Appendix C:

Benefit-Cost Analysis

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Missouri DOT Fix I-44
2020 INFRA Grant Application

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February 25, 2020

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PART 1: BCA RESULTS AND DOCUMENTATION OF BCA SOURCES AND METHODS

Benefit Cost Analysis Result Summaries

Total benefits and costs of the project in this INFRA Grant application is shown in **Table A-1**, followed by an explanation of source values and methodologies that led to this conclusion.

Table A-1 Summary of BCA Results

Benefits	3% discount rate (in $millions)	7% discount rate (in $millions)	Undiscounted (in $millions)
Vehicle Operating Costs	$63.2	$30.7	$113.9
VOT benefits	$162.2	$78.7	$292.5
Reliability	$9.0	$4.4	$16.3
Safety	$54.7	$27.5	$96.0
Environmental: Non-CO_2	$1.5	$0.7	$2.7
Total Benefits	**$290.6**	**$142.0**	**$521.4**

Costs	3% discount rate (in $millions)	7% discount rate (in $millions)	Undiscounted (in $millions)
Capital Investment Costs	$44.8	$56.2	$67.1
Preservation Costs	$2.2	$4.1	$6.7
Operation and Maintenance Costs	$0.2	$0.3	$0.5
Total Costs	**$47.2**	**$60.6**	**$74.4**

	3% discount rate (in $millions)	7% discount rate (in $millions)	Undiscounted (in $millions)
Net Present Value	$243.4	$81.4	$447.1

	3% discount rate	7% discount rate	Undiscounted
Benefit/Cost Ratio	**6.16**	**2.34**	**7.01**

The Benefit Cost Analysis conducted for the projects in this INFRA Grant application depend on assumptions and valuation factors derived from the U.S. DOT Guidance as well as from other sources including the Missouri Department of Transportation (MoDOT) for the projects. This appendix provides technical documentation of the key input assumptions and valuation factors used in the benefit-cost analysis and the Microsoft Excel modeling of travel, emissions and safety and shipper logistics benefits for each project included in this INFRA grant application package. Data sources are documented in footnotes. The dollar year used is 2018. Conversions to 2018 dollars are made using the Bureau of Economic Analysis provided in BCA guidance.[1] (The benefit cost analysis results for each project are presented in subsequent Appendix B.)

Value of Time

The per-person-hour values of time used for the analysis are those defined by the *Benefit-Cost Analysis Guidance for Discretionary Grant Programs*. Freight value of time were also taken from the same source[2], and are presented in **Table A- 2**.

Table A- 2 Value of Time by Mode and Purpose

Mode/Purpose	Value (2018 $ per person-hour)[1]
Truck – All	$29.5
Car – All Purpose	$16.6

Vehicle Occupancy

Vehicle occupancy rates were estimated for trucks and cars. For trucks, crew per truck were assumed to be equal to 1. Vehicle occupancy rate for passenger vehicle comes from the BCA Guidance.

Table A- 3 Crew, Passenger, and Freight Vehicle Loading Factors

Mode/Purpose	Crew Per Vehicle	Passenger per Vehicle[1]
Truck – All	1.0	0
Car – All purpose	0	1.67

Vehicle Operating Costs

Vehicle Operating Costs (VOC) include non-fuel costs and the fuel-related costs estimated separately (adjusted for differences in fuel consumption under congested and uncongested travel conditions). This decoupling enables a more accurate estimate of VOC and when compared to combined fixed per-mile operating cost values is a more conservative approach. The passenger car non-fuel VOC includes maintenance, tires, and mileage-based depreciation and insurance costs. Fixed costs of ownership related to depreciation, insurance, financing and licensing are removed from VOC. The truck per-mile VOC includes the costs of truck and trailer

[1] Accessible at: https://www.transportation.gov/office-policy/transportation-policy/benefit-cost-analysis-guidance

[2] Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 31.

leases and purchase payments, repair and maintenance, insurance, permits and licenses, and tires.

The non-fuel costs are shown in **Table A- 4** and fuel consumption is shown in **Table A- 5.** The values are taken from the FHWA Highway Statistics Series. The rates are calculated separately for free flow and congested conditions, with a fuel consumption penalty applied under congested conditions. For passenger cars, under free flow conditions, consumption is 0.0463 gallons per mile. Under congested conditions, consumption is 0.0532 gallons per mile for cars, with a 15% fuel consumption penalty applied. For trucks, under free flow conditions, consumption is 0.1563 gallons per mile. Under congested conditions, consumption is 0.2188 gallons per mile, with a 40% fuel consumption penalty applied. The 2018 fuel costs per gallon are averages from the AAA Gasoline process for Missouri and are $2.56 per gallon of diesel and $2.18 for motor gasoline.

Average per-mile Vehicle Operating Cost (VOC) is also provided by the BCA Guidance and is presented in **Table A- 6**. The values are do not differentiate between the congested and uncongested conditions and are used only to estimate the benefits of preservation. For passenger cars, the vehicle operating cost is $0.41 per mile and for trucks, the value is $0.96 per mile.

Table A- 4 Non-Fuel Vehicle Operating Costs

Mode	Trip Purpose	Non-Fuel Operating Cost		
		Per Mile (FF)[3]	Per Mile (Cong.)[4]	Per hour (Cong. or Idle)
Car	Business	0.291	0.291	5.03
All Trucks	Freight	0.563	0.563	22.56

Table A- 5 Gallons of Fuel Consumed

Mode	Trip Purpose	Average Gallons of Fuel Consumed		
		Per Mile (FF)[5]	Per Mile (Cong.)[6]	Per hour (Cong. or Idle)
Car	Business	0.0463	0.0532	0.0532
All Trucks	Freight	0.1563	0.2188	0.2188

Table A- 6 Per-Mile Vehicle Operating Costs

Mode/Purpose	Value (2018 $ per mile)[7]
Car – All purpose	$0.41

[3] Source: Table MV-1 of the 2016 FHWA Highway Statistics Series

[4] Source: Table MV-1 of the 2016 FHWA Highway Statistics Series, with a fuel consumption penalty applied due to congested conditions of 15% for cars and 40% for trucks.

[5] Source: Table MV-1 of the 2016 FHWA Highway Statistics Series

[6] Source: Table MV-1 of the 2016 FHWA Highway Statistics Series, with a fuel consumption penalty applied due to congested conditions of 15% for cars and 40% for trucks.

[7] Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 32.

Truck – All	$0.96

Safety Costs

MoDOT collects crash data on fatalities, injuries, and property damage. BCA Guidance recommends monetizing the value of injuries according to the Maximum Abbreviated Injury Scale (MAIS). The KABCO level values shown result from multiplying the KABCO-level accident's associated MAIS-level probabilities by the recommended unit Value of Injuries given in the MAIS level table, and then summing the products. The conversion is presented in **Table A- 7**. The resulting costs are presented in **Table A- 8**.

Table A- 7 Mapping of MoDOT Accident Classification to BCA Guidance Classification

MoDOT Crash Classification	INFRA Guidance Classification
Fatality	MAIS Fatal
Personal Injury	KABCO Injured (Severity Unknown)
Property Damage	KABCO No Injury

Table A- 8 Crash Valuation Factors[8]

Value	$ per Fatalities Accident	$ Per Personal Injury Accident	$ Per Property Damage Accident
2018 $	$10,636,000	$250,000	$4400

[8] Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 30.

Environmental Costs

Emissions generated on a per mile basis were calculated, using information from the U.S. EPA Office of Transportation and Air Quality. Emissions are valued according to TIGER and INFRA Grant Guidance, with a conversion factor from long tons to metric tons of: (2,240 lbs./2,205 lbs.) = 1.01587 metric tons per long ton.

Table A-9 Emissions Generated on a Per Hour Basis[9]

Long tons per VHT				
Mode	**VOCs**	**NOx**	**SOx**	**PM**
Passenger Car	3.42E-06	2.29E-06	0.00E+00	0
All Trucks	2.07E-06	3.99E-05	2.64E-08	9.75E-07

Table A- 10 Value per Metric Ton of Criteria Pollutant Emissions

Value per metric ton[10]	**VOCs**	**NOx**	**SOx**	**PM**
2018 $	$2,100	$8,600	$50,100	$387,300

I-44 Corridor Widening Project-Specific Assumptions

I-44 as it passes through Springfield, Missouri, has just two-lanes each direction, but it is heavily utilized by the local community for cross-town circulation. As traffic has increased in recent years, I-44 is experiencing daily congestion that is increasingly onerous. About 27% of the overall daily traffic is freight traffic. If delays continue much longer, it will be a significant drag on the national economy. The proposed project would add an additional through lane to each direction between Western Bypass Road and US 65, a total distance of 7.0 miles, including widening of six bridges to accommodate the extra lane.

The opening year of the project is 2026. The approach to estimate benefits to cost ratio (BC ratio) is comparing the monetized value of various savings with the capital and operational and maintenance (O&M) costs, between the No-Build and the Build scenarios. The benefits

[9] Values derived using multiple sources: EPA. Average Annual Emissions and Fuel Consumption for Gasoline-Fueled Passenger Cars and Light Trucks, October 2008, http://www.epa.gov/otaq/consumer/420f08024.pdf; Average In-Use Emissions from Heavy-Duty Trucks, October 2008, http://www.epa.gov/otaq/consumer/420f08027.pdf; Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2008, http://epa.gov/climatechange/emissions/usinventoryreport.html; MOVES2010 model, March 2010 Build, Database MOVES20091221, in Hours of Service (HOS) Environmental Assessment, 2011, Appendix A, Exhibit A-4, "Long-haul and Drayage Truck Travel Emission Factors," http://www.fmcsa.dot.gov/sites/fmcsa.dot.gov/files/docs/2011_HOS_Final_Rule_EA_Appendices.pdf; "Policy Discussion – Heavy-Duty Truck Fuel Economy," Presentation by Drew Kodjak, National Commission on Energy Policy, 10th Diesel Engine Emissions Reduction (DEER) Conference, August 29 – September 2, 2004, http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2004/session6/2004_deer_kodjak.pdf.

[10] Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 33.

considered were vehicle operating cost savings, value of time savings, safety benefits and emission benefits.

With the project being in a semi-rural area, the current approach is conservative. It is assumed that the traffic conditions are not congested in the off-peak time periods and the travel time savings occur only in the peak periods. The peak periods are assumed to be two hours in the AM and two hours in the PM. Of that, it is assumed that traffic volumes in one of the two hours (the shoulder hour) is just 75% of the peak hour for each of the two periods. The K-factor assumed is 12 which is a reasonable assumption for the rural area type of the current corridor. The existing year traffic counts were available for the year 2018. The traffic models provided the future year 2040 volumes for the No-Build (4-lane I-44) and the Build (6-lane I-44) scenarios. The traffic model also provided the 2017 and 2040 peak hour volumes, from which average traffic growth estimate was 0.75% annually.

The two important metrics in estimation of various benefits are vehicle miles traveled (VMT) and vehicle hours traveled (VHT). With the addition of two more lanes, the vehicle miles traveled (VMT) on I-44 increase. The additional vehicles in the build were traveling on adjacent roads in the No-Build. In the absence of traffic data for adjacent road segments, the VMT reduction on them could not be captured and therefore, we assumed that the net VMT in the system is the same. VHT is different between the No-Build and the Build due to the improved speed in the build. VHT savings occur only in the peak periods as there is no congestion assumed in the off-peak. The calculation of VHT requires segment speeds and capacity. The speeds were calculated using the volume delay function (VDF) taken from Wasatch Front Regional Council (WFRC) for similar region, and the capacities were taken from 2010 Highway Capacity Manual (HCM).

Since the VMTs are same for the No-build and the Build, the **vehicle operating costs (VOC)** were calculated based on the time spent in congestion, or VHTs, separately for autos and trucks. The additional benefits of preservation were applied to the operating cost savings. The International Roughness Index (IRI) was estimated for the No-build and the Build and corresponding reduction factors were calculated from Texas Transportation Institute, 1994 and ARRB Research Board TR VOC Model. The IRI was calculated from “MoDOT’s Aran Viewer” for the year 2019 and assumed same for the No-Build. The average value was 57. The IRI value for build is assumed to be 55 (based on MoDOT guidelines). With values very close, the reduction factors are almost same and so no preservation benefits were observed for the corridor. The difference in the operating costs between the No-build and the Build provided the VOC benefits.

The **value of time (VOT)** costs were calculated for both autos and trucks, using VOT values from BCA guidance and multiplying by the VHTs in the No-build and the Build. The difference in the VOT cost values between the No-build and the Build provided the VOT benefits.

The safety benefits were calculating by comparing the avoided crashes due to the improvements in the build. The crash data was available for year 2019, which included 1

fatality, 26 injury and 51 property-damage only crashes. The crash rate (per million VMT) was calculated using the number of 2019 crashes and 2019 VMT. The rates were applied to estimate the crashes in the 2040 No-Build. Crash modification factor (CMF) were obtained from the CMF clearinghouse for widening from 4-to-6 lanes improvement and was found to be 0.7. Applying the CMF to No-Build crashes, build crashes were determined. Total cost of crashes was estimated for the No-Build and the Build and the difference provided the monetized value of safety benefits.

The emissions were calculated using the VHTs, separately for autos and trucks. The reduction in fuel consumption due to idling in congestion at the interchange results in less emissions overall. The analysis calculates the benefits of avoided emissions of volatile organic compounds (VOC), fine particulate matter (PM), and nitrogen oxides (NOx) from motorists and truck drivers. The emissions (in tons) were calculated based on the VHTs for the No-Build and the Build and the costs were calculated using the BCA guidance. The difference in costs in the Build and the No-Build provided the monetized emission benefits.

The costs were provided by the MoDOT and consisted of capital funding of $68.3M, and various operational and maintenance (O&M) costs. The values are included in the BCA spreadsheet.

PART 2: GUIDE TO BCA WORKBOOK CALCULATIONS

Benefit Cost Analysis Details

The benefit cost analysis (BCA) of the project was conducted using the input assumptions described in Appendix A and detailed in the accompanying live Microsoft Excel Workbooks (I-44_BCA_v8.xlsx).

This Appendix B contains the summary table with the BCA results for the project. It is also included in the accompanying MS Excel BCA workbooks, documenting the results presented in the main body of the application. The project-specific BCA results summary tables follows the guide to the contents of the BCA Excel Workbooks presented next.

Benefit Cost Analysis Workbook Guide

In the Microsoft Excel workbook, the BCA inputs and results are presented across multiple worksheets in table formats that document the results, the calculations and the inputs and assumptions. There are separate worksheet tabs for overall BCA, the benefits summary, the project costs, the travel demand characteristics (TDC), the benefit calculations, the fixed factor inputs, the cost summary discounted, and the crash reductions. The content in these worksheets is provided below:

The BCA Summary tab presents the calculated benefit cost ratio for the project under net present value calculations using the 3% and 7% discount rates for the benefit and cost categories derived from the supporting tables in the other tabs.

The Benefits Summary tab includes in one tab the undiscounted and discounted at 3% and 7% benefits streams for the project year-by-year. The separately derived benefits categories are detailed in columns for Vehicle Operating Costs; Value of Time Costs; Reliability Costs; Safety Costs; Environmental Costs; and a Total for the benefits categories.

The Project Costs tab contains the year-by-year undiscounted costs for each cost category and total: Total Capital; Preservation; and, Total Operations and Maintenance (O&M).

The Travel Demand Characteristics (TDC) tab includes the travel demand modeling results comparing the no-build and the with-project scenarios interpolated year-by-year. The vehicle miles traveled, the percent congested, the vehicle hours traveled, and the buffer time are detailed for passenger cars and for freight trucks. The crashes are estimated for fatalities, personal injuries and property damage for No-Build and the Build.

The Benefit Calculations tab includes the year-by-year values comparing the No-build alternative to the with-project alternative for Vehicle Operating Cost; Value of Time; Reliability; Safety; and Non-CO2 Emissions. These benefit streams are detailed for passenger cars and trucks.

The Fixed Factors tab presents the input assumptions used for vehicle operations, safety and emissions by passenger cars and freight trucks.

The Cost Summary Discounted tab summarizes the start-up costs and the ongoing preservation, and O&M costs year-by-year with the discounting at 3% and the 7% alternative discount rates with the full-period totals at the end.

The Costs tab includes the capital costs and detailed O&M and preservation costs as provided by MoDOT.

The Inputs tab contains the traffic data and other project specific assumptions.

The Calculations tab includes the methodology and calculations used in estimating various variables like VHT, VMT, speeds, and crashes in the No-Build and Build scenarios.

IRI tab includes the IRI International Roughness Index (IRI) values by corridor segment and the average IRI value for the No-Build.

The IRI_adj tab consists of constant factors applied to the operating cost, based on the IRI value.

Crash Reduction tab includes the collected data of 2019 crashes and the Crash Modification Factor (CMF) for the project.

Inflation tab consists of adjustment values to convert the corresponding year dollars to 2018 dollars.