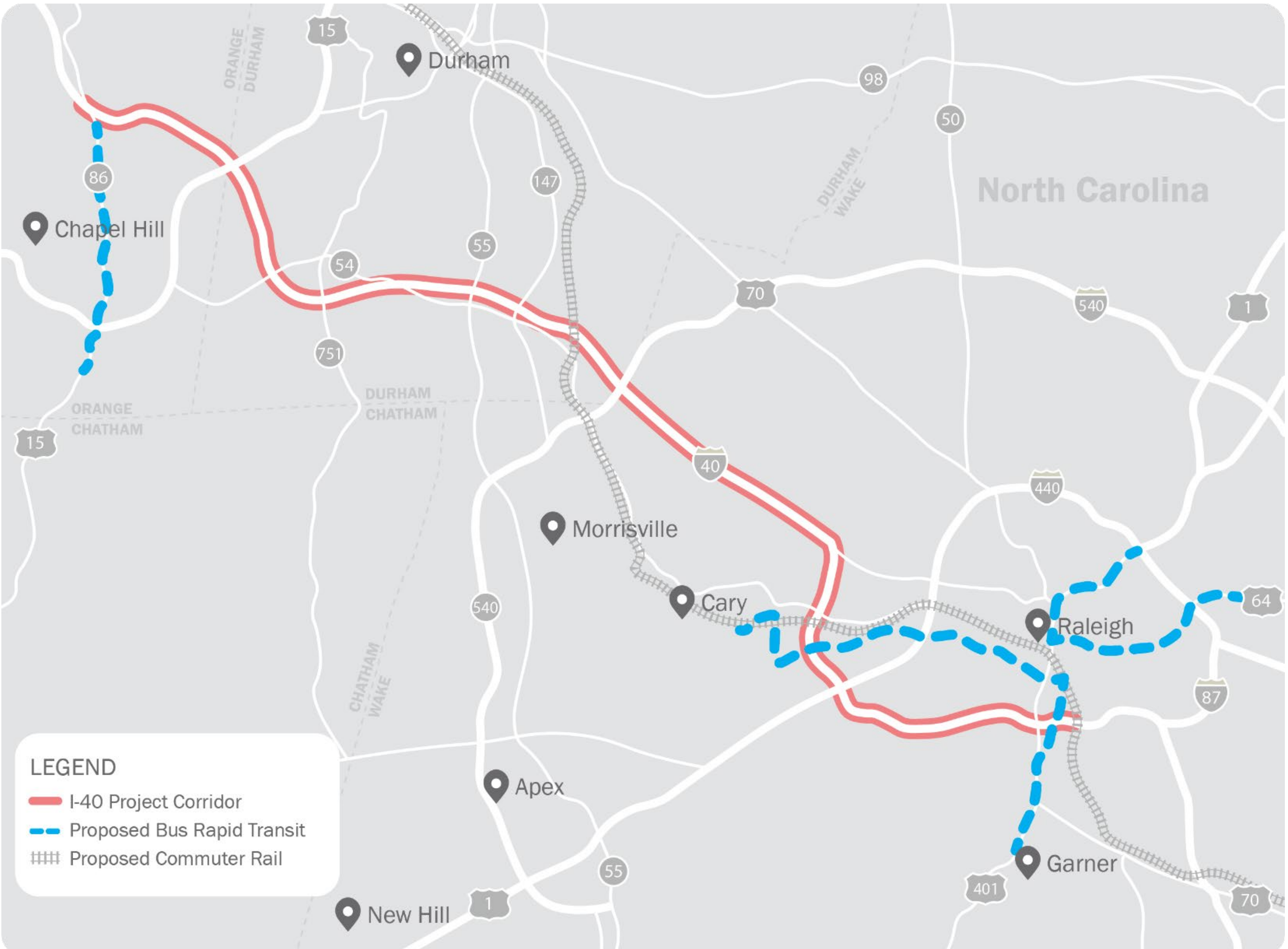


Figure 1-1. Project Corridor and Study Area

The I-40 corridor may have the potential to accommodate new transit priority facilities, such as a dedicated travel lane or shoulder for mass transit use. This would minimize overall travel delay by persons on mass transit modes; the benefits to the transit riders on the highway must balance with the effects on the rest of the roadway traffic.

The goals of this project are as follows:

- Provide connections to the five future BRT routes and proposed commuter rail line
- Identify a low-cost, near-term option for a transit priority facility
- Maintain a transit speed of 45 miles per hour (mph), regardless of travel conditions in adjacent mainline lanes on I-40

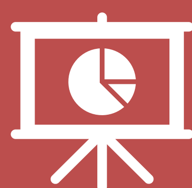
Our Approach

Potential transit facilities were screened using a two-tier analysis that is described in depth in the *Methodology and Analysis* section. Recommendations were made based on the review of transit priority success concepts from other regions. To better assess the options for the project, AECOM convened a panel of experts to review the concepts and provide feedback on options considered and criteria that should be included in the analysis. Additional guidelines and findings in this study were based on a review of relevant American Association of State Highway and Transportation Officials (AASHTO) documents and design reports, such as the Transit Cooperative Research Program (TCRP) Report 151, A Guide for Implementing Bus Shoulder Systems (2012).

This study is not meant as a substitute for a full feasibility report, but rather, as a preliminary review to screen potential alternative concepts and their application to this freeway. Transportation engineers, planners, and practitioners will find the report of special value in helping to identify appropriate dedicated alternative concepts for the I-40 corridor.

Review

Research alternative concepts and best practices that may be applicable to the project.



Apply/Screen

Screen the alternative concepts using a two-tier analysis.

Recommend

Provide recommendations for further evaluation of the most applicable alternative concepts.

2 Existing Infrastructure and Services

I-40 serves as the major route between Durham, Cary, and Raleigh. The I-40 corridor of interest for this study is approximately 33 miles in length. The current roadway characteristics and conditions for the corridor are listed below. In addition, a description of the current Bus on Shoulder System (BOSS) is provided and is later evaluated in this study.

2.1 Roadway Conditions

For this study, the I-40 corridor was divided into eight segments (labeled A through H) based on the change in typical sections (**Figure 2-1**). The labels in the map correspond to the corridor segments in **Table 2-1**.

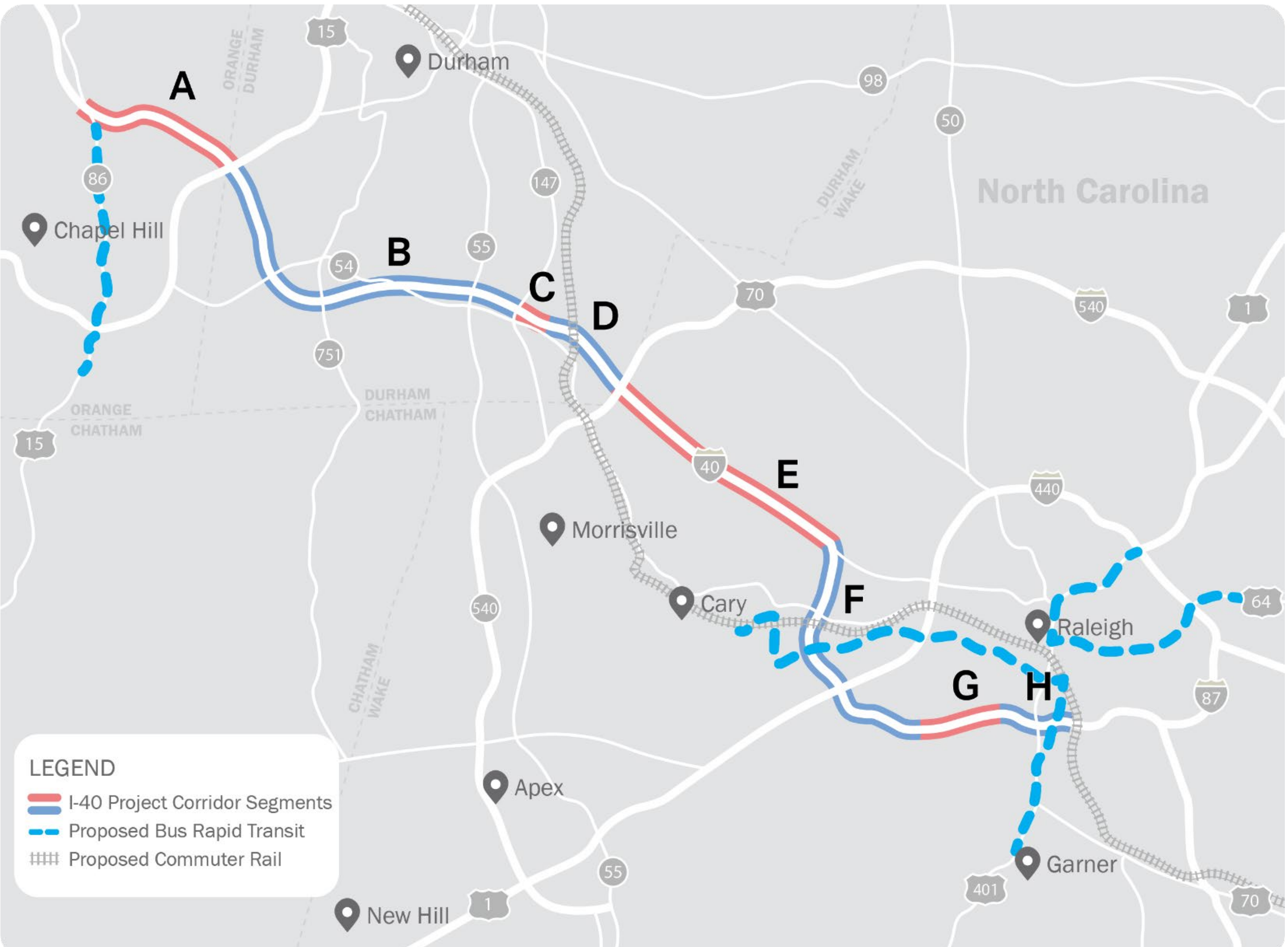


Figure 2-1. I-40 Corridor Segments

The following existing roadway characteristics were documented for each I-40 corridor segment:

- Number of lanes
- Lane width
- Shoulder width
- Rumble strip presence
- Median guardrail or separation type
- Right-of-way (ROW) width
- Daily traffic volume

The estimated ROW measurements were compiled using ArcGIS and are based on Wake and Durham Counties' property lines.

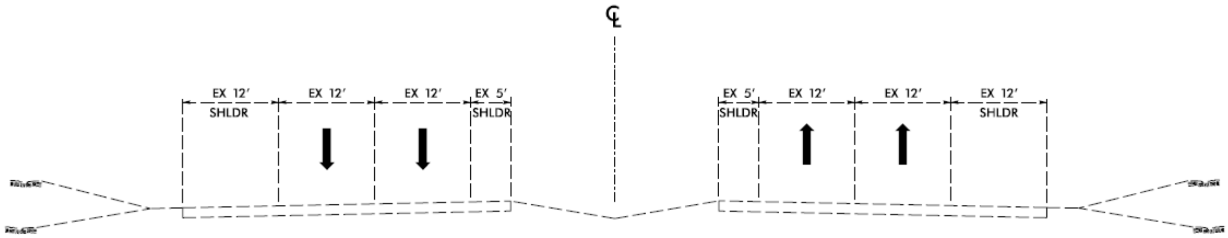
Table 2-1. *I-40 Corridor Existing Conditions*

Segment	Map Label	Typical Section	Number of Lanes	Lane Width*	Inside Paved Shoulder Width*	Outside Paved Shoulder Width*	Total Pavement*	Rumble Strips	Median/ Guardrail/ Separation	App. ROW **
MLK Jr. Blvd/NC 86 to US 15-501	A	1	4 Lane Divided	12'	5'	12'	41' EB, 41' WB **82' Total**	Y	36' Grass	260-340'
US 15-501 to NC 147	B	2	6 Lane Divided	12'	12'	11'	59' EB, 59' WB **118' Total**	Y	Concrete Barrier	290-340'
NC 147 to Davis Drive	C	4	8 Lane Divided	12'	12'	14'	73' EB, 65' WB **138' Total**	Y	Concrete Barrier	370-420'
Davis Drive to NC 540	D	5	10 Lane Divided	12'	12'	14'	86' EB, 86' WB **172' Total**	Y	Concrete Barrier	312'
NC 540 to Wade Ave	E	4	8 Lane Divided	12'	7' (WB) 11' (EB)	11'	70' EB, 66' WB **136' Total**	Y	Guardrail	355'
Wade Ave to Gorman St	F	2	6 Lane Divided	12'	12'	11'	59' EB, 59' WB **118' Total**	Y	None or Guardrail	448'
Gorman St to Lake Wheeler Rd	G	3	3 Lane eastbound (EB) and 4 Lane westbound (WB)	12'	10'	14'	60' EB, 72' WB **132' Total**	Y	None or Concrete Barrier	410'
Lake Wheeler Rd to S Wilmington St	H	4	8 Lane Divided	12'	12'	14'	73' EB, 69' WB **142' Total**	Y	Concrete Barrier	390'

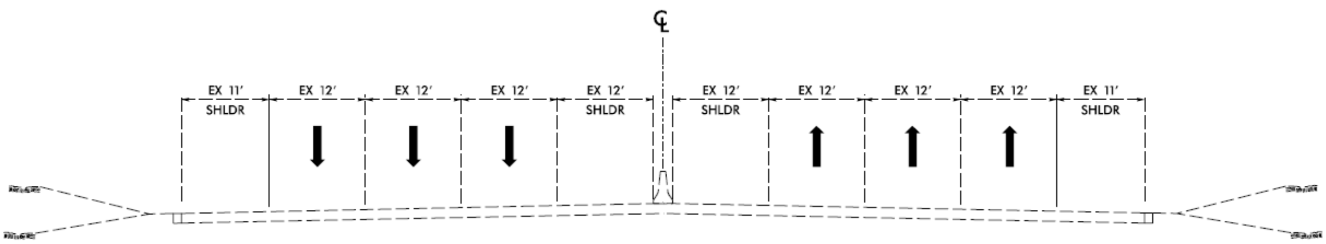
**Note: Lane, shoulder, and pavement width vary somewhat throughout each segment, most commonly at bridges and overpasses, as well as to accommodate overhead signage, drainage, among other constraints.*
***Note: Existing signs, structures, and vegetation take up ROW.*

Typical sections displaying the existing conditions for each I-40 corridor segment are provided below. Each typical section provides pavement widths for shoulders and travel lanes. Segments B and F have similar cross sections, as do segments C, E, and H.

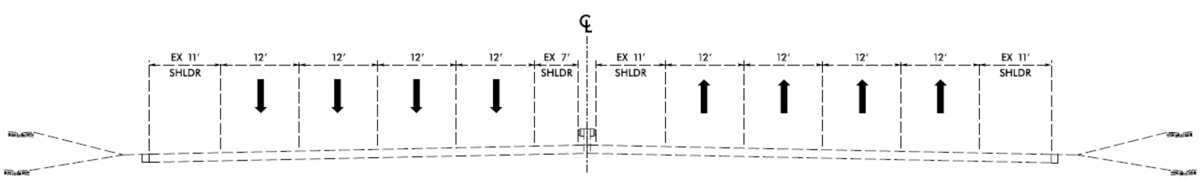
Segment A - MLK Jr. Blvd/NC 86 to US 15-501



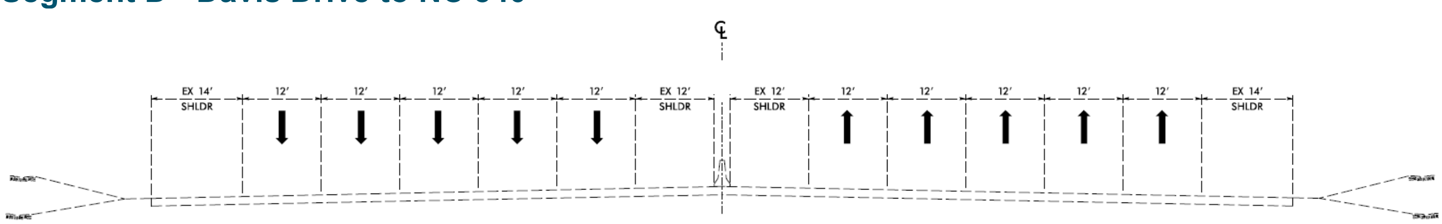
Segment B – US 15-501 to NC 147



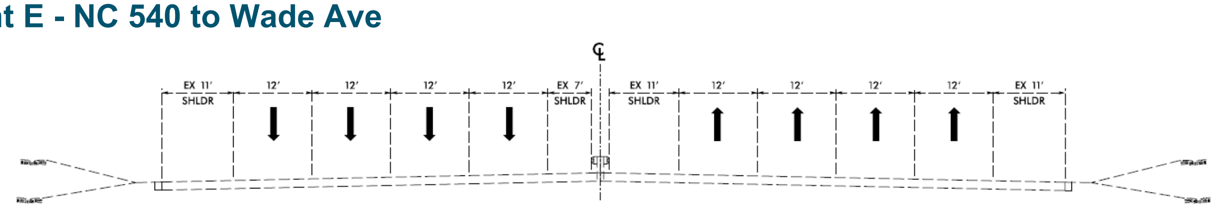
Segment C - NC 147 to Davis Drive



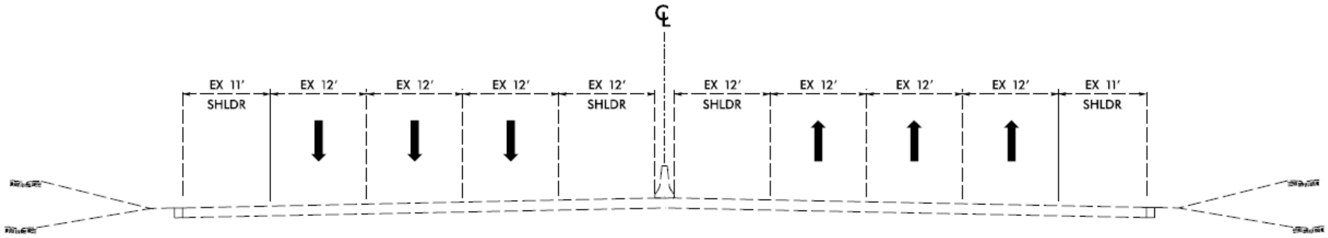
Segment D - Davis Drive to NC 540



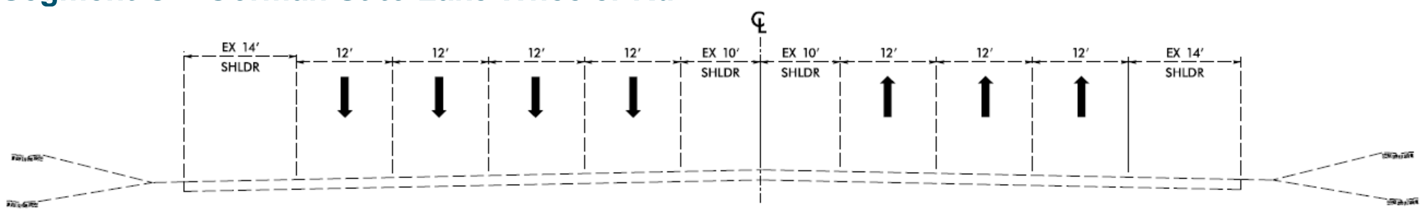
Segment E - NC 540 to Wade Ave



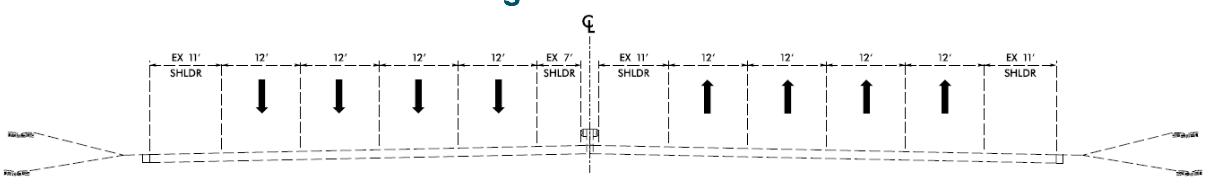
Segment F - Wade Ave to Gorman St



Segment G – Gorman St to Lake Wheeler Rd



Segment H - Lake Wheeler Rd to S Wilmington St



2.2 Planned Projects

There are many planned projects in the surrounding area (**Table 2-2**). In addition to the projects listed below, The Capital Area Metropolitan Planning Organization (CAMPO) is conducting a bus on shoulder study in the Triangle Region. CAMPO, the North Carolina Department of Transportation (NCDOT), GoTriangle, and the Durham-Chapel Hill-Carrboro (DCHC) MPO are the study partners and they desire to explore the applicability of bus on shoulder to the wider transportation network in order to properly plan for, design, and implement bus on shoulder projects on corridors throughout the region. The NCDOT has an interest in using a methodology created in the bus on shoulder study to apply to other corridors and regions throughout the state. The study is expected to be completed by late June 2021.

Table 2-2. *Nearby Planned Projects*

Project (TIP/SPOTID)	Description
EB-4707B	SR 1113 (POPE ROAD) TO SR 1116 (GARRETT ROAD)
I-3306AC (H090010)	NC 86 INTERCHANGE IMPROVEMENTS
I-5506 (H128080)	SR 1002 (AVIATION PARKWAY) INTERCHANGE. IMPROVE INTERCHANGE AND CONSTRUCT AUXILIARY LANE ON I-40 WESTBOUND FROM SR 1002 TO SR 3015 (AIRPORT BOULEVARD).
I-5700 (H128081)	SR 3015 (AIRPORT BOULEVARD). REVISE INTERCHANGE; CONSTRUCT AUXILIARY LANES ON I-40 EASTBOUND FROM I-540 TO SR 3015 (AIRPORT BOULEVARD) AND FROM SR 3015 TO SR 1002 (AVIATION PARKWAY), AND CONSTRUCT AUXILIARY LANE ON I-40 WESTBOUND FROM SR 3015 (AIRPORT BOULEVARD).
I-5701 (H090045)	I-440 / US 1 / US 64 TO SR 1370 (LAKE WHEELER ROAD) IN RALEIGH. ADD LANES.
I-5702A (H111131)	US 15 / US 501 TO NC 147
I-5702B (H111013)	NC 147 (DURHAM FREEWAY / TRIANGLE EXPRESSWAY) IN DURHAM COUNTY TO SR 1728 (WADE AVENUE) IN WAKE COUNTY.
I-5703 (H140771)	I-440 / US 1 / US 64 INTERCHANGE IN RALEIGH. RECONSTRUCT INTERCHANGE.
I-5822	I-85 TO EAST OF SR 1734 (ERWIN ROAD). PAVEMENT REHABILITATION
I-5873 (H128079)	NC 54 IN RALEIGH. INTERCHANGE IMPROVEMENTS.
I-5943	SR 1728 (WADE AVENUE) TO I-440 / US 1 IN RALEIGH. PAVEMENT REHABILITATION.
I-5982 (H150716)	I-40 IN DURHAM TO I-495 / US 64 / US 264 IN KNIGHTDALE. CONSTRUCT MANAGED SHOUDERS.
TA-6669 (T150454)	PURCHASE EXPANSION VEHICLES FOR CRX ROUTE.
TD-5272 (T141691)	SOUTH WILMINGTON STREET AT PECAN ROAD IN RALEIGH. CONSTRUCT OFF-STREET TRANSFER FACILITY (GO RALEIGH TRANSIT)
U-2719 (H090358)	SOUTH OF SR 1313 (WALNUT STREET) TO NORTH OF SR 1728 (WADE AVENUE) IN RALEIGH. WIDEN FROM FOUR TO SIX LANES, IMPROVE STORAGE AT LAKE BOONE TRAIL INTERCHANGE AND INSTALL RAMP METERS.
U-5811 (H090392)	NC 54 TO I-40 IN MORRISVILLE. WIDEN TO MULTILANES WITH INTERCHANGE MODIFICATIONS AT I-40.
U-5934 (H110997)	I-40 TO FUTURE I-885 (EAST END CONNECTOR) IN DURHAM. ADD LANES AND REHABILITATE PAVEMENT.
U-5936 (H140408)	I-40 TO I-440 IN RALEIGH. ADD LANES.

2.3 Existing Concept

To maintain bus schedules, the NCDOT partnered with local transportation systems to allow specific buses to travel on the shoulders of designated interstate segments and primary routes. This system is known as the BOSS and aims to provide reliable service and encourage public transportation use in the Triangle Region. According to NCDOT, trained bus drivers may only travel on shoulders when traffic on designated roads slows below 35 mph. The following restrictions apply to drivers participating in the BOSS:

- Buses can travel no more than 15 mph faster than traffic (maximum speed of 35 mph).
- Buses must yield to emergency response vehicles and other vehicles parked in the shoulder.
- Bus drivers must use their own judgment to determine whether conditions are safe to travel on the shoulder.

As depicted in the exhibit below, GoTriangle buses may use the BOSS on I-40 between U.S. 15-501 in Durham and Wade Avenue in Raleigh. The BOSS continues on Wade Avenue to Blue Ridge Road and is authorized for some transit routes using the I-40 shoulder east of Raleigh, from the Beltline to N.C. 42 (Exit 312) in Johnston County. **Figure 2-2** highlights this segment of the BOSS along the I-40 corridor.

Exhibit 2. *GoTriangle bus utilizing the BOSS on I-40 (NCDOT).*

According to NCDOT, the BOSS provides several benefits in the corridor, such as shorter and more predictable and reliable transit times, fewer missed connections for bus riders, reduced driver overtime, potential increased ridership, and decreased operational costs. CAMPO is currently conducting a bus on shoulder study to identify feasible, regional, corridors suitable for BOSS services in Wake, Durham, and Orange Counties.

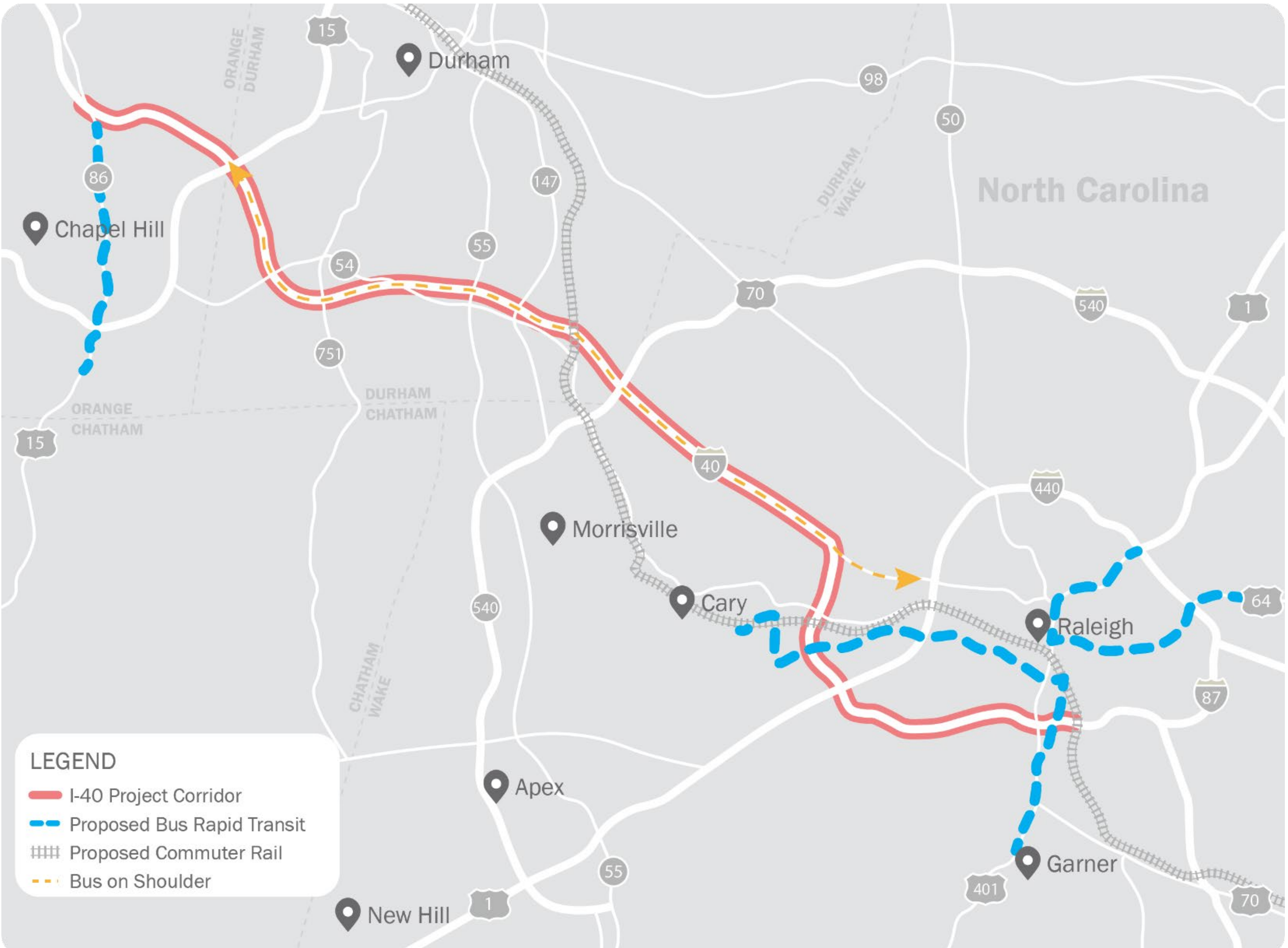


Figure 2-2. *Existing BOSS on the I-40 Project Corridor*

2.4 Existing Roadway Usage

Existing data related to the average annual daily traffic (AADT) on the I-40 project corridor is provided in **Table 2-3.** According to NCDOT, Davis Drive to NC 540 (Segment D) contains the highest AADT at 189,600, while MLK Jr. Boulevard/NC 86 to US 15-501 (Segment A) contains the lowest AADT at 79,500.

Table 2-3. *Existing Bus Data*

Segment	Map Label	Number of Lanes	AADT	AADT per Lane
MLK Jr. Blvd/NC 86 to US 15-501	A	4 Lane Divided	79,500	19,875
US 15-501 to NC 147	B	6 Lane Divided	124,700	20,783
NC 147 to Davis Drive	C	8 Lane Divided	173,000	21,625
Davis Drive to NC 540	D	10 Lane Divided	189,600	18,960
NC 540 to Wade Ave	E	8 Lane Divided	168,300	21,038
Wade Ave to Gorman St	F	6 Lane Divided	129,700	21,617
Gorman St to Lake Wheeler Rd	G	3 EB 4 WB	141,000	20,143
Lake Wheeler Rd to S Wilmington St	H	8 Lane Divided	137,900	17,238

Source: NCDOT AADT data (2019): https://ncdot.maps.arcgis.com/apps/webappviewer/index.html?id=5f6fe58c1d90482ab9107ccc03026280.

To gain a better understanding of bus use on the I-40 corridor, the team collected information from GoTriangle **(Table 2-4)**. This data set includes information on bus routes, exits used on I-40, and bus frequency and ridership.

Table 2-4. *GoTriangle Bus Data*

I-40 Exit to/from	Routes	Combined Frequency	Combined Ridership	Notes
266 - 273	CRX	2	134	Chapel Hill- Raleigh peak direction only (i.e., to Raleigh in a.m., from Raleigh in p.m.)
273 - 279	CRX, 800	8	1,193	Route 800s also operates between 273 and 276
279 - 282	CRX, DRX, 700, 800	20	2,167	N/A
282 - 284	CRX, DRX	12	897	N/A
284 - 289	CRX, DRX, 100, 105	20	1,639	Route 100 operates between 285 and 289

Source: GoTriangle.

Note: Ridership is from FY19 / pre-COVID. All figures are combined eastbound / westbound, unless noted otherwise. In addition, there are several deadhead movements at the ramp up to p.m. rush hour that would benefit from increased reliability on I-40 between exits 266 and 299.

3 Methodology and Analysis

This study will (1) identify transit priority alternative concepts and best practices, (2) review the alternative concepts and screen them through a two-tier analysis, and (3) identify, at a pre-feasibility level of analysis, the least costly, practical alternative concept(s) for the I-40 corridor. The two-tier analysis is described in depth below.

Two-Tier Analysis:

- **Tier 1:** Rule out alternative concepts that would be substantially or orders-of-magnitude higher in cost. Variables for determining cost of alternative concepts are provided in **Table 4-1**.
- **Tier 2:** The second analysis would require a deeper dive into the remaining option(s) that could include identifying adequate existing paved areas for most segments, but not all segments or identify/inventory which structures may require alterations/expansions.

According to AASHTO's Guide for Geometric Design of Transit Facilities on Highways and Streets (2014), the following alternative concepts for transit may be applied to limited access highways:

- Separated busways
- Freeway bus lanes
- Freeway high-occupancy vehicle (HOV) lanes
- Freeway high-occupancy toll (HOT) lanes
- Reversible express lane
- Bus on shoulder system
- Dynamic shoulder lane

4 Tier 1 Analysis

The Tier 1 Analysis will screen the potential dedicated transit facilities for their applicability to the I-40 corridor. Note, this screening is based on the goals of this project – to identify lower cost solutions that require less changes to the existing roadway conditions and that can be implemented in the near-term. Thus, dedicated transit concepts ruled out in the Tier 1 Analysis may in fact be viable, but for the goals of this study have been ruled out due to complexities that would lead to higher costs and require a longer-timetable to implement.

The Tier 1 Analysis evaluated the potential dedicated transit facilities based on the following criteria:

- Does the alternative concept provide a transit priority facility?
- Does the alternative concept allow for buses to travel at a reliable and consistent speed that is equal to or greater than 45 mph?
- Is the alternative concept a low-cost solution that can be implemented without substantial changes to the existing roadway?

A summary of the Tier 1 Analysis is provided below in **Table 4-1**. The alternative concepts eliminated in the Tier 1 Analysis would be substantially or orders-of-magnitude higher in cost if they potentially involve substantially increasing paved roadway surface (width), the replacement of several bridge structures, require intelligent transportation system (ITS) infrastructure, increase operational costs, and/or multiple, material acquisitions of ROW along the corridor.

Table 4-1. *Tier 1 Analysis of Alternative Concepts*

Alternative Concept	Provide a Transit Priority Facility	Allows Buses to Operate ≥ 45 mph?	Does not require substantial changes to existing infrastructure
Separated Busways	✓	✓	✗
Freeway Bus Lanes	✓	✓	✗
Freeway HOV Lanes	✓	✓	✗
Freeway HOT Lanes	✓	✓	✗
Reversible Express Lane	✓	✓	✗
BOSS	✓	✗	✓
Dynamic Shoulder Lanes	✓	✓	✗

Note: ✗ - means the alternative concept cannot meet this element of the project goals
✓ - means the alternative concept may meet this element of the project goals

Two assumptions were made as part of this analysis: (1) existing travel lanes would not be converted from their current use and (2) re-purposing or eliminating the existing shoulders to provide the required space for the alternative concept would be needed to meet the goals of this project. The Tier 1 Analysis found that none of the alternative concepts would meet the goals of this project. A snapshot of each alternative concept is provided in the following section.

4.1 Alternative Concepts

The seven alternative concepts are described in further depth below. Examples of locations where the alternative concept has been implemented are provided. An assessment is made on each alternative concept to see how it translates to the I-40 corridor. Further analysis of existing pavement and ROW are summarized in the following subsections and the full methodology and results are provided in Attachment A.

The advantages and disadvantages associated with each alternative concept (according to AASHTO) are listed below in **Table 4-2**.

Table 4-2. *Types of Preferential Treatments for Buses on Limited Access Highways*

Alternative Concepts	Advantages	Disadvantages
Separated (exclusive) Busways	▪ Increase bus speed by reducing sources of delay ▪ Improve schedule reliability ▪ Increase transit identity and visibility	▪ Difficulty obtaining sufficient ROW in existing or new corridor ▪ Cost to design and construct
Freeway Bus Lanes	Same advantages as exclusive busway; however, benefits may not be as substantial: ▪ Increase bus speed ▪ Improve schedule reliability ▪ May increase transit visibility	▪ Adverse effects on traffic, if created by eliminating an existing travel lane ▪ Cost to provide new capacity ▪ Requires provisions for preferential access
Freeway HOV Lanes	▪ Improve operating speeds for transit users, carpool, and vanpool users ▪ Improve schedule reliability ▪ Increase person movement capacity of roadway	▪ Adverse effects on traffic, if created by eliminating an existing travel lane ▪ Cost to provide new capacity ▪ Requires ongoing enforcement ▪ May pose safety problems for vehicles entering and leaving the lanes unless physically separated
Managed or Express Lanes with Preferential Access for Transit (Freeway HOT Lanes)	▪ Improve transit operating speed ▪ Improve schedule reliability	▪ Requires a policy commitment to prioritizing transit as an objective of the managed lane operation
Reversible Express Lane	▪ Flexible lanes ▪ Decrease congestion ▪ Improve peak hour travel speeds	▪ Requires educational campaign ▪ Require additional signage and safety features
BOSS	▪ Improve on-time performance ▪ Decrease trip time ▪ Low cost	▪ Operational challenge when debris or vehicles are present on the shoulder
Dynamic Shoulder Lane	▪ Decrease congestion	▪ Cost for electronic signage and tolling infrastructure

Source(s): AASHTO Guide for Geometric Design of Transit Facilities on Highways and Streets, 1st Edition (2014) and FHWA, Use of Freeway Shoulders for Travel — Guide for Planning, Evaluating, and Designing Part-Time Shoulder Use as a Traffic Management Strategy.

4.1.1 Separated Busways

Separated busways may be within the freeway's ROW or detached from the freeway. They are typically associated with BRT networks because they help improve travel times. The road surface for this facility may be a different color to deter other users from entering the lane. The facility can be built to replace a median if space allows. Separated busways may contain bollards or medians to protect buses from adjacent traffic.

Exhibit 3. *Separated busway in Melbourne, Australia.*

Example of Implementation

El Monte, located in California, has a separated busway. This busway is an 11-mile long shared-use express bus corridor and HOT lane that runs west along I-10 from I-605 and the El Monte Station. The image to the right displays a similar configuration to the El Monte busway, but it is located in Melbourne, Australia.

Table 4-3. *Snapshot of separated busways*

Alternative Concept	Typical Section (Lanes/Median)	Max Speeds	Buffer between Median	Buffer between Travel Lane
Separated Busways	2-lane / 2-way, exclusive ROW	Design speed of roadway designed	N/A	N/A

Assessment

A separated busway would be an entirely new location alignment that runs along the I-40 corridor. The pavement widths could vary depending on the need. For example, a 2-lane roadway with 1 lane in each direction could have widths of 12 feet with buffers. These widths would allow for disabled busses to pull over without blocking the travel lane.

Separated busways would improve the desired travel times for buses, by allowing for consistent travel times and for the buses to travel at a speed greater than 45 mph. Costs to implement a separated busway are expected to be moderately high, due to the need to increase the paved surface area.

Ability to Meet the Project Goals

- ✓ **Provide a Transit Priority Facility.** Separated busways would provide a priority transit facility.
- ✓ **Allow Buses to Operate ≥ 45 mph.** Designed to be a separated facility, a separated busway would be able to operate at a speed of 65 mph, regardless of the speed of traffic in adjacent lanes.
- × **Requires substantial changes to existing infrastructure.** A separated busway would require a new facility to operate on the corridor.

Decision: Eliminate separated busways from further consideration.

4.1.2 Freeway Bus Lanes

Road signs or paint markings indicate when a bus lane is in effect on a freeway. Freeway bus lanes may be made exclusive for bus use during various times throughout the day or week.

Exhibit 4. *Lincoln Tunnel bus lane.*

Example of Implementation

Exhibit 4 displays a marked exclusive bus lane leading to the Lincoln Tunnel. This bus lane runs 2.5 miles along New Jersey Route 495. The lane is open exclusively to buses each weekday between 6:00 a.m. and 10:00 a.m.

Table 4-4. *Snapshot of freeway bus lanes*

Alternative Concept	Typical Section (Lanes/Median)	Max Speeds	Buffer between Median	Buffer between Travel Lane
Freeway Bus Lanes	Existing	Design speed of roadway	N/A	N/A

Assessment

This concept would add an additional permanent lane that would be dedicated for transit during specific hours of the day. Thus, an added benefit from this concept is that the lane would be open to other roadway users during non-peak hours. In return, this would help increase the overall capacity of the I-40 corridor.

If accommodations were made for a freeway bus lane within the existing paved surface area, there would be no outside shoulder and the main travel lanes would be reduced from 12 feet to 11 feet. As a result, this would negatively impact emergency response vehicles and would take away emergency pull-offs for stalled or disabled vehicles and 11-foot travel lanes may present safety issues as well.

Ability to Meet the Project Goals

- ✓ **Provide a Transit Priority Facility.** Freeway bus lanes would provide a priority transit facility.
- ✓ **Allow Buses to Operate ≥ 45 mph.** Freeway bus lanes would allow buses to operated ≥ 45 mph.
- × **Requires substantial changes to existing infrastructure.** Freeway bus lanes would require substantial changes to existing infrastructure.

Decision: Eliminate freeway bus lanes from further consideration.

4.1.3 Freeway High-Occupancy Vehicle (HOV) Lanes

Freeway HOV lanes are exclusively reserved for vehicles that are carrying two or more passengers. In the HOV lane, these vehicles may bypass traffic in regular lanes at any given time. HOV lane users may include transit buses, cars, trucks, carpools, vanpools, motorcycles, emergency vehicles, and law enforcement. Bicycles, pedestrians, and trailer towing are not permitted.

Example of Implementation

Exhibit 5 is a rendering of the VIA Metropolitan Transit managed HOV lanes that will open along I-10 between La Cantera Parkway and Ralph Fair Road in Bexar County, Texas.

In North Carolina, the N.C. Turnpike Authority operates the NC Quick Pass app and website in which account holders can set HOV status and travel in the I-77 Express Lanes for free when the vehicle operates with three or more passengers (NC Quick Pass).

Exhibit 5. *TxDOT and VIA-managed HOV lanes.*

Table 4-5. *Snapshot of HOV lanes*

Alternative Concept	Typical Section (Lanes/Median)	Max Speeds	Buffer between Median	Buffer between Travel Lane
Freeway HOV Lanes	Existing	Design speed of roadway	6'	4'

Assessment

The assessment for freeway HOV lanes assumes that the travel lane width would be reduced by 1 foot for a total of 11 feet. There would also be a partial conversion of the inside shoulder and inside lane to a HOV lane (16 feet wide) with a 4-foot buffer between general-purpose lanes. All lanes would be shifted to the outside. Thus, an added benefit from this concept is that the lane would increase the overall capacity of the I-40 corridor.

Operationally, when buses enter or exit the HOV lane, they are required to cross or weave through the mainline traffic. This may lead to slower operations.

The only way to accommodate a freeway HOV lane within the existing paved surface area would be to eliminate the inside and outside shoulders, creating safety issues. Realistically, additional right of way would be needed to accommodate this concept.

Ability to Meet the Project Goals

- ✓ **Provide a Transit Priority Facility.** Freeway HOV lanes would provide a priority transit facility.
- ✓ **Allow Buses to Operate ≥ 45 mph.** Freeway HOV lanes would allow buses to operate at a speed ≥ 45 mph.
- × **Requires substantial changes to existing infrastructure.** Freeway HOV lanes would require substantial changes in infrastructure.

Decision: Eliminate freeway HOV lanes from further consideration.

4.1.4 Freeway High-Occupancy Toll (HOT) Lanes

Exhibit 6 is an example of a managed bus lane. These facilities generate revenue, improve safety, facilitate the movement of people and goods, and improve traffic operations through the regulation, warning, guidance, and redistribution of traffic.[1] HOT lanes are a form of managed lanes that require toll infrastructure, toll fees, and typically allow all users except for trucks. By comparison, an HOV lane is a more flexible managed lane that allows a wider range of vehicles to use it.

Exhibit 6. *Managed bus lane.*

Example of Implementation

The I-77 express lanes are tolled dedicated travel lanes located between I-277 in Charlotte and NC 150 in Mooresville near the Lake Norman area (**Exhibit 7**). The speed limit on the freeway is 65 mph and in the express/toll lanes it is 70 mph, however, people have observed express lane users operating at higher speeds. Vehicles may use the express lane for free if there are three passengers and a transponder.

Northern Virginia also has express lanes, along I-495 northbound. Inside shoulder use is permitted for about 1.5 miles along I-495 north for all vehicles. The speed limit along this stretch is 55 mph.

The I-85 express lanes in Georgia are HOT lanes on the inside shoulder that allow the following users in the express lanes to travel toll-free:

Exhibit 7. *I-77 express lanes in Charlotte.*

- Registered transit
- Three or more person carpools
- Motorcycles
- Emergency vehicles
- Alternative fuel vehicles (AFV) with the proper AFV license plate (does not include hybrid vehicles)

Vehicles with fewer than three occupants may pay to use the express lane or continue to use the general-purpose lanes. Vehicles with two or more axles and/or six or more wheels are not allowed in the express lanes. Toll costs vary depending on the number of vehicles using the express lanes.

Table 4-6. *Snapshot of HOT lanes*

Alternative Concept	Typical Section (Lanes/Median)	Max Speeds	Buffer between Median	Buffer between Travel Lane
Freeway HOT Lanes	Existing	Design speed of roadway	6’	4’

[1] FHWA. Freeway Management and Operations Handbook. https://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter8_01.htm

Assessment

The assessment for HOT lanes assumes travel lanes are 12 feet wide and a partial conversion of inside shoulder and inside lane to a managed lane (16 feet wide) with 4-foot buffer between general-purpose lanes. All lanes would be shifted outside.

The only way to accommodate a HOT lane within the existing paved surface area would be to eliminate the inside and outside shoulders, creating safety issues. Realistically, additional right of way would be needed to accommodate this concept.

This alternative concept would require the installation of ITS infrastructure along the corridor and involve significant operational costs.

Ability to Meet the Project Goals

- ✓ **Provide a Transit Priority Facility.** Freeway HOT lanes would provide a priority transit facility.
- ✓ **Allow Buses to Operate ≥ 45 mph.** Freeway HOT lanes would allow buses to operate at a speed ≥ 45 mph.
- × **Requires substantial changes to existing infrastructure.** Freeway HOT lanes would require ITS installment and toll infrastructure, as well as operational costs.

Decision: Eliminate Freeway HOT Lanes from further consideration.

4.1.5 Reversible Express Lane

Reversible express lanes allow traffic to travel in either direction, depending on the road conditions. **Exhibit 8** provides an example of the lanes with overhead signage and lighting that signals to drivers which direction to travel in. Reversible lanes are often found in tunnels or on bridges and may contain barriers between the reversible lane and other travel lanes.

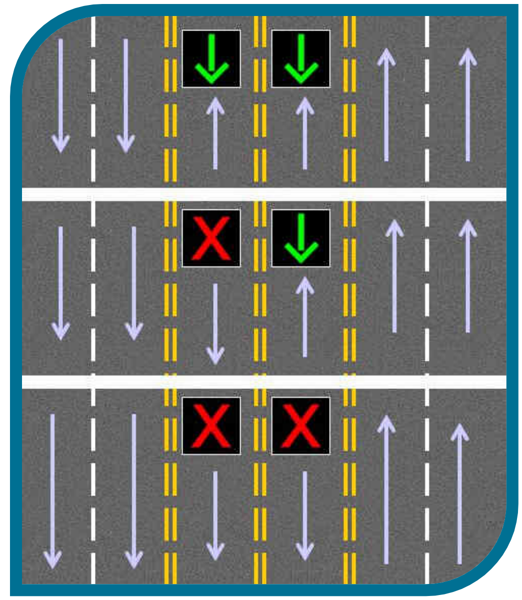


Exhibit 8. Reversible lanes with signage examples.

Example of Implementation

The Lee Roy Selmon Expressway contains reversible lanes and is an all-electronic, limited access toll road that travels through Hillsborough County in Florida. This route is elevated between Brandon and Tampa (**Exhibit 9)**.

Exhibit 9. Elevated reversible lanes on the Lee Roy Selmon Expressway.

Table 4-7. Snapshot of a reversible express lane

Alternative Concept	Typical Section (Lanes/Median)	Max Speeds	Buffer between Median	Buffer between Travel Lane
Reversible Express Lane	Existing	Design speed of roadway	12’	12’

Assessment

The assessment for reversible express lanes assumes that both travel lanes and a new reversible lane are 12 feet wide. The reversible lane (18 feet wide) will also have a varying buffer and barriers on both sides.

To accommodate a reversible express lane within the existing paved surface area, there would be no outside shoulder which would negatively impact emergency response vehicles and would take away emergency pull-offs for stalled or disabled vehicles.

This alternative concept would require the installation of ITS infrastructure along the corridor and involve substantial operational costs.

Ability to Meet the Project Goals

- ✓ **Provide a Transit Priority Facility.** Reversible express lanes would provide a priority transit facility.
- ✓ **Allow Buses to Operate ≥ 45 mph.** Reversible express lanes would allow buses to operate at a speed ≥ 45 mph.
- × **Requires substantial changes to existing infrastructure.** Reversible express lanes would require ITS installment and operational costs.

Decision: Eliminate Reversible Express Lanes from further consideration.

4.1.6 Bus on Shoulder

When buses operate on shoulders, they typically use the outer (right) shoulder when freeways are congested. The outer shoulder allows buses to enter and leave the freeway with ease. This concept is a low-cost strategy since existing shoulders can sometimes be used without design upgrades. In many cases shoulders must be modified and strengthened to accommodate bus operations. It can be implemented when the free-flow speed of the travel lanes drops below a specific threshold.

According to the design guidelines in the Transit Cooperative Research Program (TCRP) Report 151, A Guide for Implementing Bus Shoulder Systems (2012), BOSS programs do not affect general traffic flow. Unlike HOV lanes, BOSS systems typically carry lower volumes of traffic which minimize pressure on emergency vehicle travel. BOSS is currently operating in the I-40 corridor.

Example of Implementation

The Minneapolis-St. Paul Twin Cities area contains 271 miles of shoulders for authorized BOSS and is often used as a BOSS model (Douma, 2007). The concept was quickly implemented within a couple of weeks following a flooding event that closed major highways (TCRP Report 151, 2012).

Additional examples of bus on shoulder facilities include the following:

- I-264/Virginia Beach, all vehicles can use the outside shoulder during peak periods.
- I-93 north of Boston, all vehicles can use the outside shoulder during peak periods, with a speed limit of 45 mph.
- I-70 eastbound, west of Denver use the inside shoulder during peak periods.

Exhibit 10. *Bus on shoulder system in Kansas.*

Table 4-8. *Snapshot of bus on shoulder*

Alternative Concept	Typical Section (Lanes/Median)	Max Speeds	Buffer between Median	Buffer between Travel Lane
Bus on Shoulder	Existing	15 mph faster than traffic/max 35 mph	N/A	N/A

Assessment

The assessment for the bus on shoulder concept assumes that both travel lanes and the outside shoulder are 12 feet wide. The shoulder width was selected with respect to the existing conditions of the corridor which range between 11 and 14 feet. The TCRP Report 151 states that 10-foot width shoulders are sufficient for BOSS operations, however; 12-foot shoulder widths are more desirable.

Ability to Meet the Project Goals

- ✓ **Provide a Transit Priority Facility.** Bus on shoulder would provide a priority transit facility.
- × **Allow Buses to Operate ≥ 45 mph.** Bus on shoulder limits bus operation to 45mph or less.
- ✓ **Does not require substantial changes to existing infrastructure.** Bus on shoulder can be implemented with existing infrastructure.

Decision: Eliminate bus on shoulder from further consideration.

4.1.7 Dynamic Shoulder Lanes

The Federal Highway Administration (FHWA) considers dynamic shoulder lanes to be a type of part-time shoulder use. Most vehicles (except for trucks) can use this facility based on need and real-time traffic conditions. According to FHWA, major safety issues have not been identified for dynamic shoulders implemented in the United States.

Example of Implementation

Minneapolis, Minnesota, developed the first dynamic part-time shoulder use application in the United States on I-35W (see Exhibit 11). The left shoulder (17-19 feet wide) was converted from a BOSS to a dynamic shoulder that could be used by buses, vanpools, carpoolers (2+), and MnPass users during congested periods. The shoulder contains message signs every 0.5 miles to provide information related to shoulder openings and price per segment.

Exhibit 11. *I-35W priced dynamic shoulder lane cross section.*

The Georgia Department of Transportation (GDOT) added dynamic signs to GA 400 (**Exhibit 12**). In addition, GDOT planned a part-time shoulder facility on I-85 that contains dynamic signs (**Exhibit 13**). Dynamic signs notify users when the shoulder is closed.

Exhibit 12. *GA 400 dynamic shoulder lane.*

Exhibit 13. *I-85 dynamic shoulder lane.*

Table 4-9. *Snapshot of a dynamic shoulder lane*

Alternative Concept	Typical Section (Lanes/Median)	Max Speeds	Buffer between Median	Buffer between Travel Lane
Dynamic Shoulder Lanes	Existing	Varies	None	N/A

Assessment

The assessment for the dynamic shoulder concept assumes that both travel lanes and the outside shoulder are 12 feet wide. The shoulder width was selected with respect to the existing conditions of the corridor which range between 11 and 14 feet. GoTriangle has also indicated that a minimum of 12-foot shoulder widths are desirable for bus operations.

This alternative concept would require overhead signage, which may include static signs or electronic/ ITS signage. Tolling would be optional, but it would increase costs associated with ITS infrastructure and operations.

To accommodate a dynamic shoulder within the existing paved surface area, the outside shoulder would be unavailable for emergency response vehicles or emergency pull-offs for stalled or disabled vehicles, during the hours of operation (peak travel times), but they would remain available for use as a shoulder during all other times.

Ability to Meet the Project Goals

- ✓ **Provide a Transit Priority Facility.** Dynamic shoulder lanes would provide a priority transit facility.
- ✓ **Allow Buses to Operate ≥ 45 mph.** Dynamic shoulder lanes would allow buses to operate at 45 mph or greater.
- × **Requires substantial changes to existing infrastructure.** Dynamic shoulder lanes require new infrastructure for implementation. ITS should be installed to cue drivers on shoulder openings.

Decision: Eliminate dynamic shoulders from further consideration.

4.2 Recommended Alternative Concept

Based on the results of the Tier 1 Analysis, none of the alternative concepts meet the goals of the project. In response to the results, the team re-evaluated whether any of the alternative concepts could be modified to meet the needs of the project. Given that the bus on shoulder alternative concept only failed the analysis due to not being able to meet the 45 mph speed criteria, the team looked at how this alternative concept could be modified to achieve the 45-mph threshold. The solution was to move the bus on shoulder concept to the inside shoulder where the speed differential would not present the same safety issues. Note that inside shoulder operations do present other safety issues, such as the need to merge back across multiple lanes of traffic and the need to overcome blind spots must be overcome. Coordination with GoTriangle and NCDOT is recommended to identify appropriate safety measures that could be implemented to address safety and operational concerns.

What is a Transit Priority Shoulder?

- Left shoulder would be modified or expanded to 14 feet wide to provide adequate room for buses to operate safely by providing a buffer between the median and general-purpose travel lanes.
- Buses can operate in the inside (left) shoulder at a maximum speed of 45 mph when traffic in the general-purpose travel lanes are moving at a reduced speed.

4.2.1 Transit Priority Shoulder

The team evaluated the potential shift of the bus on shoulder system from the outside shoulder to the inside shoulder. This transit priority shoulder concept would require an expansion of the inside shoulder to 14 feet to allow for sufficient buffers between median barriers as well as the general-purpose travel lanes. With this condition met, the NCDOT Mobility and Safety Unit has stated that they would be willing to consider a 45-mph max speed adjacent to slower moving traffic in the general-purpose lanes. The use of the inside shoulder eliminates on-ramp and off-ramp conflicts at interchanges; however, it does create a new conflict point when the buses must merge across multiple lanes of slower moving traffic when entering or exiting the interstate. In addition, in many of the segments of the I-40 corridor, the main travel lanes would need to be reduced from 12 feet to 11 feet to accommodate this alternative concept without adding additional pavement. NCDOT has raised concerns about potential impacts on safety and operations from a reduction in lane width

Overall, this alternative concept would save 12 minutes for a bus running the entire corridor when traveling at 45 mph vs 35 mph.

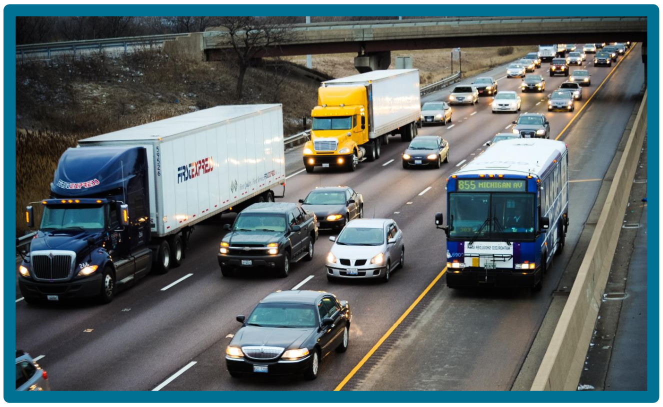


Exhibit 14. A Pace Suburban Bus utilizing the inside shoulder in Chicago.

Exhibit 15. Time savings for buses utilizing the transit priority shoulder.

The goal of the transit priority shoulder is to strike a balance of the following variables:

- Safety
- Travel speed
- Cost
- Speed of implementation
- "Viability" and opportunity

Table 4-10. *Snapshot of a transit priority shoulder*

Alternative Concept	Typical Section (Lanes/Median)	*Max Speeds*	*Buffer between Median*	*Buffer between Travel Lane*
Transit Priority Shoulder	Use of inside shoulder	*Max 45 mph*	*Hard buffer*	*Rumble strips*

5 Tier 2 Analysis – Segment Evaluation

The Tier 2 Analysis provides an overview of the transit priority shoulder concept for the entire study corridor. Structures that are within 1000 feet of the I-40 project corridor are displayed in **Figure 5-1** (approx. 178 structures, NCDOT GIS). Under each segment is a description of the roadway characteristics, renderings of the typical section, common destinations, nearby planned projects, and structures (estimates from NCDOT GIS; bridges are only counted once per segment).

The tier 2 Analysis involved a three-step approach to evaluating the transit priority shoulder concept for applicability to the I-40 corridor. Step 1 was to divide the 33-mile corridor into 8 segments based on the changes to the typical section (i.e. number of lanes, size of shoulders, and median barrier). Step 2 compared the existing pavement widths to the proposed pavement widths. Step 3 reviewed the pavement needs and right-of-way needs.

The results of the tier 2 analysis found that overall, no additional right-of-way was needed anywhere along the I-40 corridor. Existing pavement widths may be sufficient for the majority of the I-40 corridor if the general-purpose lanes are reduced from 12-feet to 11-feet. Two segments where this is not the case is the segment west of US 15-501 and the segment from NC 540 to Wade Avenue. Full results are available in Appendix A.

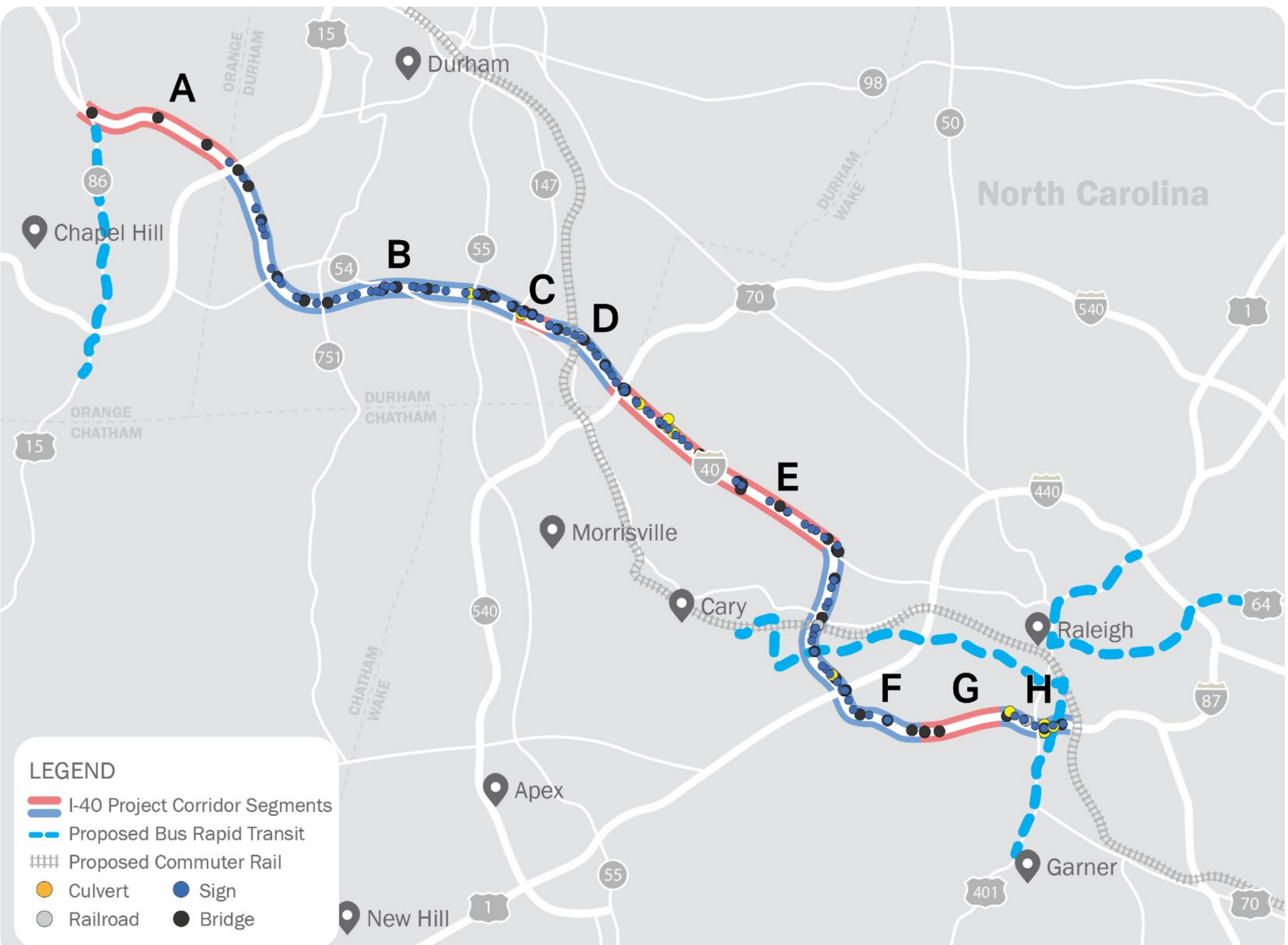


Figure 5-1. Structures along the I-40 Project Corridor

Segment A - MLK Jr. Blvd/NC 86 to US 15-501

Description

Segment A is the first segment in the I-40 corridor, and it begins at MLK Jr. Boulevard/NC 86 and ends at US 15-501. It is a 4-lane divided segment that contains 12-foot wide lanes, a 5-foot-wide paved inside shoulder, and a 12-foot paved outside shoulder. The EB and WB pavement widths are both 41 feet wide and the combined pavement width for the segment is 82 feet. Rumble strips are present, and it contains a 36-foot strip of grass. The ROW width varies between 260 feet and 340 feet. Concrete medians are recommended for segments that lack hard barriers.

Typical Section

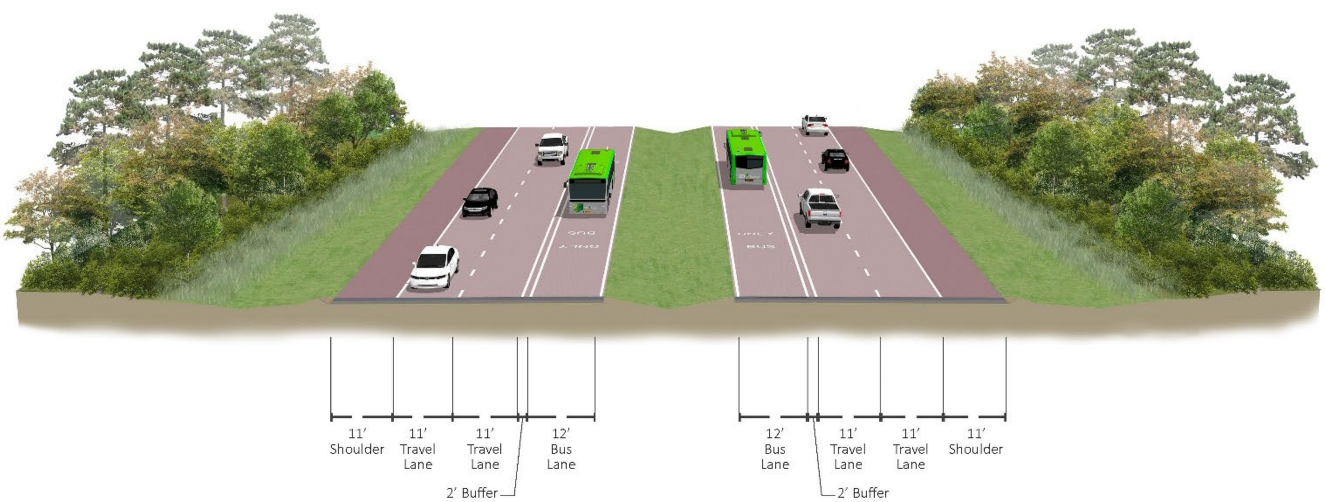


Figure 5-2. *Proposed Transit Priority Shoulders for Segment A (MLK Jr. Blvd/NC 86 to US 15-501)*

Destinations

Buses utilizing this segment could travel to major nearby destinations, such as the University of North Carolina at Chapel Hill and the proposed North-South BRT route. This segment could also be used to travel into Durham.

Planned Projects

The following planned STIP projects are located within the vicinity of the segment:

Table 5-1. *STIP projects near Segment A*

Project (TIP/SPOTID)	Description
I-3306AC (H090010)	NC 86 INTERCHANGE IMPROVEMENTS
I-5822	I-85 TO EAST OF SR 1734 (ERWIN ROAD). PAVEMENT REHABILITATION
I-5702A (H111131)	US 15 / US 501 TO NC 147
EB-4707B	SR 1113 (POPE ROAD) TO SR 1116 (GARRETT ROAD)
U-5304F (H149001-E)	SR 1742 (EPHESUS CHURCH ROAD) TO I-40. CORRIDOR CAPACITY IMPROVEMENTS
U-6067 (H090366-A)	I-40 TO US 15 / US 501 BUSINESS IN DURHAM. UPGRADE CORRIDOR TO EXPRESSWAY
U-5774C (H149000-C)	SR1110 (BARBEE CHAPEL ROAD) TO I-40. UPGRADE ROADWAY CORRIDOR

Structures

The estimated number and type of structures within the segment are provided below.

Table 5-2. *Structures in Segment A*

Structure Type	Number
Culvert	0
Railroad Crossing	0
Bridge	7
Sign	8

Segment B – US 15-501 to NC 147

Description

Segment B begins at US 15-501 and ends at NC 147. This 6-lane divided facility contains 12-foot wide lanes, a 5-foot-wide paved inside shoulder, and a 11-foot paved outside shoulder. The EB and WB pavement widths are both 59 feet wide for a combined pavement width of 118 feet. Rumble strips are present, and it contains a concrete barrier in the middle. The ROW width varies between 290 feet and 340 feet.

Typical Section

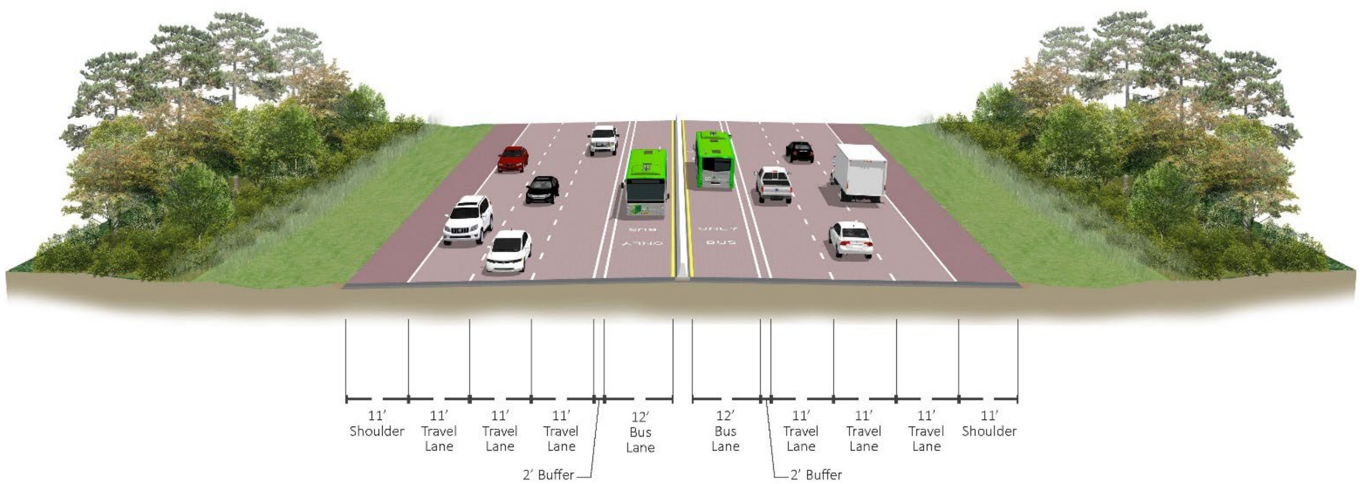


Figure 5-3. *Proposed Transit Priority Shoulders for Segment B (USA 15-501 to NC 147)*

Destinations

Buses can use this segment to travel to the Streets at Southpoint Mall located on Renaissance Road in Durham or access points to the American Tobacco Trail that runs perpendicular with this I-40 segment.

Planned Projects

The following planned STIP projects are located within the vicinity of the segment:

Table 5-3. *STIP projects near Segment B*

Project (TIP/SPOTID)	Description
I-5702A (H111131)	US 15 / US 501 TO NC 147.
U-5774C (H149000-C)	SR1110 (BARBEE CHAPEL ROAD) TO I-40. UPGRADE ROADWAY CORRIDOR.
U-5934 (H110997)	I-40 TO FUTURE I-885 (EAST END CONNECTOR) IN DURHAM. ADD LANES AND REHABILITATE PAVEMENT.

Structures

The number and type of structures within the segment are provided below.

Table 5-4. *Structures in Segment B*

Structure Type	Number
Culvert	2
Railroad Crossing	0
Bridge	16
Sign	25

Segment C - NC 147 to Davis Drive

Description

Segment C begins at NC 147 and ends at Davis Drive. This 8-lane divided facility contains 12-foot wide lanes, a 12-foot-wide paved inside shoulder, and a 14-foot paved outside shoulder. The EB pavement width is 73 feet and the WB width is 65 feet. The segment's combined pavement width is 138 feet. Rumble strips are present, and it contains a concrete barrier in the middle. The ROW width ranges between 370 feet and 420 feet. The segment contains 1 bridge and 2 interchanges.

Typical Section

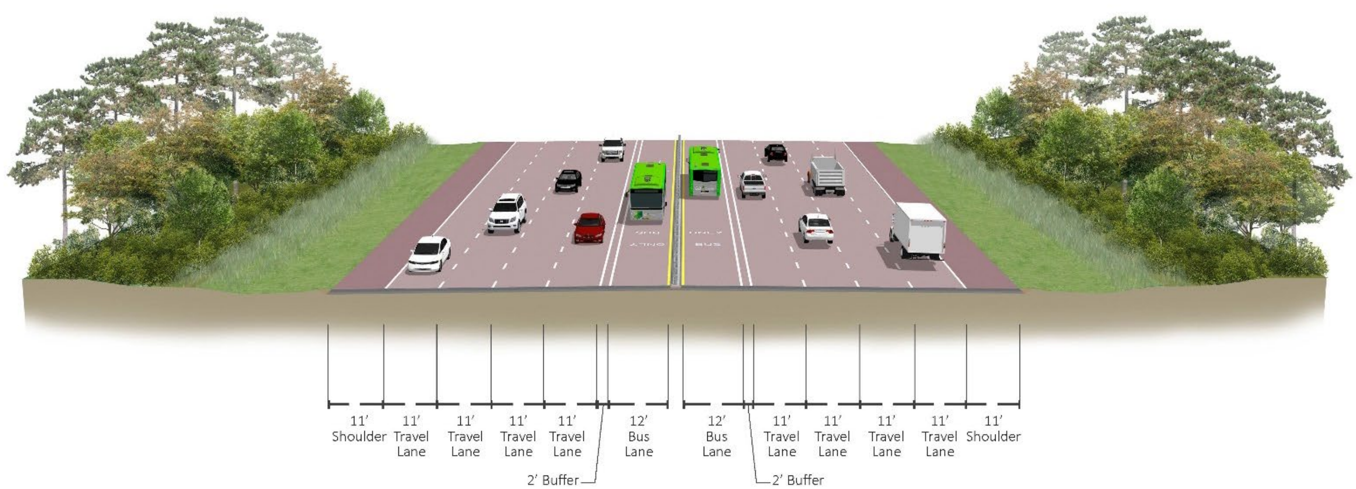


Figure 5-4. *Proposed Transit Priority Shoulders for Segment C (NC 147 to Davis Drive)*

Destinations

Segment C provides access to businesses located in the Research Triangle.

Planned Projects

The following planned STIP projects are located within the vicinity of the segment:

Table 5-5. *STIP Projects Near Segment C*

Project (TIP/SPOTID)	Description
U-5934 (H110997)	I-40 TO FUTURE I-885 (EAST END CONNECTOR) IN DURHAM. ADD LANES AND REHABILITATE PAVEMENT.
I-5702B (H111013)	NC 147 (DURHAM FREEWAY / TRIANGLE EXPRESSWAY) IN DURHAM COUNTY TO SR 1728 (WADE AVENUE) IN WAKE COUNTY.

Structures

The number and type of structures within the segment are provided below.

Table 5-6. *Structures in Segment C*

Structure Type	Number
Culvert	0
Railroad Crossing	0
Bridge	1
Sign	7

Segment D - Davis Drive to NC 540

Description

Segment D starts at Davis Drive and ends at NC 540. This segment contains the greatest number of lanes at 10 and they are divided in the middle with a concrete barrier. It contains 12-foot wide lanes, a 12-foot-wide paved inside shoulder, and a 14-foot paved outside shoulder. Both the EB and WB pavement widths are 86 feet wide for a combined total pavement width of 172 feet. Rumble strips are present, and the ROW is approximately 312 feet.

Typical Section

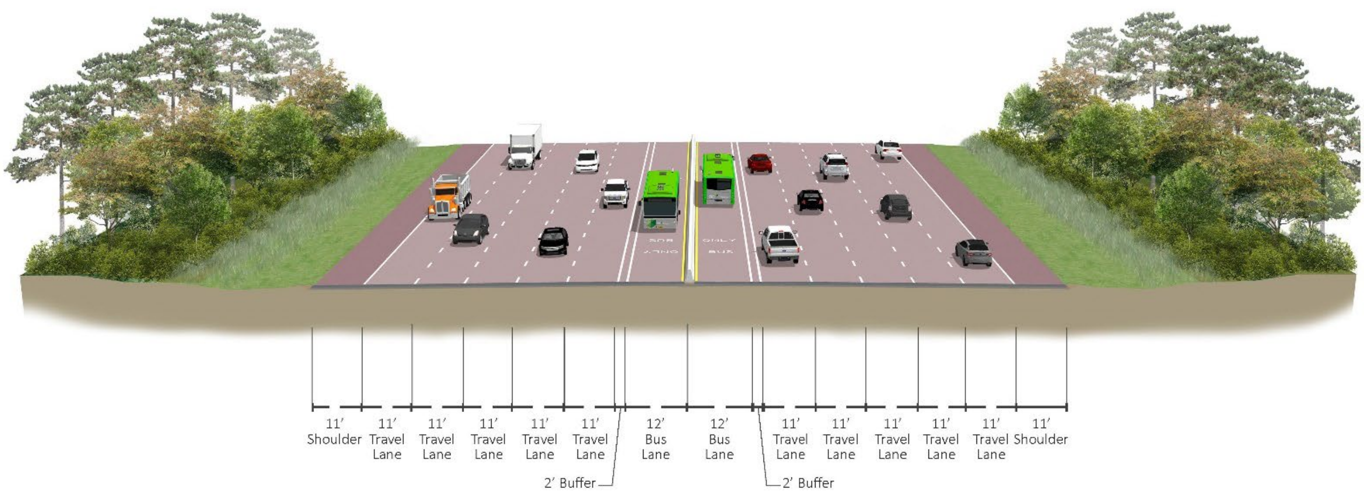


Figure 5-5. *Proposed Transit Priority Shoulders for Segment D (Davis Drive to NC 540)*

Destinations

Segment D provides access to businesses located in the Research Triangle and along South Miami Boulevard.

Planned Projects

The following planned STIP projects are located within the vicinity of the segment:

Table 5-7. *STIP Projects Near Segment D*

Project (TIP/SPOTID)	Description
I-5702B (H111013)	NC 147 (DURHAM FREEWAY / TRIANGLE EXPRESSWAY) IN DURHAM COUNTY TO SR 1728 (WADE AVENUE) IN WAKE COUNTY.
I-5982 (H150716)	I-40 IN DURHAM TO I-495 / US 64 / US 264 IN KNIGHTDALE. CONSTRUCT MANAGED SHOUDERS.

Structures

The number and type of structures within the segment are provided below.

Table 5-8. *Structures in Segment D*

Structure Type	Number
Culvert	0
Railroad Crossing	1
Bridge	4
Sign	12

Segment E - NC 540 to Wade Ave

Description

Segment E starts at NC 540 and ends at Wade Avenue. This 8-lane divided highway contains a guardrail as a divider and 12-foot-wide lanes. The inside shoulder width is 7 feet (WB) and 11 feet (EB). The outside shoulder width is 11 feet and the total pavement width is 136 feet. Rumble strips are present, and the ROW is approximately 355 feet. The segment contains 10 bridges and 5 interchanges.

Typical Section

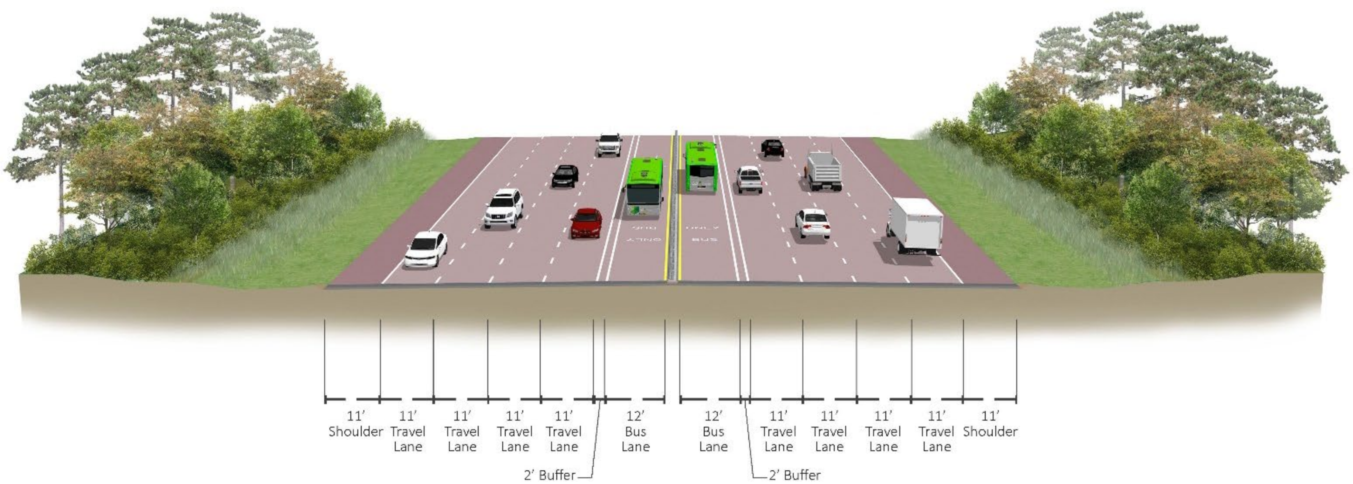


Figure 5-6. *Proposed Transit Priority Shoulders for Segment E (NC 540 to Wade Ave)*

Destinations

Major destinations near this segment include a Walmart Supercenter, Lake Crabtree, Lake Crabtree County Park, the Raleigh-Durham International Airport, William B. Umstead State Park, the Town of Cary, and the Town of Morrisville.

Planned Projects

The following planned STIP projects are located within the vicinity of the segment:

Table 5-9. *STIP Projects Near Segment E*

Project (TIP/SPOTID)	Description
I-5702B (H111013)	NC 147 (DURHAM FREEWAY / TRIANGLE EXPRESSWAY) IN DURHAM COUNTY TO SR 1728 (WADE AVENUE) IN WAKE COUNTY.
I-5982 (H150716)	I-40 IN DURHAM TO I-495 / US 64 / US 264 IN KNIGHTDALE. CONSTRUCT MANAGED SHOUDERS.
TA-6669 (T150454)	PURCHASE EXPANSION VEHICLES FOR CRX ROUTE.
I-5700 (H128081)	SR 3015 (AIRPORT BOULEVARD). REVISE INTERCHANGE; CONSTRUCT AUXILIARY LANES ON I-40 EASTBOUND FROM I-540 TO SR 3015 (AIRPORT BOULEVARD) AND FROM SR 3015 TO SR 1002 (AVIATION PARKWAY), AND CONSTRUCT AUXILIARY LANE ON I-40 WESTBOUND FROM SR 3015 (AIRPORT BOULEVARD).
I-5506 (H128080)	SR 1002 (AVIATION PARKWAY) INTERCHANGE. IMPROVE INTERCHANGE AND CONSTRUCT AUXILIARY LANE ON I-40 WESTBOUND FROM SR 1002 TO SR 3015 (AIRPORT BOULEVARD).
U-5811 (H090392)	NC 54 TO I-40 IN MORRISVILLE. WIDEN TO MULTILANES WITH INTERCHANGE MODIFICATIONS AT I-40.
U-5936 (H140408)	I-40 TO I-440 IN RALEIGH. ADD LANES.
I-5943	SR 1728 (WADE AVENUE) TO I-440 / US 1 IN RALEIGH. PAVEMENT REHABILITATION.

Structures

The number and type of structures within the segment are provided below.

Table 5-10. *Structures in Segment E*

Structure Type	Number
Culvert	3
Railroad Crossing	0
Bridge	10
Sign	23

Segment F - Wade Ave to Gorman St

Description

Segment F runs between Wade Avenue and Gorman Street. This 6-lane divided highway contains a guardrail or no separation as a divider and 12-foot-wide lanes. The inside shoulder width is 12 feet wide the outside shoulder width is 11 feet. The total pavement width is 118 feet. Rumble strips are present, and the ROW is approximately 448 feet.

Typical Section

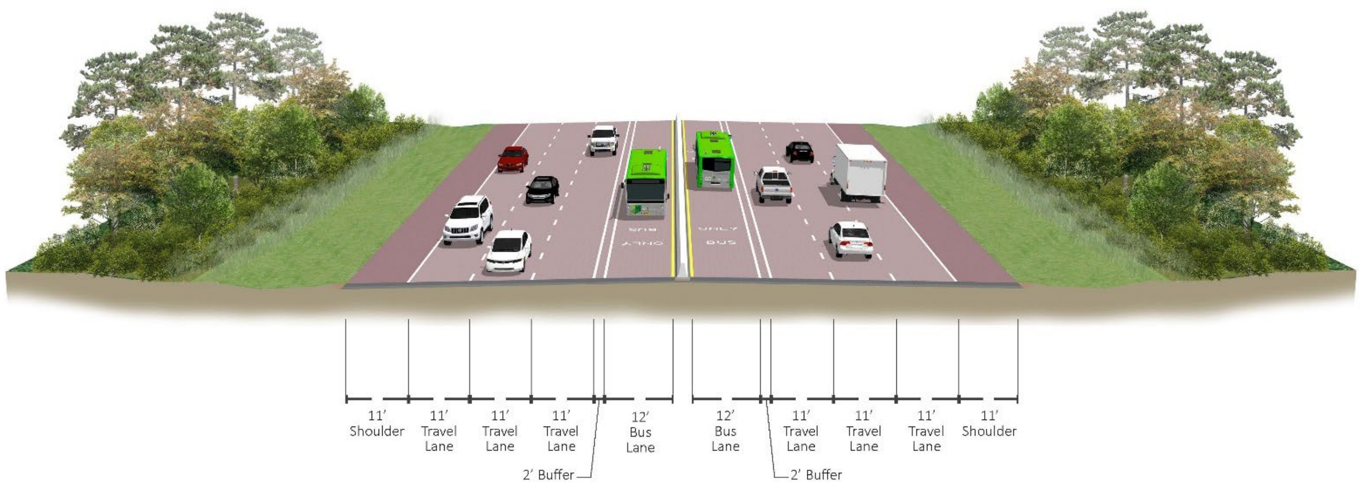


Figure 5-7. *Proposed Transit Priority Shoulders for Segment F (Wade Ave to Gorman St)*

Destinations

PNC Arena, Carter-Finley Stadium, Lake Johnson, Lake Johnson Park, and the Town of Cary can be accessed from this segment.

Planned Projects

The following planned STIP projects are located within the vicinity of the segment:

Table 5-11. *STIP Projects Near Segment F*

Project (TIP/SPOTID)	Description
I-5943	SR 1728 (WADE AVENUE) TO I-440 / US 1 IN RALEIGH. PAVEMENT REHABILITATION.
I-5873 (H128079)	NC 54 IN RALEIGH. INTERCHANGE IMPROVEMENTS.
I-5703 (H140771)	I-440 / US 1 / US 64 INTERCHANGE IN RALEIGH. RECONSTRUCT INTERCHANGE.
U-2719 (H090358)	SOUTH OF SR 1313 (WALNUT STREET) TO NORTH OF SR 1728 (WADE AVENUE) IN RALEIGH. WIDEN FROM FOUR TO SIX LANES, IMPROVE STORAGE AT LAKE BOONE TRAIL INTERCHANGE AND INSTALL RAMP METERS.
I-5701 (H090045)	I-440 / US 1 / US 64 TO SR 1370 (LAKE WHEELER ROAD) IN RALEIGH. ADD LANES.

Structures

The number and type of structures within the segment are provided below.

Table 5-12. *Structures in Segment F*

Structure Type	Number
Culvert	1
Railroad Crossing	1
Bridge	16
Sign	20

Segment G – Gorman St to Lake Wheeler Rd

Description
Segment G begins at Gorman Street and ends at Lake Wheeler Road. The EB lane contains 3 lanes and the WB lane contains 4 lanes. Each lane is 12 feet wide and the median a either a concrete barrier or none. The inside shoulder width is 10 feet and the outside shoulder width is 14 feet. The total pavement width for the segment is 132 feet. Rumble strips are present, and the ROW is approximately 410 feet.

Typical Section

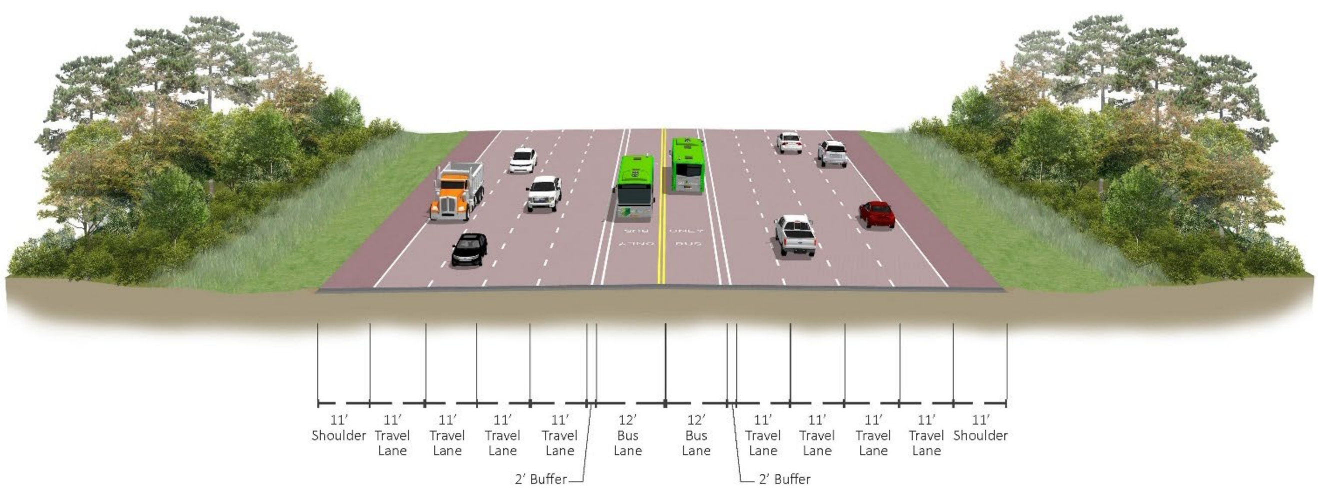


Figure 5-8. *Proposed Transit Priority Shoulders for Segment G (Gorman St to Lake Wheeler Rd)*

Destinations
Raleigh, Lake Raleigh, North Carolina State University. Lonnie Poole Course, and the Town of Garner can be accessed from Segment G.

Planned Projects
The following planned STIP projects are located within the vicinity of the segment:

Table 5-13. *STIP Projects Near Segment G*

Project (TIP/SPOTID)	Description
I-5701 (H090045)	I-440 / US 1 / US 64 TO SR 1370 (LAKE WHEELER ROAD) IN RALEIGH. ADD LANES.

Structures
The number and type of structures within the segment are provided below.

Table 5-14. *Structures in Segment G*

Structure Type	Number
Culvert	0
Railroad Crossing	0
Bridge	2
Sign	0

Segment H - Lake Wheeler Rd to S Wilmington Street

Description

The final segment, H, starts at Lake Wheeler Road and ends at South Wilmington Street. This 8-lane divided highway contains a concrete barrier as a median and 12-foot wide lanes. The inside shoulder width is 12 feet and the outside shoulder width is 14 feet. The total pavement width is 142 feet, rumble strips are present, and the ROW is approximately 390 feet.

Typical Section

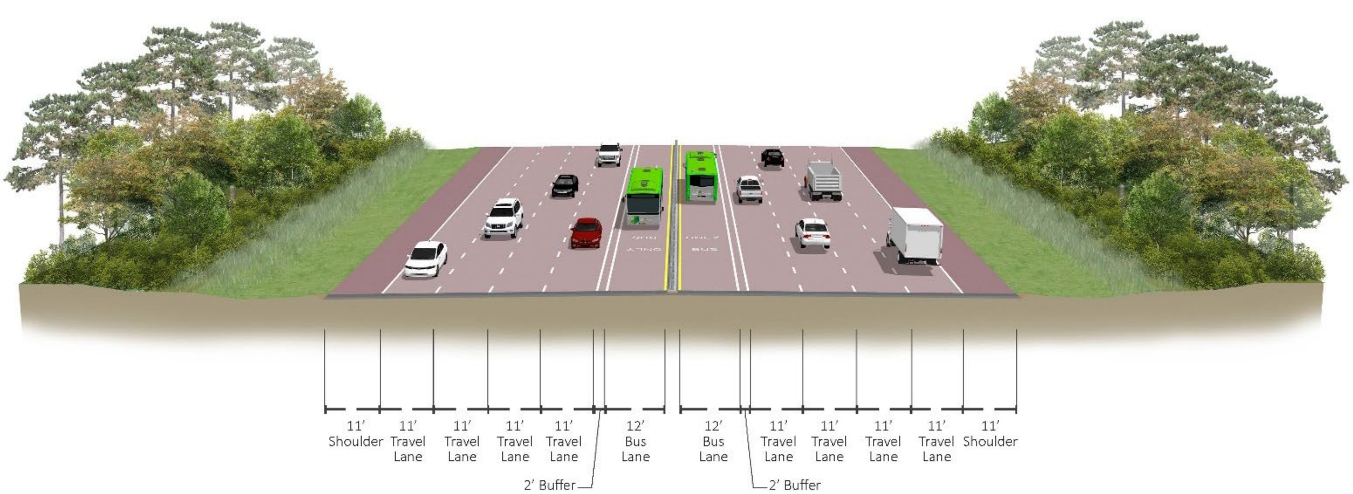


Figure 5-9. *Proposed Transit Priority Shoulders for Segment H (Lake Wheeler Rd to S Wilmington St)*

Destinations

Raleigh is a major destination located near this segment.

Planned Projects

The following planned STIP projects is located within the vicinity of the segment:

Table 5-15. *STIP Projects Near Segment H*

Project (TIP/SPOTID)	Description
TD-5272 (T141691)	SOUTH WILMINGTON STREET AT PECAN ROAD IN RALEIGH. CONSTRUCT OFF-STREET TRANSFER FACILITY (GO RALEIGH TRANSIT)

Structures

The number and type of structures within the segment are provided below.

Table 5-16. *Structures in Segment H*

Structure Type	Number
Culvert	1
Railroad Crossing	1
Bridge	2
Sign	6

6 Additional Research

Similar concepts to the proposed transit priority shoulder discussed in this report have been implanted in places throughout the United States. To better understand how those concepts were implemented and function, the project team decided to reach out to a peer community. The project team selected the I-85 Corridor in Gwinnett County, Georgia (metro Atlanta).

In this example, a HOT express lane operates on the inside left lane, which fully replaced the inside shoulder for this segment of I-85. The use of this lane is limited to buses, regular carpoolers, and vehicles that pay a dynamically priced toll. The posted speed limit is 70 mph.

__Exhibit 16.__ The HOT express lane on the I-85 Corridor in Gwinnett County, Georgia.

According to the GDOT, this HOT express lane was originally designed as an HOV lane in the mid-90's in preparation for the 1996 Summer Olympic Games. The HOV lane was converted to the present HOT express lane in 2007. GDOT reported that HOT express lane functions well in this location. It was noted that there is an increased presence of State Highway Patrol that is dedicated to this section of I-85 to help stranded motorists remove vehicles or address other emergency situations given that there is no inside shoulder available.

7 Next Steps

Based on these findings, the project team recommends that a full feasibility study be conducted on the transit priority shoulder. A full feasibility study would provide a detailed assessment and full understanding of infrastructure improvements and costs required to implement the alternative concept. It is recommended that the scope of the feasibility study include the following elements:

- Determine the design criteria through coordination with NCDOT, GoTriangle, CAMPO, and DCHC MPO
- Assess structures along the corridor to determine if modifications would be required
- Assess the cross section along the route for areas requiring additional pavement width
- Evaluate the depth of the shoulder pavement to determine if it is enough to handle regular use by buses
- Evaluate median barriers to determine if additional reinforcement is needed
- Identify utilities, signage, ITS infrastructure for relocations
- Develop a detailed cost estimate for the transit priority shoulder
- Identify possible minimum operable segment(s) and/or pilot projects

The project team held preliminary conversations with GoTriangle to discuss the transit priority shoulder. To better access future bus on shoulder operations, further coordination with GoTriangle bus operators is recommended to ascertain programmatic or policy changes that could alleviate safety concerns and improve operations from a bus operator perspective. This evaluation and coordination could include the following:

- Driver safety technology improvements to buses (e.g., blind spot cameras, flashing lights)
- Creating or changing state laws to require roadway drivers yield to buses merging in and out of the transit priority shoulder

The following decision-making framework steps may be used to carry this Transit Priority Shoulder alternative concept forward (TCRP Report 151):

1. Identify a problem and need
2. Develop a concept plan
3. Establish a multi-agency team
4. Perform a feasibility study
5. Develop a project definition
6. Plan implementation
7. Project start-up
8. Monitor performance

8 Sources

References
AASHTO. 2014. Guide for Geometric Design of Transit Facilities on Highways and Streets, 1st Edition.

Douma, F. June 2007. Bus-Only Shoulders in the Twin Cities. FTA-MN-26-7004.

FHWA. Use of Freeway Shoulders for Travel — Guide for Planning, Evaluating, and Designing Part-Time Shoulder Use as a Traffic Management Strategy. Retrieved from: https://ops.fhwa.dot.gov/publications/fhwahop15023/apa.htm

National Cooperative Highway Research Program Report 155. 1975. Bus Use of Highways. Planning and Design Guidelines. Retrieved from: http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_155.pdf

NCDOT AADT data (2019). Retrieved from: https://ncdot.maps.arcgis.com/apps/webappviewer/index.html?id=5f6fe58c1d90482ab9107ccc03026280

NCDOT. Bus on Shoulder System. Retrieved from: https://www.ncdot.gov/divisions/public-transit/Pages/bus-on-shoulder-system.aspx and https://www.ncdot.gov/news/press-releases/Pages/2012/Buses-on-Shoulders-System-Ready-to-Roll-.aspx

NC Quick Pass. NC Quick Pass HOV. Retrieved from: https://www.ncquickpass.com/nc-quickpass-help/Pages/hov-app.aspx#:~:text=%E2%80%8B%E2%80%8B%E2%80%8B%E2%80%8BNC,more%20occupants%20in%20the%20vehicle.

Transit Cooperative Research Program Report 151. 2012. A Guide for Implementing Bus Shoulder Systems. Retrieved from: http://www.trb.org/TCRP/Blurbs/166878.aspx

Images
Exhibit 1. North-South Bus Rapid Transit. Photo courtesy of Chapel Hill Transit.

Exhibit 2. GoTriangle bus utilizing the BOSS on I-40 (NCDOT). https://www.ncdot.gov/divisions/public-transit/Pages/bus-on-shoulder-system.aspx

Exhibit 3. Separated busway in Melbourne, Australia. https://infrastructuremagazine.com.au/2017/11/27/high-speed-busway-to-be-built-in-melbourne/

Exhibit 4. Lincoln Tunnel bus lane. https://www.6sqft.com/self-driving-buses-proposed-for-busy-lane-in-lincoln-tunnel/

Exhibit 5. TxDOT and VIA-managed HOV lanes. https://www.viainfo.net/2020/08/05/bexar-countys-first-hov-lane-opening-fall-2020/

Exhibit 6. Managed bus lane. https://ops.fhwa.dot.gov/freewaymgmt/publications/frwy_mgmt_handbook/chapter8_01.htm

Exhibit 7. I-77 express lanes in Charlotte. https://www.wfae.org/post/part-i-77-toll-lanes-opens-some-vow-never-use-them#stream/0

Exhibit 8. Reversible lanes with signage examples. http://www.rubenmcenzano.engineer/2017/02/atlantas-reversible-express-lanes.html

Exhibit 9. Elevated reversible lanes on the Lee Roy Selmon Expressway. Landmarkhunter.com

Exhibit 10. Bus on shoulder system in Kansas. https://ridekc.org/blog/kansas-moves-to-expand-bus-on-shoulder-for-kck

Exhibit 11. I-35W priced dynamic shoulder lane cross section. https://transops.s3.amazonaws.com/uploaded_files/MnDOT-Hard%20Shoulder%20Running%20Slides.pdf

Exhibit 12. GA 400 dynamic shoulder lane. Google Maps, 2020.

Exhibit 13. I-85 dynamic shoulder lane. Google Maps, 2020.

Exhibit 14. A Pace Suburban Bus utilizing the inside shoulder in Chicago. https://www.pacebus.com/expressway-based-routes.

Exhibit 15. Time savings for buses utilizing the transit priority shoulder. https://www.timeanddate.com/time/travel.html.

Exhibit 16. HOT express lane on the I-85 Corridor in Gwinnett County, Georgia. Google Maps, 2020.

Attachment A

To evaluate whether there is enough existing pavement and ROW to accommodate each alternative concept, the team completed a GIS assessment using parcel data and roadway characteristics. The table below provides a detailed breakdown of the specific pavement width requirements for each segment. Pavement widths are provided for both eastbound (EB) and westbound (WB) lanes for each corridor segment. Pavement widths that are highlighted in green signify that no additional pavement is needed to accommodate the alternative concept. Yellow highlighting represents minimal pavement width needs and red highlighting signifies major pavement width needs.

The results of our pre-feasibility analysis for the transit priority shoulder show that no additional ROW would be needed on the I-40 corridor. In addition, existing pavement widths may be sufficient along the majority of the corridor if general-purpose travel lanes are reduced to 11-feet. There are two sections where additional pavement would be needed – Segment A, west of US 15-501 and Segment E, from NC 540 to Wade Avenue. A rigid median barrier should also be considered for these segments.

Table A-1. *Additional Paved Roadway Surface Requirements*

Paved Roadway Surface Width Requirements (feet)									
Segment	**Lane Direction**	**Separated Busway**	**Freeway Bus Lanes**	**Freeway HOV Lanes**	**Freeway HOT Lanes**	**Reversible Express Lane**	**Bus on (outside) Shoulder**	**Dynamic Shoulder Lane**	**Transit Priority Shoulder**
A - MLK Jr. Blvd/NC 86 to NC 54	(EB)	-5	-1	-5	-5	-13	0	0	-6
	(WB)	-5	-1	-5	-5	-13	0	0	-6
B - NC 54 to NC 147	(EB)	3	5	1	1	-1	-1	-1	1
	(WB)	3	5	1	1	-1	-1	-1	1
C - NC 147 to Davis Drive	(EB)	3	4	3	0	1	-1	-1	4
	(WB)	-1	0	-1	-4	-3	-1	-1	0
D - Davis Drive to NC 540	(EB)	5	8	4	4	-1	2	2	6
	(WB)	5	8	4	4	-1	2	2	6
E - NC 540 to Wade Ave	(EB)	3	4	0	0	1	-1	-1	1
	(WB)	-1	0	-4	-4	-3	-1	-1	-3
F - Wade Ave to Gorman St	(EB)	3	1	1	1	-1	-1	-1	1
	(WB)	3	1	1	1	-1	-1	-1	1
G - Gorman St to Lake Wheeler	(EB)	1	6	2	2	0	2	2	2
	(WB)	2	6	2	2	0	2	2	3
H - Lake Wheeler Rd to S Wilmington St	(EB)	3	4	3	0	1	-1	-1	4
	(WB)	-1	0	-1	-4	-3	-1	-1	0

Pavement needs: Green=None; Yellow=Minimal; Red=Major