Technical Memorandum: Benefit-Cost Analysis of the I-95/U.S. 70 Innovative Technology and Rural Mobility Corridor Improvements Project

Date:	November 2, 2017
Subject:	Benefit-Cost Analysis for the I-95/U.S. 70 Innovative Technology and Rural Mobility Corridor Improvements

Project Description

The *I-95/U.S. 70 Innovative Technology and Rural Mobility Corridor Improvements* (hereafter the "Project") is comprised of 1) improvements to U.S. 70 (future I-42) and 2) improvements to I-95. The I-95 part of the Project will bring the most heavily traveled segment of the facility into a state of good repair and up to current design standards, add capacity, improve safety and increase the reliability of this national artery in North Carolina. It will ensure connections between the Southeast, Mid-Atlantic, Northeast, military installations and international ports on the eastern seaboard are maintained and enhanced. Over 20 million travelers used the I-95 segment of the Project in 2016; trucks accounted for about 23 percent of those trips.

The U.S. 70 (future I-42) portion of the Project completes the remaining gaps between I-40 and Havelock to bring the entire segment of road up to freeway standards. At grade intersections will be converted to interchanges and the roadway will be reconstructed to the standards of a modern freeway. The Project's completion will be the culmination of a decades-long effort to develop this major east-west facility to serve Eastern North Carolina. U.S. 70 serves as an evacuation route and is an important logistics corridor serving the Port of Morehead City, the Global TransPark, and the MCAS Cherry Point. Nearly 7.5 million travelers used the U.S. 70 (future I-42) portion of the Project area in 2016; the Project area will address one of the remaining high-crash segments of the corridor in Craven County.

Fiber optic cable will be installed in the right-of-way in each corridor. It will run the full 181-mile border-to-border span of I-95 and traverse the length of U.S. 70 (future I-42) from I-40 to Havelock. In the near-term, the fiber optic cable will be coupled with cell towers and intelligent transportation system (ITS) equipment to provide variable message signs along U.S. 70 (future I-42), implement integrated corridor management, and allow the state to exchange access to the highway right-of-way for private telecommunications capacity to fill gaps in access to high-speed communications in rural Eastern North Carolina. Longer term, the availability of the fiber optic cable prepares for future use of connected and autonomous vehicles.

Each component of the Project has independent utility, but the greatest benefits are realized when the two investments are made jointly. The ITS features included in the Project will facilitate detours when severe crashes close I-95 for hours at a time. The combined fiber optic and cell tower coverage provided with U.S.70 (future I-42) and I-95 is readily extended to include the southern portion of U.S. 117 between I-40 and U.S. 70. Collectively, by wiring this "triangle" near the center of I-95 as it traverses the state, the North Carolina Department of Transportation (NCDOT) creates the ability to manage that capacity in real time using the Intelligent Transportation System (ITS) enhancements as it responds to crash and natural hazard events.

The Project includes the following elements:

I-95

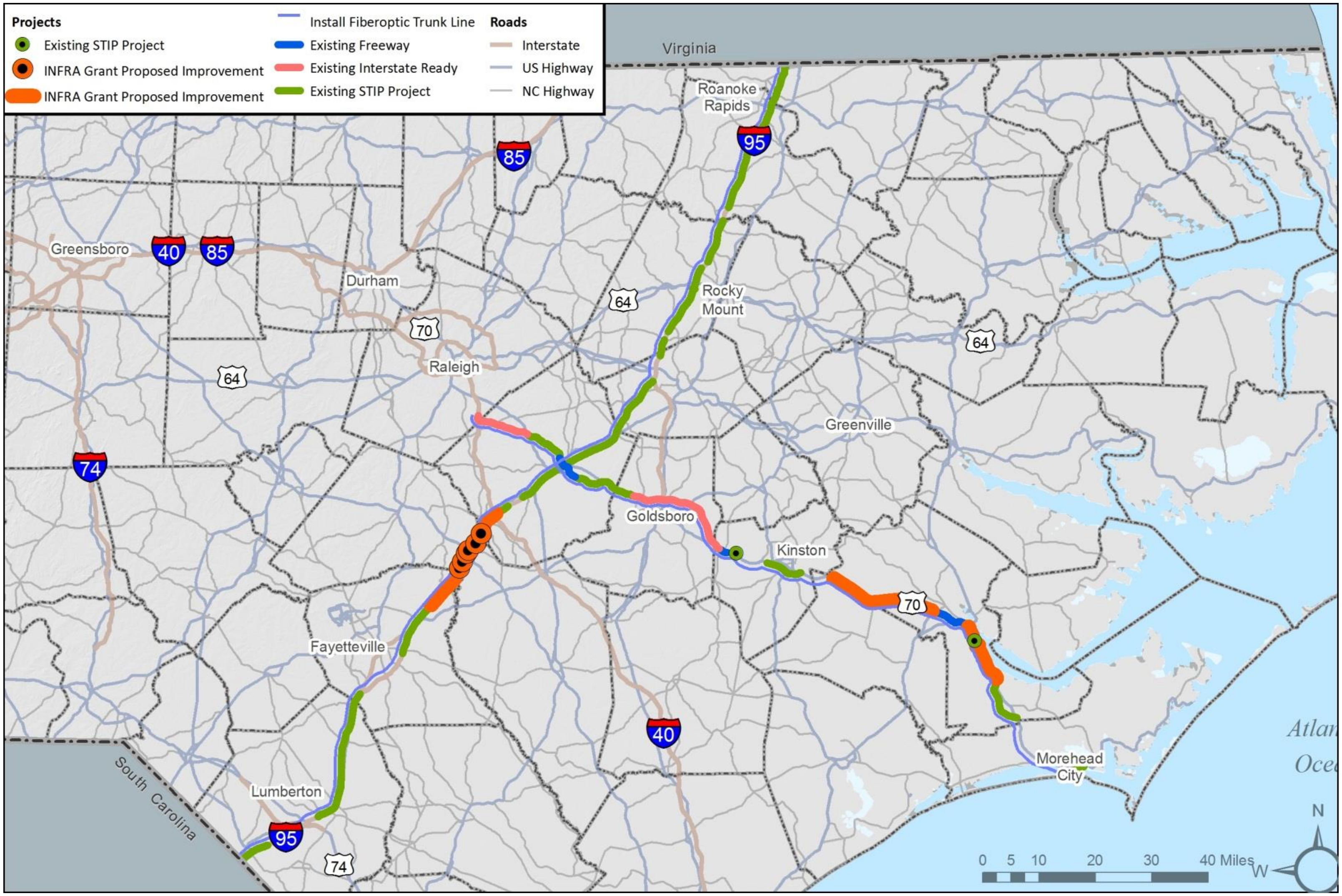
- Widen I-95 to eight lanes from Exit 65 to Exit 81 (I-5986A and I-5986B)
- Interchange improvements (I-5883, I-5878, I-5877)
- Install ITS devices
- Install fiber from South Carolina to Virginia

U.S. 70

- Upgrade U.S. 70 to freeway standard from West Thurman Road/East Thurman Road interchange to the Havelock Bypass (R-5777C)
- Upgrade U.S. 70 to freeway standard from Grantham Road to the Havelock Bypass and interchange improvements at Taberna Way and West Thurman Road/East Thurman Road (R-5777A and R-5777B)
- Upgrade to freeway standard from Grantham Road to Neuse River Bridge (U-5713)
- Upgrade to interstate standards from the eastern end of the Kinston Bypass to the Neuse River Bridge (New Project "10")
- Install ITS devices
- Install fiber along entire corridor

A map of the Project is shown in Exhibit 1.

Exhibit 1 – Project Locations



Introduction

This technical memorandum estimates the long-term benefits associated with the Project. The long-term benefits presented relate to three goals identified in the INFRA 2017 Notice of Funding Opportunity (NOFO)[1]: Safety, Economic Vitality, and Environmental. The final section discounts the stream of anticipated benefits and costs and calculates the Benefit-Cost Ratios for the Project at 7 percent and 3 percent.

The Project described in this application would support the region's economy over the long-term by providing the workforce and residents of North Carolina with improved interstate and freeway facilities, generating travel time savings, improving reliability, auto emissions reductions, reducing the likelihood for accidents, providing new fiber internet connections to the coastal counties, eliminating the need to detour during flood events, and providing the infrastructure for autonomous vehicles.

The balance of this discussion describes the assumptions and methods used to develop the benefit-cost analysis and estimates the value of the long-term benefits generated by the investment. As directed in the INFRA guidance, the benefits of the capital investment have been estimated over a 20-year analysis horizon.

The Project's construction would be completed in 2027, and a benefits period of 2028-2047 was used.

Benefits are estimated in accordance with guidance provided by U.S. Department of Transportation (U.S. DOT) for benefit-cost analysis. If no U.S. DOT guidance was available for the estimate, the Project team consulted industry research for the best practice and information on which to base the assumptions and methodology.

The benefits quantified in the benefit-cost analysis are described in the following pages in 2017 dollars. Benefits for each Project element are described within the benefit categories.

Analysis Assumptions

A list of assumptions for the project is provided in the BCA workbook (see Inputs tab in the file NCDOT_US70I-95INFRA_2017BCA.xls) as well as in Exhibit 2.

Exhibit 2 - BCA Calculation Inputs

Input	Value	Source
General		
Discount Rate	7%	2017 TIGER BCA Resource Guide
Discount Rate	3%	2017 TIGER BCA Resource Guide
Deflator	See "Deflator" Sheet	https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/budget/fy2018/hist10z1.xls
Auto Occupancy	1.39	2017 TIGER BCA Resource Guide, FHWA Statistics 2015, Table VM1
Annualization Factor	280	Assumption
Speed Limit on I-95	70	

[1] See INFRA 2017 Notice of Funding Opportunity, https://www.transportation.gov/buildamerica/infra/infra-notice-funding-opportunity

Speed Limit on US70	55	
Annual O&M Fiber	$50,000	
Annual O&M ITS	$100,000	
2016 AADT Harnett County	57000	https://connect.ncdot.gov/resources/State-Mapping/Documents/NCDOT2016InterstateFreewayReport.pdf
2040 AADT US70	30000	US 70 Corridor Economic Assessment
2016 AADT US70	20400	NCDOT https://nc01920485.schoolwires.net/cms/lib/NC01920485/Centricity/Domain/16/US 70 Corridor 2014-2016 Crash Data.pdf
AADT Growth US70	1.6%	based on 2016 and 2040 AADT as shown above
Average Trip Length US70	27.3	Assumption
I-95 average traffic growth (2011-2020)	13%	North Carolina I-95 Economic Assessment Study, Task 4 Travel Demand Modeling, 2013
I-95 average traffic growth (2011-2040)	41%	North Carolina I-95 Economic Assessment Study, Task 4 Travel Demand Modeling, 2013
Truck share I-95	25%	Statewide Travel Demand Model
Truck share US 70	10%	Statewide Travel Demand Model
I-95 annual AADT growth	3.7%	NCDOT
Economic Vitality		
Value of Personal Time, 2016$	$13.60	2017 TIGER BCA Resource Guide
Value of Business Time, 2016$	$25.40	2017 TIGER BCA Resource Guide
Value of Time All Purposes, 2016$	$14.10	2017 TIGER BCA Resource Guide
Value of Time Truck, 2016$	$27.20	2017 TIGER BCA Resource Guide
Value of Personal Time, 2017$	$13.85	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
Value of Business Time, 2017$	$25.87	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
Value of Time All Purposes, 2017$	$14.36	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
Value of Time Truck, 2017$	$27.70	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
Truck operating savings per hour (2014$)	$46.23	Table 9 ATRI Operational Cost of Trucking 2015. Includes fuel, oil, truck/trailer lease, repair, maintenance, driver benefits, and insurance. Excludes driver time (valued in travel time savings)
Truck operating savings per hour (2017$)	$48.20	Table 9 ATRI Operational Cost of Trucking 2015, Adjusted by GDP Deflator
Average Trip Length on I-95, 2009	45.10	Table 2.10 North Carolina I-95 Economic Assessment Study, Task 4 Travel Demand Modeling, 2013
Average Trip Length on I-95, 2040 No Build	44.06	Table 2.10 North Carolina I-95 Economic Assessment Study, Task 4 Travel Demand Modeling, 2013
Reliability savings	4%	Assumption based on range of results found https://ntl.bts.gov/lib/54000/54300/54346/ICM_Modeling_Results_Report__FHWA-JPO-12-037_.pdf
Environmental		
VOC Value of Emissions (2016$) per metric ton	$1,872	2017 TIGER BCA Resource Guide
NOx Value of Emissions (2016$) per metric ton	$7,377	2017 TIGER BCA Resource Guide

PM Value of Emissions (2016$) per metric ton	$337,459	2017 TIGER BCA Resource Guide
SOx Value of Emissions (2016$) per metric ton	$43,600	2017 TIGER BCA Resource Guide
VOC Value of Emissions (2017$) per metric ton	$1,906	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
NOx Value of Emissions (2017$) per metric ton	$7,512	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
PM Value of Emissions (2017$) per metric ton	$343,654	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
SOx Value of Emissions (2017$) per metric ton	$44,400	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
Passenger Car Emission Rates per Mile, VOC, 2013-2024	0.6	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, Nox, 2013-2024	0.91	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, PM25, 2013-2024	0.01	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, CO2, 2013-2024	532	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, VOC, 2025-2034	0.27	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, Nox, 2025-2034	0.28	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, PM25, 2025-2034	0.01	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, CO2, 2025-2034	434	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, VOC, 2035-	0.21	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, Nox, 2035-	0.2	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, PM25, 2035-	0.01	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Emission Rates per Mile, CO2, 2035-	397	http://www.apta.com/gap/fedreg/Documents/NS-SS_Final_PolicyGuidance_August_2013.pdf
Passenger Car Gasoline Consumption Per mile	0.04149	http://www.epa.gov/otaq/consumer/420f08024.pdf
LDGV Emissions Rates g/hr VOC	2.683	nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EVXV.TXT
LDGV Emissions Rates g/hr NOX	3.515	nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EVXV.TXT
Truck Emissions Rate g per hour VOC (average of 8a and 8b trucks)	3.868	Source: https://www3.epa.gov/otaq/consumer/420f08025.pdf, Class 8 trucks include long-haul semi-tractor trailer rigs ranging from 33,001 lbs to >60,000 lbs
Truck Emissions Rate g per hour Nox (average of 8a and 8b trucks)	39.0515	Source: https://www3.epa.gov/otaq/consumer/420f08025.pdf, Class 8 trucks include long-haul semi-tractor trailer rigs ranging from 33,001 lbs to >60,000 lbs
Truck Emissions Rate g	1.092	Source: https://www3.epa.gov/otaq/consumer/420f08025.pdf,

per hour PM2.5 (average of 8a and 8b trucks)		Class 8 trucks include long-haul semi-tractor trailer rigs ranging from 33,001 lbs to >60,000 lbs
Truck Emissions Rate g per hour PM10 (average of 8a and 8b trucks)	1.187	Source: https://www3.epa.gov/otaq/consumer/420f08025.pdf, Class 8 trucks include long-haul semi-tractor trailer rigs ranging from 33,001 lbs to >60,000 lbs
Safety		
AIS 0 (2016$) per vehicle	$4,252	2017 TIGER BCA Resource Guide
AIS 1 (2016$)	$28,800	2017 TIGER BCA Resource Guide
AIS 2(2016$)	$451,200	2017 TIGER BCA Resource Guide
AIS 3(2016$)	$1,008,000	2017 TIGER BCA Resource Guide
AIS 4(2016$)	$2,553,600	2017 TIGER BCA Resource Guide
AIS 5(2016$)	$5,692,800	2017 TIGER BCA Resource Guide
AIS 6(2016$)	$9,600,000	2017 TIGER BCA Resource Guide
AIS 0 (2017$) per vehicle	$4,330	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
AIS 1 (2017$)	$29,329	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
AIS 2 (2017$)	$459,483	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
AIS 3 (2017$)	$1,026,505	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
AIS 4 (2017$)	$2,600,480	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
AIS 5 (2017$)	$5,797,311	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
AIS 6 (2017$)	$9,776,242	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
C - possible injury (2016$)	$63,900	2017 TIGER BCA Resource Guide
B - non-incapacitating injury (2016$)	$125,000	2017 TIGER BCA Resource Guide
A - incapacitating (2016$)	$459,100	2017 TIGER BCA Resource Guide
K - killed (2016$)	$9,600,000	2017 TIGER BCA Resource Guide
C - possible injury (2017$)	$65,073	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
B - non-incapacitating injury (2017$)	$127,295	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
A - incapacitating (2017$)	$467,528	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator
K - killed (2017$)	$9,776,242	2017 TIGER BCA Resource Guide, Adjusted by GDP Deflator

The analysis assumes that construction work could be scheduled in a manner that does not result in disruptions to daily vehicular operations.

Benefits

Safety

Reduced Highway Fatalities and Crashes

U.S. 70

The improved facility will attract traffic away from other local roads, many of which have higher crash rates than the freeway corridor. Assuming an average trip length of 27.3 miles (approximately 20 percent of the corridor length) and the AADT in the corridor,[2] the change in vehicle miles traveled (VMT) is estimated. Using the average crash rates for Craven and Johnston Counties, where the projects will be constructed,[3] it is found that in the baseline, a rural facility with partial access control has 114.6 crashes per 100 million VMT. A rural full access controlled facility has an average crash rate of 74.3 per 100 million VMT, or a reduction of 40.3 crashes per 100 million VMT.

This crash reduction factors were converted to the Maximum Abbreviated Injury Score (MAIS) crash types in order to apply U.S. DOT Guidance on the value of avoided crashes. The conversion is based on the National Highway Safety and Traffic Administration (NHTSA) KABCO-AIS Conversion Table (July 2011) for Injury (severity unknown), and No Injury crashes. KABCO refers to the letters used to designate five levels of crash severity used by police at a crash scene; AIS refers to the Abbreviated Injury Scale used by hospitals. These factors provide the probability that an injury will range from critical to minor to more accurately capture the total number of different types of injuries associated with the VMT avoided on less safe facilities. Estimating the distribution of expected injury types is important because each type of injury has a different associated economic cost.

The total annual value for crash severity is based on U.S. DOT guidance and the National Highway Safety Council estimates for the value of avoiding a crash. These estimates are applied to the number of crashes avoided to estimate the total value of crashes avoided from auto VMT avoided. Exhibit 2 provides the estimated cost of different types of crashes.

Based on the value of accidents avoided, the value of safety incidents avoided due to the reduction in truck VMT is estimated. ***The total reduction in fatalities and crashes on U.S. 70 is $0.01 million, discounted at 7 percent.***

I-95

Based on crash reduction factors estimated by AECOM safety analysis that considers the current geometry of the facilities compared to the facilities with the Project, there are savings of 0.1 fatalities, 0.1 incapacitating injuries, 0.7 non-incapacitating injuries, 1 injury, and 10.5 property damage only (PDO) crashes per year. These safety reduction factors were held constant throughout the analysis period.

These crash reduction factors were valued based on the KABCO score. KABCO refers to the letters used to designate five levels of crash severity used by police at a crash scene. The distribution of expected injury types is important because each type of injury has a different associated economic cost (Exhibit 3).

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[2] U.S. 70 Corridor Commission Crash Summary for 2014-2016 – see Supplemental Materials
[3] Ibid.

Exhibit 3 – I-95 Crash Reduction Factors

Location	Crash Reduction (Crashes/Year)				
	Fatal	Incapacitating Injury (A)	Non-incapacitating Injury (B)	Possible Injury (C)	PDO
I-5986A	0.1	0	0.2	0.3	3.2
I-5986B	0	0.1	0.5	0.7	7.3
I-5877	0	0	0	0	0
I-5878	0	0	0	0	0
I-5883	0	0	0	0	0
Total	**0.1**	**0.1**	**0.7**	**1**	**10.5**

Source: AECOM safety analysis. For more information, see Supplemental Materials.

The total annual value for crash severity is based on U.S. DOT guidance and the National Highway Safety Council estimates for the value of avoiding a crash as found in Exhibit 2.

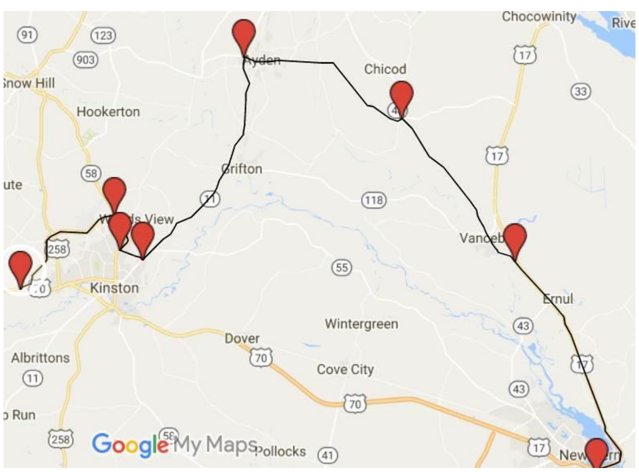
The total reduction in fatalities and crashes was valued as $6.6 million, discounted at 7 percent.

Detour Safety Savings

U.S. 70

The Project will save vehicle miles traveled (VMT) in the event of flooding in low-lying areas of the existing U.S. 70 corridor. Drivers must detour around by a longer route, costing travel time and miles. The Project will eliminate these low-lying areas and therefore VMT will be saved relative to the No Build. Shown in Exhibit 4 is one detour route used by vehicles to get around flooded sections of U.S. 70. The route shown is an extra 66 miles and takes an additional 1 hour and 14 minutes to traverse. This is conservative as there are other detours that take longer, up to 101 miles or 1 hour and 45 minutes.

Exhibit 4 – Example Detour Route around Kinston



Source: GoogleMaps

Assuming that a flooding event occurs once every five years and lasts 3 days, the volume of vehicles on this segment of U.S. 70 were assumed to detour. The VMT avoided by detours with the Project is shown in Exhibit 5.

Exhibit 5 – Detour VMT Saved by Project

Year	VMT for Detour
2028	979,650
2029	995,519
2030	1,011,646
2031	1,028,034
2032	1,044,687
2033	1,061,610
2034	1,078,807
2035	1,096,282
2036	1,114,041
2037	1,132,088
2038	1,150,426
2039	1,169,062
2040	1,188,000
2041	1,207,245
2042	1,226,801
2043	1,246,674
2044	1,266,869
2045	1,287,391
2046	1,308,245
2047	1,329,438
Total	**22,922,514**

The rates of crashes that result in fatalities, injuries, and property damage only are applied to the VMT avoided to derive the estimated crashes avoided from reduced VMT. To ensure consistency between the types of crashes, the crash rates for fatalities, injuries, and property damage only are the national average crash rates. These crash rates are shown in Exhibit 6.

Exhibit 6 - Crashes by Type per 100,000,000 VMT

	Rate	
Fatalities	1.133692236	per 100,000,000 VMT
Injured persons	78.92426005	per 100,000,000 VMT
Crashes	203.4003853	per 100,000,000 VMT

Source: 2015 BTS Motor Vehicle Safety Data Table 2-17, http://www.rita.dot.gov/bts/sites/rita.dot.gov.bts/files/publications/national_transportation_statistics/html/table_02_17.html

These crash reduction factors were converted to the Maximum Abbreviated Injury Score (MAIS) crash types in order to apply U.S. DOT Guidance on the value of avoided crashes. The conversion is based on the National Highway Safety and Traffic Administration (NHTSA) KABCO-AIS Conversion Table (July 2011) for Injury (severity unknown), and No Injury crashes. KABCO refers to the letters used to designate five levels of crash severity used by police at a crash scene; AIS refers to the Abbreviated Injury Scale used by hospitals. These factors provide the probability that an injury will range from critical to minor to more accurately capture the total number of different types of injuries associated with the VMT avoided. Estimating the distribution of expected injury types is important because each type of injury has a different associated economic cost.

The total annual value for crash severity is based on U.S. DOT guidance and the National Highway Safety Council estimates for the value of avoiding a crash. These estimates are applied to the number of crashes avoided to estimate the total value of crashes avoided from auto VMT avoided. Exhibit 2 provides the estimated cost of different types of crashes.

Based on the value of accidents avoided, the value of safety incidents avoided due to the reduction in truck VMT is estimated. ***The total reduction in fatalities and crashes due to detour reductions results in a value of $1.6 million, discounted at 7 percent.***

Economic Vitality

Residual Value

U.S. 70

Construction of the new roadway and interchanges would have residual value after the end of the 20-year analysis period, because the useful life of these elements is longer than 20 years. Highways and streets have a useful life of 60 years, and sewer systems (utilities) also have a useful life of 60 years,[4] while land does not depreciate. The undiscounted value of land was added to the total discounted value of the other assets in the final analysis year (2047). Assuming straight-line depreciation for all assets besides land, ***the residual value for the I-70 portion of the Project discounted at 7 percent is $168.1 million.***

I-95

Construction of the new roadway and interchanges would have residual value after the end of the 20-year analysis period, because the useful life of these elements is longer than 20 years. Highways and streets have a useful life of 60 years, and sewer systems (utilities) also have a useful life of 60 years,[5] while land does not depreciate. The undiscounted value of land was added to the total discounted value of the other assets in the final analysis year (2047). Assuming straight-line depreciation for all assets besides land, ***the residual value for the I-95 portion of the Project discounted at 7 percent is $79.7 million.***

Travel Time Savings

U.S. 70

Based on the U.S. 70 Corridor Economic Assessment,[6] improvements to U.S. 70 would result in travel time savings for users. According to Table 5.5, there would be time savings for travelers between the Global TransPark (GTP) and I-95 as well as GTP and the Port of Morehead City.

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[4] Source: U.S. DOT Bridge Preservation guide, Maintaining a State of Good Repair Using Cost Effective Investment Strategies, August 2011, page 2

[5] Source: U.S. DOT Bridge Preservation guide, Maintaining a State of Good Repair Using Cost Effective Investment Strategies, August 2011, page 2

[6] North Carolina Department of Transportation, U.S. 70 Corridor Economic Assessment, March 07, 2014

Based on the mileage and travel time savings between the segments, an average of 0.314 minutes per mile would be saved when the facility is upgraded.

Multiplying this average time savings by the mileage of the individual segments that the project is upgrading to freeway standards and the average build volumes of traffic in the applicable corridors, as found in the same source, yields the total travel time savings. Applying the truck share and the value of time for truckers as found in Exhibit 2 results in the truck time savings. The remaining traffic was multiplied by the auto occupancy rate and the value of auto time, as found in Exhibit 2. ***The travel time savings on U.S. 70 amounts to $213.3 million discounted at 7 percent.***

Truck Operating Savings

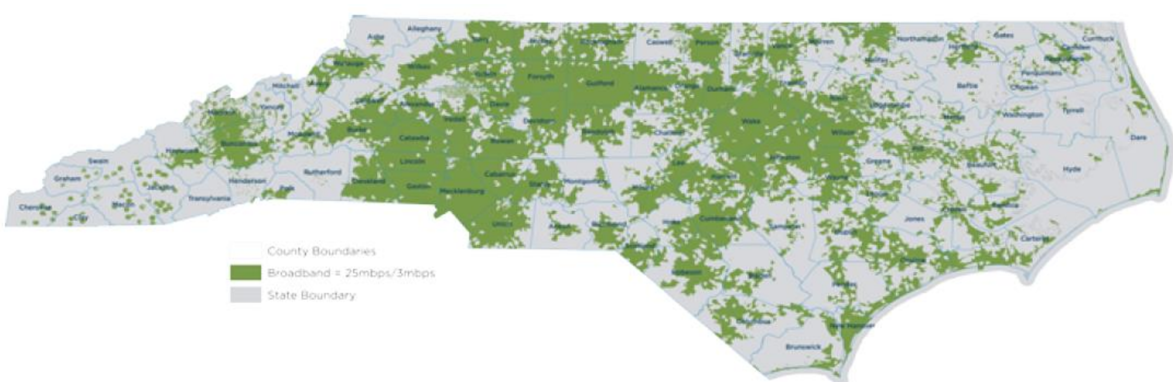
U.S. 70

The travel time savings on U.S. 70 results in operating cost savings for trucks. The operating cost per hour for trucks was found in the ATRI Operational Cost of Trucking,[7] which is inclusive of fuel, oil, truck/trailer lease, maintenance, driver benefits, and insurance. Driver time, as valued in Exhibit 3, was excluded as it is valued in the Travel Time Savings benefit. Multiplying the truck operating time savings by the hours saved results in the total operating time savings for truck diversions. ***The total operating time savings for trucks on U.S. 70 amounts to $47.2 million discounted at 7 percent.***

Fiber Benefits

The Project utilizes transportation infrastructure investment to accomplish more than just transportation. There is a digital divide between rural and urban areas in terms of access to the high-speed broadband and communications capability needed to run modern applications. Exhibit 7 highlights the geographic pattern of high speed connectivity in the state and the large gaps in service in the Project area. This lack of access hinders economic development in small communities, limits agricultural access to applications that use big data to monitor and assess micro climate and yield data over large areas, and restricts educational opportunities. NCDOT will be working with its State Agency partners to utilize this new communications backbone to deliver these types of benefits.

Exhibit 7 - Broadband Availability at 25 MBPS Download Speeds



Source: Connecting North Carolina, State Broadband Plan, 2016

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[7] Table 9 ATRI Operational Cost of Trucking 2015. Includes fuel, oil, truck/trailer lease, repair, maintenance, and insurance.

The installation of fiber would allow for more accurate use of apps such as Waze and others that allow users to anticipate traffic conditions and plan ahead appropriately. The transportation system is therefore used more efficiently. In addition, emergency services, evacuation, public safety, and roadside safety can all be improved with better broadband connectivity.

U.S. 70

The Project will install fiber along the entire U.S. 70 corridor, allowing for faster internet access for much of eastern North Carolina, among other connectivity improvements. This benefit is quantified using a willingness to pay (WTP) methodology. As found in the literature,[8] the value of an increase in broadband internet up to at least 4 megabytes per second (MBPS) is worth $10.37. This is assumed to be per household and is conservative as a typical internet speed is about 25 MBPS and therefore would be valued higher. It is assumed that each household within the counties, as found from Census 2010, along the U.S. 70 corridor would be WTP once per year for the improved internet connection. The county households increase annually based on population growth from the NC Office of Budget and Management (OSBM).[9] ***The total fiber benefit for U.S. 70 amounts to $16.7 million discounted at 7 percent.***

I-95

The Project will install fiber along the entire I-95 corridor from the South Carolina border to the Virginia border, allowing for faster internet access for much of eastern North Carolina, among other connectivity improvements. This benefit is quantified using a willingness to pay (WTP) methodology. As found in the literature,[10] the value of an increase in broadband internet up to at least 4 MBPS is worth $10.37. This is assumed to be per household and is conservative as a typical internet speed is about 25 MBPS and therefore would be valued higher. It is assumed that each household within the counties, as found from Census 2010, along the I-95 corridor would be WTP once per year for the improved internet connection. The county households increase annually based on population growth from the NC OSBM.[11] ***The total fiber benefit for I-95 amounts to $44.4 million discounted at 7 percent.***

Autonomous Vehicles Benefit

The installation of fiber along the corridor would provide the groundwork for the future of autonomous vehicles. As smart vehicles are becoming more affordable, drivers will increasingly be driving autonomous vehicles. Preparing the transportation infrastructure for these new vehicle capabilities allows for the continued safe and efficient movement of goods and people along corridors.

This analysis considers a slow ramp-up of the use of autonomous vehicles on the corridors. Based on the paper “Autonomous Cars Self-Driving the New Auto Industry Paradigm,” by Morgan Stanley,[12] the costs and benefits of autonomous vehicles can be estimated for the corridor.

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[8] Peterson, Richard, “Paying for Speed: Measuring Willingness to Pay in U.S. Broadband Markets,” University of Colorado, October 17, 2017, https://www.colorado.edu/economics/gradplacement/PetersonJMP.pdf

[9] NC Management and Budget, https://files.nc.gov/ncosbm/demog/countygrowth_cert_2016.html

[10] Peterson, Richard, “Paying for Speed: Measuring Willingness to Pay in U.S. Broadband Markets,” University of Colorado, October 17, 2017, https://www.colorado.edu/economics/gradplacement/PetersonJMP.pdf

[11] NC Management and Budget, https://files.nc.gov/ncosbm/demog/countygrowth_cert_2016.html

[12] "Autonomous Cars Self-Driving the New Auto Industry Paradigm", Morgan Stanley, November 6, 2013, pp48-52, http://orfe.princeton.edu/~alaink/SmartDrivingCars/PDFs/Nov2013MORGAN-STANLEY-BLUE-PAPER-AUTONOMOUS-CARS%EF%BC%9A-SELF-DRIVING-THE-NEW-AUTO-INDUSTRY-PARADIGM.pdf

The paper estimates costs to drivers for vehicle upgrades to be about $10,000 in the near-term (assumed to be the first ten years of the benefits period) and $2,000 for the long-term (assumed for the last ten years of the benefits period.) No costs for infrastructure or maintenance were assumed for the vehicles, but costs and maintenance were included in this analysis as part of the fiber installation. An adoption curve for the equipped-vehicles was assumed to be 15 percent in year 1 (2028) and increases to 86 percent by the end of the benefits period. The analysis therefore assumes that the region can attain all of the benefits of autonomous vehicles without 100 percent of the vehicles having autonomous capabilities.

To estimate the benefits, which include fuel savings, accident savings, productivity gains, and fuel and productivity savings from reduced congestion, the source estimated national benefits of $1.3 trillion in 2013 dollars, which are appropriately shared down to represent the Project areas. This analysis assumes a low scenario of realizing benefits, where autonomous vehicles and their associated benefits slowly "ramp up" in use in the corridor from 0 percent in year 1 (2028) to 38 percent by year 20 (2047).

A high benefits ramp-up scenario was also estimated, which assumes benefits accrue at 1 percent in year 1 and increase to 87 percent by year 20. To be conservative, the low scenario ramp-up was used in this analysis.

U.S. 70

The costs to drivers of updating vehicles to autonomous features is estimated by assuming the approximately $10,000 cost per vehicle, factored by AADT in the corridor annually, for the first ten years. Because each year an increasing proportion of vehicles are autonomous-equipped, the costs of the net new vehicles adopted is added. For the last ten years, the net new vehicles are multiplied by the approximately $2,000 cost per vehicle.

Based on the AADT in the corridor in 2028 (about 24,000), the share of national benefits estimated for autonomous vehicles was shared down by a ratio of 24,000 vehicles compared to the national 250,000,000 cars on the road. For U.S. 70 this represents 0.01 percent, or $137 million annually. This is held constant throughout the analysis period even though AADT increases. Multiplying the low scenario annual ramp-up of benefits by the annual benefit amount results in the total benefits per year.

Subtracting the total costs from the total benefit yields the net benefit of autonomous vehicles in the corridor. ***The total autonomous vehicle benefit for U.S. 70 amounts to $24.0 million discounted at 7 percent.***

I-95

The costs to drivers of updating vehicles to autonomous features is estimated the same for I-95 as for U.S. 70, based on I-95 AADT.

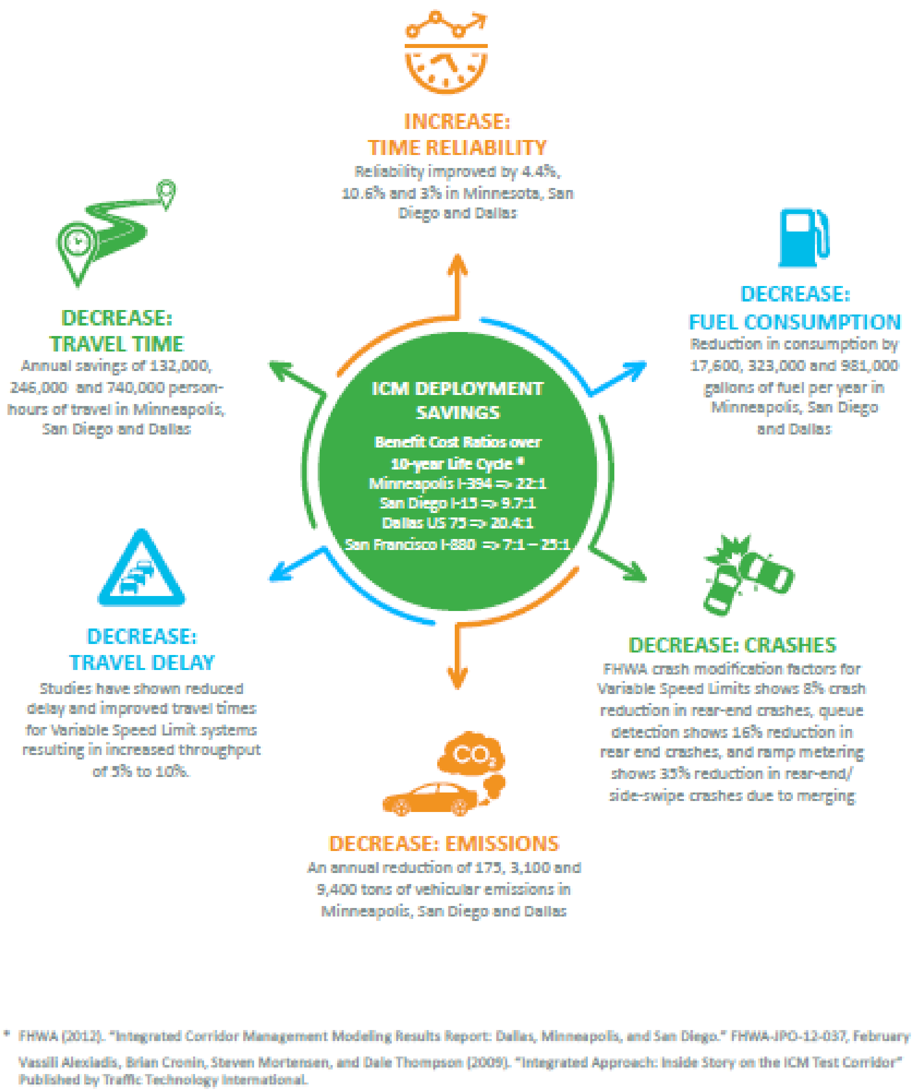
Based on the AADT in the corridor in 2028 (about 67,000), the share of national benefits estimated for autonomous vehicles was shared down by a ratio of 67,000 vehicles compared to the national 250,000,000 cars on the road. For I-95 this represents 0.03 percent, or $372 million annually. This is held constant throughout the analysis period even though AADT increases. Multiplying the low scenario annual ramp-up of benefits by the annual benefit amount results in the total benefits per year.

Subtracting the total costs from the total benefit yields the net benefit of autonomous vehicles in the corridor. ***The total autonomous vehicle benefit for I-95 amounts to $19.5 million discounted at 7 percent.***

Reliability Savings from Integrated Corridor Management

Integrated Corridor Management (ICM) will allow the corridor to be centrally managed and therefore will benefit users from increased efficiencies, as shown in Exhibit 8. One such efficiency is an increase in reliability, or a reduced buffer time on trips. Because of unreliable congestion in the No Build, users may add extra time to trips; with the Build, however, that extra time can be reduced. As estimated by the FHWA for pilot studies in San Diego, Dallas, and Minneapolis, an improvement in travel time reliability was found to range from 3.3 percent to 10.6 percent; 4 percent was conservatively used in this analysis.[13] This reduction in travel time variance is quantified as travel time savings.

Exhibit 8 – ICM Deployment Savings



[13] Integrated Corridor Management Modeling Results Report: Dallas, Minneapolis, and San Diego, https://ntl.bts.gov/lib/54000/54300/54346/ICM_Modeling_Results_Report__FHWA-JPO-12-037_.pdf

U.S. 70

Based on the average traffic volume in the Project area, the average trip length on U.S. 70, and the speed limit as shown in Exhibit 2, an estimated baseline travel time can be calculated. Applying the 4 percent reliability improvement to the average trip time results in the time savings in the corridor. Traffic is expected to increase by about 1.6 percent per year. Applying the truck share and the value of time for truckers as found in Exhibit 2 results in the truck time savings. The remaining traffic was multiplied by the auto occupancy rate and the value of auto time, as found in Exhibit 2.

The total reliability savings from ICM on U.S. 70 amounts to $36.7 million discounted at 7 percent.

I-95

Based on the average traffic volume in the Project area of Harnett County,[14] the average trip length on I-95 for 2009 and 2040,[15] and the speed limit of 70 mph, an estimated baseline travel time can be calculated. Applying the 4 percent reliability improvement to the average trip time results in the time savings in the corridor. Traffic is expected to increase by about 3.7 percent per year.[16] Applying the truck share and the value of time for truckers as found in Exhibit 2 results in the truck time savings. The remaining traffic was multiplied by the auto occupancy rate and the value of auto time, as found in Exhibit 2.

The total reliability savings from ICM on I-95 amounts to $195.1 million discounted at 7 percent.

Detour Travel Time Savings

U.S. 70

The Project will save vehicles time in the event of flooding in low-lying areas of the existing U.S. 70 corridor. Drivers must currently detour around by a longer route, costing travel time and miles. The Project will eliminate these low-lying areas and therefore travel time will be saved relative to the No Build. Shown in Exhibit 4 is one detour route used by vehicles to get around flooded sections of U.S. 70. The route shown is takes an additional 1 hour and 14 minutes to traverse. This is conservative as there are worse detours that take longer, up to 101 miles or 1 hour and 45 minutes.

Factoring the increased time by the number of vehicles, vehicle occupancy, and value of time as shown in Exhibit 2 results in the avoided travel time for detoured autos and trucks. ***The total travel time savings for detoured vehicles on U.S. 70 amounts to $2.3 million discounted at 7 percent.***

Detour Truck Operating Savings

U.S. 70

The travel time savings from the detours avoided on U.S. 70 results in operating cost savings for trucks. The operating cost per hour for trucks was found in the ATRI Operational Cost of Trucking,[17] which is inclusive of fuel, oil, truck/trailer lease, maintenance, and insurance. Driver time, as valued in Exhibit 3, was excluded as it is valued in the Detour Travel Time Savings benefit. Multiplying the truck operating time savings by the hours saved results in the total

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[14] NCDOT Transportation Planning Branch, 2016 Freeway AADT Volumes, https://connect.ncdot.gov/resources/State-Mapping/Documents/NCDOT2016InterstateFreewayReport.pdf
[15] Table 2.10 North Carolina I-95 Economic Assessment Study, 2013
[16] NCDOT Traffic Survey Annual Average Daily Traffic excel report – see Supplemental Materials
[17] Table 9 ATRI Operational Cost of Trucking 2015. Includes fuel, oil, truck/trailer lease, repair, maintenance, and insurance.

operating time savings for truck diversions. ***The total operating time savings for detoured trucks on U.S. 70 amounts to $0.5 million discounted at 7 percent.***

Environmental

Auto Emissions Savings

U.S. 70

Based on the U.S. 70 Corridor Economic Assessment,[18] improvements to U.S. 70 would result in travel time savings for users and therefore reduced emissions. Annual VOC and NOX savings were estimated based on the travel time saving in the corridor for autos and rates found from the EPA.[19] The tons of reduced emissions were held constant throughout the analysis period and monetized using the recommended value of emissions from INFRA 2017 guidance as shown in Exhibit 2. ***In total, U.S. 70 results in auto emissions savings of $0.3 million, discounted at 7 percent.***

In addition to VOC and NOx, carbon dioxide (CO_2) or greenhouse gas would also be reduced. Because there is no official guidance on the value of CO_2 emissions, this benefit is not valued in the analysis.

I-95

Based on the travel time saved as estimated in the Reliability Savings from ICM benefit, reduced idling also reduces emissions. Annual VOC and NOX savings were estimated based on the travel time saving in the corridor for autos and rates found from the EPA.[20] The tons of reduced emissions were held constant throughout the analysis period and monetized using the recommended value of emissions from INFRA 2017 guidance as shown in Exhibit 2. ***In total, I-95 results in auto emissions savings of $0.1 million, discounted at 7 percent.***

In addition to VOC and NOx, CO_2 or greenhouse gas would also be reduced. Because there is no official guidance on the value of CO_2 emissions, this benefit is not valued in the analysis.

Truck Emissions Savings

U.S. 70

Based on the U.S. 70 Corridor Economic Assessment,[21] trucks also save time on U.S. 70 when the Project is operational. Based on emissions rates per idling hour as found in EPA guidance,[22] the tons of VOC, NOX, PM2.5, and PM10 were estimated. The tons of reduced emissions were monetized using the recommended value of emissions from INFRA 2017 guidance as shown in Exhibit 2. ***In total, truck emissions savings on U.S. 70 total $1.1 million, discounted at 7 percent.***

In addition, CO_2 or greenhouse gas would also be reduced. Because there is no official guidance on the value of CO_2 emissions, this benefit is not valued in the analysis.

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[18] North Carolina Department of Transportation, U.S. 70 Corridor Economic Assessment, March 07, 2014
[19] EPA, Idling Vehicle Emissions for Passenger Cars, Light-Duty Trucks, and Heavy-Duty Trucks, EPA420=F-8-025, October 2008, nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EVXV.TXT
[20] Ibid.
[21] North Carolina Department of Transportation, U.S. 70 Corridor Economic Assessment, March 07, 2014
[22] EPA, Idling Vehicle Emissions for Passenger Cars, Light-Duty Trucks, and Heavy-Duty Trucks, EPA420=F-8-025, October 2008, nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EVXV.TXT. Class 8 trucks include long-haul semi-tractor trailer rigs ranging from 33,001 lbs to >60,000 lbs

I-95

Based on the travel time saved as estimated in the Reliability Savings from ICM benefit, trucks also save time on I-95 when the Project is operational. Based on emissions rates per idling hour as found in EPA guidance,[23] the tons of VOC, NOX, PM2.5, and PM10 were estimated. The tons of reduced emissions were monetized using the recommended value of emissions from INFRA 2017 guidance as shown in Exhibit 2. ***In total, truck emissions savings on I-95 total $1.2 million, discounted at 7 percent.***

In addition, CO_2 or greenhouse gas would also be reduced. Because there is no official guidance on the value of CO_2 emissions, this benefit is not valued in the analysis.

Costs

Capital Costs

U.S. 70

The capital costs for the Project include the costs for the purchase of land, construction, soft costs, and contingency. The costs of the project elements are shown in Exhibit 9.

Exhibit 9 – U.S. 70 Construction Costs, 2017$

STIP #	Project Build Cost (U,R,C)	Utilities Cost	Right-of-Way Cost	Construction Cost
R-5777 C	131,900,000	1,100,000	28,500,000	102,300,000
R-5777A	52,200,000	3,300,000	26,700,000	22,200,000
R-5777B	51,700,000	3,000,000	24,500,000	24,200,000
U-5713	180,000,000	2,727,272	68,181,819	109,090,909
Project 10	20,000,000			20,000,000

Source: NCDOT

The capital costs are applied over a nine year construction period, beginning in 2019 and ending in 2027. ***The capital costs for the project discounted at 7 percent total to $300.8 million.***

I-95

The capital costs for the Project include the costs for the purchase of land, construction, soft costs, and contingency. The costs of the project elements are shown in Exhibit 10.

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[23] EPA, Idling Vehicle Emissions for Passenger Cars, Light-Duty Trucks, and Heavy-Duty Trucks, EPA420=F-8-025, October 2008, nepis.epa.gov/Exe/ZyPURL.cgi?Dockey=P100EVXV.TXT. Class 8 trucks include long-haul semi-tractor trailer rigs ranging from 33,001 lbs to >60,000 lbs

Exhibit 10 – I-95 Construction Costs, 2017$

STIP #	Project Build Cost (U,R,C)	Utilities Cost	Right-of-Way Cost	Construction Cost
I-5986A (portion)	120,000,000	672,080	7,224,868	112,103,052
I-5986B	216,800,000	700,000	42,100,000	174,000,000
I-5883	14,580,000		1,080,000	13,500,000
I-5878	31,320,000		4,320,000	27,000,000
I-5877	14,580,000		1,080,000	13,500,000

Source: NCDOT

The capital costs are applied over a ten year construction period, beginning in 2018 and ending in 2027. ***The capital costs for the project discounted at 7 percent total to $243.0 million.***

Operating and Maintenance Costs

U.S. 70

The project requires annual and periodic operating and maintenance (O&M) costs to keep the roads and bridges in a state of good repair. Maintenance begins in 2028, as the first full year of operation, and the O&M costs are the incremental difference between the current O&M costs for the corridor compared to the costs to maintain the upgraded segments. The O&M includes Renewal & Replacement (R&R) costs.

ITS and fiber are assumed to require minimal maintenance annually, estimated at $100,000 and $50,000 per year, respectively.

The total O&M costs over the analysis period and discounted at 7 percent is $39.3 million.

I-95

The project requires annual and periodic operating and maintenance (O&M) costs to keep the roads and bridges in a state of good repair. Maintenance begins in 2028, as the first full year of operation, and the O&M costs are the incremental difference between the current O&M costs for the corridor compared to the costs to maintain the upgraded segments. The O&M includes Renewal & Replacement (R&R) costs.

ITS and fiber are assumed to require minimal maintenance annually, estimated at $100,000 and $50,000 per year, respectively.

The total O&M costs over the analysis period and discounted at 7 percent is $45.5 million.

Summary

Exhibit 11 summarizes the discounted value of the benefits discussed in this memorandum for the total Project. Taken in total and using a 7 percent discount rate, the Project provides $773.7 million dollars of benefits over the analysis period. Compared to a similarly discounted cost estimate, the Benefit Cost Ratio for the Project is 1.42, a solid return on these critical investments. The net benefits total $229.9 million.

In addition, each of the project elements – U.S. 70 and I-95 – also has greater benefits than costs. U.S. 70 and I-95 have $171.7 million and I-95 has $58.2 million in net benefits, respectively.

Exhibit 11 – Total Project Benefit-Cost Analysis (2028-2047 in 2017 $M)

	Values stated in 2017 $M	
	Discounted at 7%	Discounted at 3%
Costs		
Capital Costs	$543.8	$708.9
Total Costs	***$543.8***	***$708.9***
Benefits		
Safety		
Reduced Highway Fatalities and Crashes	$6.6	$13.6
Detour Safety Savings	$1.6	$3.3
Sub-Total Safety Benefits	***$8.2***	***$16.9***
Economic Vitality		
Residual Value	$247.8	$342.0
Travel Time Savings (US 70 Report)	$213.3	$443.9
Truck Vehicle Operating Savings	$47.2	$98.2
Fiber Benefits	$61.2	$128.5
Autonomous Vehicles Benefit	$43.6	$316.1
Reliability Savings from ICM	$231.8	$495.8
Detour Travel Time Savings	$2.3	$4.8
Detour Truck Operating Savings	$0.5	$1.1
Sub-Total Economic Vitality	***$847.6***	***$1,830.5***
Environmental		
Emissions Savings (auto)	$0.4	$0.9
Emissions Savings (truck)	$2.3	$4.9
Sub-Total Environmental	***$2.8***	***$5.8***
O&M Costs	-$84.9	-$174.5
Net O&M	***-$84.9***	***-$174.5***
Total Benefits	***$773.7***	***$1,678.7***
BC Ratio	**1.42**	**2.37**
Net Present value	**$229.9**	**$969.9**

Exhibit 12 – U.S. 70 Benefit-Cost Analysis (2028-2047 in 2017 $M)

	Values stated in 2017 $M	
	Discounted at 7%	Discounted at 3%
Costs		
Capital Costs	$300.8	$377.3
Total Costs	***$300.8***	***$377.3***

Benefits		
Safety		
Reduced Highway Fatalities and Crashes	$0.01	$0.02
Detour Safety Savings	$1.6	$3.3
Sub-Total Safety Benefits	***$1.6***	***$3.3***
Economic Vitality		
Residual Value	$168.1	$211.1
Travel Time Savings (US 70 Report)	$213.3	$443.9
Truck Vehicle Operating Savings	$47.2	$98.2
Fiber Benefits	$16.7	$35.2
Autonomous Vehicles Benefit	$24.0	$106.1
Reliability Savings from ICM	$36.7	$76.9
Detour Travel Time Savings	$2.3	$4.8
Detour Truck Operating Savings	$0.5	$1.1
Sub-Total Economic Vitality	***$508.9***	***$977.4***
Environmental		
Emissions Savings (auto)	$0.3	$0.6
Emissions Savings (truck)	$1.1	$2.3
Sub-Total Environmental	***$1.4***	***$2.9***

O&M Costs	-$39.3	-$80.9
Net O&M	***-$39.3***	***-$80.9***

Total Benefits	***$472.5***	***$902.8***

BC Ratio	**1.57**	**2.39**
Net Present value	**$171.7**	**$525.5**

Exhibit 13 – I-95 Project Benefit-Cost Analysis (2028-2047 in 2017 $M)

	Values stated in 2017 $M	
	Discounted at 7%	Discounted at 3%
Costs		
Capital Costs	$243.0	$331.6
Total Costs	***$243.0***	***$331.6***

Benefits		
Safety		
Reduced Highway Fatalities and Crashes	$6.6	$13.6
Sub-Total Safety Benefits	***$6.6***	***$13.6***
Economic Vitality		
Residual Value	$79.7	$130.8
Fiber Benefits	$44.4	$93.3
Autonomous Vehicles Benefit	$19.5	$210.1
Reliability Savings from ICM	$195.1	$418.9
Sub-Total Economic Vitality	***$338.7***	***$853.1***
Environmental		
Emissions Savings (auto)	$0.1	$0.3
Emissions Savings (truck)	$1.2	$2.6
Sub-Total Environmental	***$1.4***	***$2.9***
O&M Costs	-$45.5	-$93.6
Net O&M	***-$45.5***	***-$93.6***
Total Benefits	***$301.2***	***$776.0***

BC Ratio	**1.24**	**2.34**
Net Present value	**$58.2**	**$444.4**

List of Supporting Information

AECOM, NCDOT_US70I-95INFRA_2017BCA.xls (Excel spreadsheet with BCA calculations by benefit type and summary)

ATRI Operational Cost of Trucking 2015

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