# Appendix C:

Benefit-Cost Analysis

**Benefit-Cost Analysis Supplementary Documentation**

INFRA Grant Program

# 251 Missouri Bridges

*Missouri Department of Transportation*

March 4, 2019

The Missouri Department of Transportation (MoDOT) is pursuing an Infrastructure For Rebuilding America (INFRA) grant for the **251 Missouri Bridges** project. The project entails construction of a new Missouri River Bridge at Rocheport (the Rocheport Bridge), and to reconstruct, rehabilitate, and re-deck 250 bridges throughout the state.

The Rocheport Bridge and the 250 bridges were assessed through two separate Benefit-Cost Analysis (BCA) models. Each BCA uses a unique methodology. The two BCA models were then combined to determine the overall project benefits, costs, net present value, and benefit-cost ratio in the workbook titled “BCA Model MoDOT INFRA – 02Mar2019.xlsm”. Because each portion of the project utilizes a unique BCA methodology, this appendix contains one report relevant to the Rocheport Bridge BCA and a separate report relevant to the 250 bridges BCA.

The table below outlines the BCA results for each project component and the overall BCA results for the **251 Missouri Bridges** project:

| **Benefit Cost Summary** | **Rocheport Bridge** | **250 Bridges** | **Combined** |
|---|---|---|---|
| **Benefit** | **7% discount rate (in $millions)** | **7% discount rate (in $millions)** | **7% discount rate (in $millions)** |
| Vehicle Operating Costs | $338.0 | $2,554.5 | $2,892.4 |
| Business Time and Reliability Costs | $796.7 | not quantified | $796.7 |
| Value of Personal Time and Reliability | $847.4 | $2,934.4 | $3,781.8 |
| Safety | $142.3 | not quantified | $142.3 |
| Environmental: Non-$CO_2$ | $32.7 | $28.7 | $61.4 |
| Logistics/Freight Costs | $78.7 | not quantified | $78.7 |
| **Total Benefits** | **$2,235.8** | **$5,517.5** | **$7,753.4** |
| **Costs** | **7% discount rate (in $millions)** | **7% discount rate (in $millions)** | **7% discount rate (in $millions)** |
| Capital Investment Costs | $158.4 | $341.7 | $500.1 |
| Operation and Maintenance Costs | -$0.2 | $0.0 | -$0.2 |
| **Total Costs** | **$158.2** | **$341.7** | **$500.0** |
| | **7% discount rate (in $millions)** | **7% discount rate (in $millions)** | **7% discount rate (in $millions)** |
| Net Present Value | $2,077.6 | $5,175.8 | $7,253.4 |
| | **7% discount rate** | **7% discount rate** | **7% discount rate** |
| **Benefit/Cost Ratio** | **14.11** | **16.15** | **15.50** |

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# Supplementary Documentation – Rocheport Bridge
# A: Benefit-Cost Analysis Sources and Approach
# B: Benefit Cost Analysis and Guide to Workbooks

*Prepared for:*

**Missouri DOT**

2019 INFRA Grant Application

*Prepared by:*

**Metro Analytics**

**March 3, 2019**

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# SUPPLEMENTARY DOCUMENTATION A: TECHNICAL DOCUMENTATION OF BCA SOURCES AND METHODS

The Benefit Cost Analysis conducted for the Rocheport Bridge portion of the project 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 for the projects. This supplementary documentation 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. Conversions to 2017 dollars are made using the Bureau of Labor Statistics CPI Inflation Calculator.[1] (The benefit cost analysis results for the Rocheport Bridge portion of the project are presented in subsequent Supplementary Documentation 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*. Benefit estimation also adopts the Guidance-suggested car trip purpose splits for intercity travel by conventional surface modes[2]. Freight time costs were also taken from the same source.[3]

Table A-1 Value of Time by Mode and Purpose

| Mode/Purpose | Value (2017 $ per person-hour)[4] |
|---|---|
| **Truck – All** | $28.60 |
| **Car – Business** | $26.50 |
| **Car – Personal** | $14.80 |

Table A-2 Car Trip Purpose Split

| Trip Purpose | Percentage[5] |
|---|---|
| **Car – Business** | 21.4% |
| **Car – Personal** | 78.6% |

[1] Accessible at: http://www.bls.gov/data/inflation_calculator.htm

[2] *Revised Departmental Guidance on Valuation of Travel Time in Economic Analysis* https://www.transportation.gov/office-policy/transportation-policy/revised-departmental-guidance-valuation-travel-time-economic

[3] Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 29.

[4] Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 29.

[5] The Value of Travel Time Savings: Departmental Guidance for Conducting Economic Evaluations Revision 2, Page 10.

# Vehicle Occupancy

Vehicle occupancy rates are estimated from separate factors for trucks and cars. For trucks, crew per truck and freight tons per truck are used in the estimation. Passenger vehicle load factors come from the BCA Guidance.

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

| Mode/Purpose | Crew Per Vehicle | Passenger per Vehicle[6] | US Freight Tons Per Vehicle[7] |
|---|---|---|---|
| **Truck – All** | 1.0[8] | 0 | 24.05 |
| **Car – Business** | 0 | 1.68 | 0 |
| **Car – Personal** | 0 | 1.68 | 0 |

# Vehicle Operating Costs

Vehicle Operating Costs (VOC) are estimated using mileage-based costs (maintenance, tires, and mileage-based depreciation and insurance) that are separated from fuel-related costs (adjusted for differences in fuel consumption under congested and uncongested travel conditions) instead of one fixed per-mile Vehicle Operating Cost. 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 Vehicle Operating Cost (VOC) in dollars-per-mile includes the average per-mile cost of vehicles' tires, maintenance, and depreciation for travel in free-flow and congested conditions. (Fuel costs are treated separately, below). In order to derive costs per mile without fuel, the per mile fuel costs (see Table A-5) was subtracted from the $.39 per mile cited in the BCA Guidance (which includes operations and fuel), For passenger cars, for either business or personal use these amount to $.34 per mile. The passenger car per-mile 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 leases and purchase payments, repair and maintenance, insurance, permits and licenses, and tires. Costs for labor, fuel and truck tolls are included separately and amount to $.90 per mile.

Table A- 4 Per-Mile Vehicle Operating Costs Except Fuel

| Mode/Purpose | Value (2017 $ per mile)[9] |
|---|---|
| **Car – Personal** | $0.39 |
| **Car – Business** | $0.39 |
| **Truck – All** | $0.90 |

6 Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 30.

7 2002 Vehicle Travel Information System (VTRIS) average estimates of truck share and mean gross vehicle weight for straight trucks and tractor + single trailer trucks nationally, as summarized in FAF2 Freight Traffic Analysis. Chapter 3: Development of Truck Payload Equivalency Factors. Table 3.1: Results of Vehicle Weight Validation. http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/faf2_reports/reports7/c3_payload.htm

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

9 Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 30.

The fuel cost factors for Vehicle Gallons Per Mile (estimated gallons of fuel consumed per vehicle mile travelled) are from the FHWA Highway Statistics Series, in Table MV-1. The rates are calculated separately for free flow and congested conditions, with a fuel consumption penalty applied under congested conditions.[10] For passenger cars, under free flow conditions, consumption is .045 gallons per mile. Under congested conditions, consumption is .052 gallons per mile for cars, with a 15% fuel consumption penalty applied. For trucks, under free flow conditions, consumption is .156 gallons per mile. Under congested conditions, consumption is .218 gallons per mile, with a 40% fuel consumption penalty applied.  The 2019 fuel costs per gallon are averages from the U.S. Department of Energy and are $3.01 per gallon of diesel and $2.32 for motor gasoline.[11]

Table A- 5 Per-Mile Vehicle Operating Costs – Gallons of Fuel Consumed

| Mode | Trip Purpose | Average Gallons of Fuel Consumed | | |
|---|---|---|---|---|
| | | Per Mile (FF)[12] | Per Mile (Cong.)[13] | Per hour (Cong. or Idle) |
| Passenger Car | Business | 0.0454 | 0.0522 | 0.0522 |
| Passenger Car | Personal | 0.0454 | 0.0522 | 0.0522 |
| All Trucks | Freight | 0.1559 | 0.2183 | 0.2183 |

# 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-6. The resulting costs are presented in Table A-7.

Table A- 6 Mapping of Mo DOT Accident Classification to BCA Guidance Classification

| Mo DOT Crash Classification | INFRA Guidance Classification |
|---|---|
| Fatality | MAIS Fatal |
| Personal Injury | KABCO Injured (Severity Unknown) |
| Property Damage | KABCO No Injury |

Table A- 7 Crash Valuation Factors

| Value | $ per Fatalities Accident[14] | $ Per Personal Injury Accident | $ Per Property Damage Accident[15] |
|---|---|---|---|
| 2017 $ | $9,600,000 | $174,000[16] | $4,300 |

[10] Source: Zhang, K., S. Batterman, and F. Dion. 2011. Vehicle Emissions in Congestion: Comparison of work zone, rush hour, and free-flow conditions. Atmospheric Environment 45, pages 1929-1939.
[11] Taken from the US Department of Energy website on 2/20/2019. https://www.eia.gov/petroleum/gasdiesel/
[12] Source: Table MV-1 of the 2016 FHWA Highway Statistics Series
[13] 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.
[14] Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 28.
[15] Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 28.
[16] Benefit-Cost Analysis Guidance for Discretionary Grant Programs, Page 28.

# 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-7 Emissions Generated on a Per Mile Basis[17]

| | Long tons per VMT | | | | |
|---|---|---|---|---|---|
| **Mode** | **VOCs** | **NOx** | **Sox** | **PM** | **CO2** |
| **Passenger Car** | 1.05E-06 | 7.04E-07 | 0.00E+00 | 4.32E-09 | 3.74E-04 |
| **All Trucks** | 1.18E-06 | 2.47E-06 | 1.79E-09 | 4.37E-08 | 9.63E-04 |

Table A- 8 Value per Metric Ton of Criteria Pollutant Emissions

| Value per metric ton[18] | VOCs | NOx | SOx | PM |
|---|---|---|---|---|
| 2017 $ | $2,000 | $8,300 | $48,900 | $377,800 |

[17] 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.

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

# Shipper Logistics Costs

Shipper logistics costs are the value of freight quantifying the value of time for reliability in deliveries which are part of just-in-time and lean logistics supply chain inventory management. Standard operating procedures for many industries such as high-value manufacturers including maintaining reduced safety stocks, which lowers the opportunity cost of capital.  The calculation of the shipper logistics cost category requires a profile of the types of commodities that are being shipped within, to, and from the study area and cannot readily be calculated within a spreadsheet but is adapted from a methodology used and documented in Missouri DOT's 2017 INFRA application for the I-70 corridor projects.

# Project-Specific Assumptions

## I-70 Rocheport Bridge Replacement Assumptions

The Rocheport bridge on I-70 is approaching the end of its useful life.  It needs to be either replaced right away, or undergo a major renewal to help keep it in service another ten-years, at which point it will likely no longer be safe for use by trucks, and within five years thereafter will not be safe for use by passenger cars either.  Lost use of the Rocheport bridge would impose significant costs on the US Economy as I-70 would no longer be a continuous trans-continental route, and there would be significant diversion costs as documented in the supplemental report:  *Rocheport Bridge Posting and Closure Analysis*.  A full accounting of costs associated with loss of the Rocheport bridge due to lack of funding is beyond what can be quantified in the current application.  Consequently, the BCA methodology here focuses primarily on the minimum potential long-term costs associated with passenger and care diversion imposed by failure to replace the Rocheport bridge.

The analysis does not quantify additional unknown costs such as the safety implications of diverting trucks and long-distance car traffic from interstate to non-interstate facilities (with commensurate changes in average crash rates), the environmental implications of diverting traffic from a fully controlled highway to routes characterized by intersection stops and the costs of decommissioning and de-constructing the Rocheport bridge to ensure safe navigation on the Missouri River. Furthermore, the localized air quality and noise costs associated with passing even a share of Rocheport's traffic through local communities on the NHS are not quantified here as such would require a major study beyond the resources, timing or complexity of the current application.  Hence in effect, the user benefits of preserving the Rocheport bridge are presented as a minimum. Furthermore, based on feedback received from Missouri DOT's 2017 INFRA application, the current application does not presume an eventual, but later replacement in the base-case condition – as the funds for such a replacement are not identified and no such replacement is programmed at this time.

To analyze this situation, the minimum costs imposed by loss of the Rocheport bridge are shown in the base-case to begin in 2030; eight years after a $16 Million rehabilitation; when Mo DOT engineering estimates indicate a likely closure to trucks would be needed.  Five years later (by 2035, approximately 12 years after completion of a 2023 rehabilitation, it is assumed that the bridge would close to all traffic and impose diversion costs on both cars and trucks without the replacement requested in the current grant application.  Furthermore, it is assumed that the annual operation and maintenance costs will be higher during the period following the rehabilitation leading up to posting and closure in the base case than they would be under the replacement build scenario enabled by the INFRA grant on account of the replacement providing a new starting bridge condition. While many of the ancillary facilities that have been used as short-term detour routes are not today capable of accommodating permanent re-assignment from loss of the Rocheport bridge, the analysis conservatively assumes that in the period leading up to the posting and closure, these facilities may be prepared for this function. Consequently instead of assuming diversion as would have to occur on today's national network (as represented in the ITTS SHIFT model described in the supplemental report (*Rocheport Bridge Posting and Closure Analysis)* the analysis assumes that routes that have been used in the past as short-term diversion routes would ultimately be available, enabling the benefit of Rocheport's preservation to be less than might be the case if conditions shown in the ITTS network alone prevail. Consequently, Mo DOT's . Mo DOT's data for the last three years of lane closures and their duration for bridge maintenance together with a spatial analysis of available Missouri river crossings and alternative routes is presented in the supplemental report and underlies this scenario. In every case lane were reduced from 2/direction to 1/direction. Delays under such conditions can be substantial and would cause many local trips who are aware of the delays to reroute, and even some national interstate trips would reroute.

# Supplementary Documentation B: BCA Results By Project and Guide to BCA Workbook Calculations

## Benefit Cost Analysis Results Details

The benefit cost analysis (BCA) of the I-70 Rocheport Bridge replacement was conducted using the input assumptions described in Supplementary Documentation A and detailed in the accompanying live Microsoft Excel Workbook titled "BCA Model MoDOT INFRA - 02Mar2019.xlsm."

This Supplementary Documentation B contains the summary tables with the BCA results for the Rocheport Bridge replacement as well as the total for the combined application package of projects. Each of these 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 follow the guide to the contents of the BCA Excel Workbooks presented next.

## Benefit Cost Analysis Workbook Guide

Within the application's benefit cost analysis Microsoft Excel workbook are individual worksheets with the details of each component project's BCA and the combined BCA for the INFRA grant application package of projects.

Within the BCA workbook, the BCA inputs and results for the Rocheport Bridge replacement 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 each project and the combined total with the 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.

Within the BCA workbook, the BCA Summary tabs present the calculated benefit cost ratio for the Rocheport Bridge portion of 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; Business Time & Reliability Costs; Value of Personal Time & Reliability; Safety Cost; Environmental Cost; Shipper/ Logistics Cost; and a Total for the benefits categories.

The Project Costs tab contains the year-by-year no-build baseline and the with-project build alternative undiscounted costs for each cost category and total: Property Acquisition Engineering and Design; Right of Way; Transport Structures; Terminal; Vehicles; Total Capital; Ongoing Operations; Maintenance and Rehabilitation; and, Total Operations and Maintenance.

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

The Benefit Calculations tabs include the year-by-year values comparing the baseline 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 personal and business use of passenger cars and for freight trucks.

The Fixed Factors tabs present the input assumptions used for vehicle operations and for emissions by business and personal use of passenger cars and for freight trucks.
The Cost Summary Discounted tabs summarize the start-up costs and the ongoing operations and maintenance costs year-by-year with the discounting at 3% and the 7% alternative discount rates with the full-period totals at the end.

The tabs for Crash Reductions, compare the no-build alternative to the project alternative costs of property damage, personal injury and fatal accidents discounted at 7% and 3% across the evaluation period from 2020 to 2053. The costs are separately calculated for freight trucks as well as personal and business use of passenger cars. The crash rates are from the Bureau of Transportation Statistics (BTS) National Transportation Statistics (NTS) Tables. Car and truck crash rates are from NTS Chapter 2 Section C.

# Benefit Cost Analysis Results

The summary of the total benefits and costs of the Rocheport Bridge replacement component of the project follows.

## I-70 Rocheport Bridge Replacement BCA Summary

**I-70 Rocheport Bridge Replacement Benefit Cost Summary**

| Benefit | 3% discount rate (in $millions) | 7% discount rate (in $millions) | Undiscounted (in $millions) |
|---|---|---|---|
| Vehicle Operating Costs | $944.2 | $338.0 | $2,166.9 |
| Business Time and Reliability Costs | $2,038.7 | $796.7 | $4,400.1 |
| Value of Personal Time and Reliability | $2,298.4 | $847.4 | $5,135.1 |
| Safety | $402.2 | $142.3 | $929.1 |
| Environmental: Non-$CO_2$ | $89.1 | $32.7 | $201.4 |
| Logistics/Freight Costs | $203.9 | $78.7 | $445.7 |
| **Total Benefits** | **$5,976.5** | **$2,235.8** | **$13,278.3** |

| Costs | 3% discount rate (in $millions) | 7% discount rate (in $millions) | Undiscounted (in $millions) |
|---|---|---|---|
| Capital Investment Costs | $189.9 | $158.4 | $218.7 |
| Operation and Maintenance Costs | -$0.2 | -$0.2 | -$0.3 |
| **Total Costs** | **$189.6** | **$158.2** | **$218.4** |

| | 3% discount rate (in $millions) | 7% discount rate (in $millions) | Undiscounted (in $millions) |
|---|---|---|---|
| Net Present Value | $5,786.9 | $2,077.6 | $13,059.9 |

| | 3% discount rate | 7% discount rate | Undiscounted (in $millions) |
|---|---|---|---|
| **Benefit/Cost Ratio** | **31.48** | **14.11** | **60.72** |

# ROCHEPORT BRIDGE POSTING AND CLOSURE ANALYSIS

The Rocheport bridge is at the end of its useful life. If it is not replaced right away, MoDOT will be compelled to spend significantly within a year or two in order to squeeze another 10-years of useful life from the bridge. At that point, somewhere around 2030, the bridge can no longer be rehabilitated for continued safe passage, and will need to be closed to truck traffic. It is expected the bridge could safely serve lighter weight passenger vehicles until about 2035, at which point it would be closed entirely due to safety concerns.

To test this scenario, two methods were used. The first method is based on a national TransCAD travel demand model, known as the SHIFT model, which was obtained from the Institute for Trade and Transportation Studies (ITTS). The model was run with and without the Rocheport bridge for a base year and horizon year.

When the bridge is gone, both passenger and truck traffic will be forced to divert to their next best options. For transcontinental freight, alternative path decisions will be made states away, and the TransCAD model shows significant rerouting to I-80 to the north, and I-40/I-44 to the south. For more localized trips, there are closer bridges that passenger traffic would use, but these bridges and the roadways serving them are not capable of supporting high levels of sustained truck traffic, so the TransCAD modeling assumed that trucks would be required to divert to roadways and bridges that could sustain them for years on end.

In addition to the added VMT, TransCAD predicts that the hours of delay for both passenger vehicles and trucks would skyrocket. This is partly because the added traffic to parallel interstates (I-80 and I-40/I-44), would increase congestion on those routes through urban areas. But the main source of additional delay comes from at-grade rural arterial highways all within Missouri that are often impeded by stop signs and traffic signals in small towns. These routes would simply get massively congested if forced to handle traffic diverted from I-70, and pavements would also degrade quickly. Below is the number of Passenger and Truck trips and associated VMT and VHT as per the TransCAD model.

| **Annual Summary** | Pass Trip | Trk Trip | Pass VMT | Trk VMT | Pass VHT | Trk VHT |
|---|---|---|---|---|---|---|
| 2016, No Bridge | 8,700,000 | 2,400,000 | 2,301,970,000 | 1,534,650,000 | 35,720,000 | 23,810,000 |
| 2016, Yes Bridge | 8,700,000 | 2,400,000 | 2,034,000,000 | 1,356,000,000 | 23,130,000 | 15,420,000 |
| 2040, No Bridge | 11,400,000 | 3,000,000 | 3,082,920,000 | 2,055,280,000 | 70,020,000 | 46,680,000 |
| 2040, Yes Bridge | 11,400,000 | 3,000,000 | 2,610,000,000 | 1,740,000,000 | 37,210,000 | 24,800,000 |

Assuming that the bridge were closed to all traffic in 2020 and remained closed until 2060, these VMT and VHT increases, when converted into a benefits stream, are shown in the following table. At a 7% discount rate, keeping the bridge open during those years is worth $18.8 billion in societal benefit, while the cost to replace it, and thereby keep it open, is $158 million (7% discounted). The resulting Benefit / Cost ratio is thereby a very impressive $119 benefit for every dollar spent.

| Benefit | 3% discount rate (in $millions) | 7% discount rate (in $millions) | Undiscounted (in $millions) |
|---|---|---|---|
| Vehicle Operating Costs | $9,159 | $4,598 | $17,183 |
| Business Time and Reliability Costs | $13,752 | $6,758 | $26,242 |
| Value of Personal Time and Reliability | $10,453 | $5,064 | $20,181 |
| Safety | $3,471 | $1,736 | $6,534 |
| Environmental: Non-$CO_2$ | $1,080 | $546 | $2,016 |
| Logistics/Freight Costs | $204 | $79 | $446 |
| **Total Benefits** | **$38,120** | **$18,782** | **$72,603** |
| **Costs** | **3% discount rate (in $millions)** | **7% discount rate (in $millions)** | **Undiscounted (in $millions)** |
| Capital Investment Costs | $189.9 | $158.4 | $218.7 |
| Operation and Maintenance Costs | -$0.2 | -$0.2 | -$0.3 |
| **Total Costs** | **$190** | **$158** | **$218** |
| | **3% discount rate (in $millions)** | **7% discount rate (in $millions)** | **Undiscounted (in $millions)** |
| Net Present Value | $37,930 | $18,623 | $72,384 |
| | **3% discount rate (in $millions)** | **7% discount rate (in $millions)** | **Undiscounted (in $millions)** |
| **Benefit/Cost Ratio** | **201** | **119** | **332** |

The reality of closing a federal interstate for 40 years would no doubt create huge economic losses, but at this scale it caused us to ask more probing questions. Missouri does believe that by spending around $16-million fairly soon, they can extend the bridge life by 10 years for trucks, and 15 for vehicles, so we ran a second BCA analysis assuming the closure could be delayed. Secondly, if I-70 did close and never reopened, Missouri would end up improving alternative rural highways to handle their local truck traffic at far less congested conditions. Additionally, the TransCAD model assumes VMT would increase as normal, but in reality the huge increase in travel time would cause many trips not to be made, or to adjust to more favorable times and modes.

Thus a second analysis was conducted which assumed transcontinental trips would not incur much additional VMT because when deciding in California how to get to Chicago, I-80 and I-40/44 are nearly the same as I-70 in terms of VMT. And while VHT would likely increase due to increased congestion, urbanized areas would adjust to the modest increase. Locally within Missouri, diverted VMT was calculated by assuming some of the traffic would divert to a bridge that crosses the Missouri River slightly north of Rocheport in a town called Boonville, and the rest would divert to a roadway that is more capable of higher volumes, but also further away, crossing the river at Jefferson City. The table below shows how the second method allocates annual VMT and VHT.

| **Annual Summary** | Pass Trip | Trk Trip | Pass VMT | Trk VMT | Pass VHT | Trk VHT |
|---|---|---|---|---|---|---|
| 2016, No Bridge | 8,700,000 | 2,400,000 | 2,317,680,000 | 1,362,600,000 | 42,900,000 | 21,560,000 |
| 2016, Yes Bridge | 8,700,000 | 2,400,000 | 2,070,600,000 | 1,302,000,000 | 29,580,000 | 18,600,000 |
| 2040, No Bridge | 11,400,000 | 3,000,000 | 3,036,960,000 | 1,703,250,000 | 56,220,000 | 26,950,000 |
| 2040, Yes Bridge | 11,400,000 | 3,000,000 | 2,713,200,000 | 1,627,500,000 | 38,760,000 | 23,250,000 |

Processing the VMT and VHT values of the second method through the same BCA spreadsheet as before yields about $6.0 Billion in benefits, where before was about $38 billion. This is largely because the benefit stream does not start until 2030 for trucks, and 2035 for passenger vehicles, but also because of assumptions that traffic would adjust over time, and Missouri's highways would also adapt to the additional traffic (though the cost of those upgrades was not accounted for in the BCA analysis). Thus the overall Benefit / Cost ratio at 7% discount is 14.11 in this case, where the TransCAD method predicted 119.

| Benefit | 3% discount rate (in $millions) | 7% discount rate (in $millions) | Undiscounted (in $millions) |
|---|---|---|---|
| Vehicle Operating Costs | $944.2 | $338.0 | $2,166.9 |
| Business Time and Reliability Costs | $2,038.7 | $796.7 | $4,400.1 |
| Value of Personal Time and Reliability | $2,298.4 | $847.4 | $5,135.1 |
| Safety | $402.2 | $142.3 | $929.1 |
| Environmental: Non-$CO_2$ | $89.1 | $32.7 | $201.4 |
| Logistics/Freight Costs | $203.9 | $78.7 | $445.7 |
| **Total Benefits** | **$5,976.5** | **$2,235.8** | **$13,278.3** |
| **Costs** | **3% discount rate (in $millions)** | **7% discount rate (in $millions)** | **Undiscounted (in $millions)** |
| Capital Investment Costs | $189.9 | $158.4 | $218.7 |
| Operation and Maintenance Costs | -$0.2 | -$0.2 | -$0.3 |
| **Total Costs** | **$189.6** | **$158.2** | **$218.4** |
| | **3% discount rate (in $millions)** | **7% discount rate (in $millions)** | **Undiscounted (in $millions)** |
| Net Present Value | $5,786.9 | $2,077.6 | $13,059.9 |
| | **3% discount rate (in $millions)** | **7% discount rate (in $millions)** | **Undiscounted (in $millions)** |
| **Benefit/Cost Ratio** | **31.48** | **14.11** | **60.72** |

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# Benefit-Cost Analysis Supplementary Documentation

INFRA Grant Program

# 250 Bridges

*Missouri Department of Transportation*

**March 4, 2019**

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# Benefit-Cost Analysis Supplementary Documentation

## 1. Executive Summary

The Benefit-Cost Analysis (BCA) conducted for this grant application compares the costs associated with the proposed investment to the benefits of the project. To the extent possible, benefits have been monetized. Efforts have been made to quantify a benefit where it was not possible to assign a dollar value. A qualitative discussion is also provided when a benefit is anticipated to be generated but is not easily monetized or quantified.

Missouri Department of Transportation (MoDOT) is pursuing an Infrastructure For Rebuilding America (INFRA) grant for the 251 Missouri Bridges Project in order to construct a new Missouri River Bridge at Rocheport, also referred to as the Rocheport Bridge, and to reconstruct, rehabilitate, and re-deck 250 bridges throughout the state. These efforts would prevent major traffic disruption that would occur as a result of closure of the Rocheport Bridge and 250 bridges. **For purposes of simplicity and due to the fact that the Rocheport Bridge and the 250 bridges have unique BCA methodologies, this document only outlines the BCA methodology and results for the 250 bridges portion of the project.**

The 250 bridges are expected to have significant impacts related to eliminating the need for lengthy detours around bridge closures, including:

- Providing significant travel time savings for private and commercial drivers;
- Reducing vehicle operating costs for private and commercial drivers; and
- Decreasing pollution caused by increased travel distances for private and commercial drivers.

A table summarizing the changes expected from the project (and the associated benefits) is provided below.

**Table ES-1: Summary of Infrastructure Improvements and Associated Benefits for the 250 Bridges**

| Current Status or Baseline & Problems to Be Addressed | Changes to Baseline / Alternatives | Type of Impacts | Benefits | Summary of Results (millions of $2017) | Page # |
|---|---|---|---|---|---|
| Travel delays as a result of bridge postings, closures, and/or failures requiring major detours | Replacement, rehabilitation, and re-decking of the 250 bridges | Eliminating the need for a detour, reducing travel time, reducing vehicle operating costs, decreasing emissions, improving travel time reliability, improving safety | Travel Time Savings | $2,934.4 | 8,10,12 |
| | | | Vehicle Operating Cost Savings | $2,554.5 | 8,10,12 |
| | | | Emissions Cost Savings | $28.7 | 8,10,12 |
| | | | Residual Value | Not Monetized | 2 |
| | | | Accident Cost Savings | Not Monetized | 2 |
| | | | Travel Time Reliability | Not Monetized | 3 |

The period of analysis used in the estimation of benefits and costs corresponds to up to 35 years, including up to 5 years of project support and construction and 30 years of operation. The total (undiscounted) project costs for the 250 bridges are $444.3 million dollars according to the distribution shown in Table ES-2.

**Table ES-2: Summary of Project Costs for 250 Bridges, in Millions of Dollars of 2017**

| Cost Category | Undiscounted Project Cost | Percentage of Undiscounted Project Cost |
|---|---|---|
| Construction Costs | $344.8 | 77.6% |
| Project Support Costs | $99.5 | 22.4% |
| TOTAL COST | $444.3 | 100.0% |

A summary of the relevant data and calculations used to derive the benefits and costs of the project are shown in the Benefit-Cost Analysis (BCA) model (in dollars of 2017). Based on the analysis presented in the rest of this document, the **250 bridges portion** of the project is expected to generate $5,517.5 million in discounted benefits and $341.7 million in discounted costs, using a 7 percent real discount rate. Therefore, the **250 bridges portion** of the project is expected to generate a Net Present Value (NPV) of $5,175.8 million and a Benefit/Cost Ratio of 16.15.

In addition to the monetized benefits, the 250 bridges of the project would generate benefits that were not quantified for the BCA. A brief description of those benefits is provided below.

Residual Value

- The 250 bridges are analyzed for a period of 30 years; however, the bridges are being replaced, rehabilitated, and re-decked to last longer than this analysis period. The remaining service life of each bridge adds to the benefits of the construction projects.

Accident-Related Cost Savings

- The 250 bridges analysis does not include accident-related cost savings due to a lack of availability of adequate and robust safety-related data. Additional travel distance increases the likelihood of accidents which would indicate that the additional travel distance required by the lengthy detours would increase the number of accidents throughout the network. Therefore, by eliminating the need for drivers to take the detours, this project would reduce the number of accidents over the course of the analysis period and result in accident cost savings.

Travel Time Reliability

- By keeping the bridges open and eliminating the need for lengthy detours, this project reduces the variability of travel time for trips involving the bridges. Travel time reliability is an important factor for personal drivers who need to be on time for work or other appointments as well as for commercial drivers whose companies depend on just-in-time deliveries.

The inclusion of these benefits (residual value, accident-related cost savings, and travel time reliability) would increase the overall benefit-cost ratio.

# 2. Introduction

This document provides detailed technical information on the economic analyses conducted in support of the grant application for the **250 bridges portion** of the project.

Section 3, Methodological Framework, introduces the conceptual framework used in each of the BCAs. Section 4, Project Overview, provides an overview of the project, including a brief description of existing conditions and proposed alternatives; a summary of cost estimates and schedule; and a description of the types of effects that the 250 bridges portion of the project is expected to generate. Section 5, General Assumptions, discusses the general assumptions used in the estimation of project costs and benefits, while estimates of travel demand and traffic growth can be found in Section 6, Demand Projections. Specific data elements and assumptions pertaining to the long-term outcome selection criteria are presented in Section 7, Benefits Measurement, Data and Assumptions, along with associated benefit estimates. Estimates of the project's Net Present Value (NPV), its Benefit/Cost ratio (BCR) and other project evaluation metrics are introduced in Section 8, Summary of Findings and BCA Outcomes. Next, Section 9, BCA Sensitivity Analysis, provides the outcomes of the sensitivity analysis. Additional data tables are provided within the BCA model including annual estimates of benefits and costs to assist the U.S. Department of Transportation (USDOT) in its review of the application.[1]

# 3. Methodological Framework

The BCA conducted for this project includes the monetized benefits and costs measured using USDOT guidance, as well as the quantitative and qualitative merits of the project. A BCA provides estimates of the benefits that are expected to accrue from a project over a specified period and compares them to the anticipated costs of the project. Costs include both the resources required to develop the project and the costs of maintaining the new or improved asset over time. Estimated benefits are based on the projected impacts of the project on both users and non-users of the facility, valued in monetary terms.[2]

While BCA is just one of many tools that can be used in making decisions about infrastructure investments, USDOT believes that it provides a useful benchmark from which to evaluate and compare potential transportation investments.[3]

The specific methodology for this application was developed using the BCA guidance published by USDOT and is consistent with the INFRA program guidelines. In particular, the methodology involves:

- Establishing existing and future conditions under the build and no-build scenarios,
- Assessing benefits that align with those identified in the Discretionary Grant Programs BCA guidance;

[1] The BCA model is provided separately as part of the application.

[2] USDOT, Benefit-Cost Analysis Guidance for Discretionary Grant Programs, December 2018.

[3] Ibid.

- Measuring benefits in dollar terms, whenever possible, and expressing benefits and costs in a common unit of measurement;
- Using USDOT guidance for the valuation of travel time savings, safety benefits and reductions in air emissions, while relying on industry best practice for the valuation of other effects;
- Discounting future benefits and costs with the real discount rates recommended by USDOT (7 percent); and
- Conducting a sensitivity analysis to assess the impacts of changes in key estimating assumptions.

# 4. Project Overview

The scope of work for the remaining 250 bridges includes replacing 159 bridges which are 72 years on average, rehabilitating 80 bridges with an average age of 52 years, and re-decking 11 bridges of an average of 54 years.

## 4.1 Base Case and Alternatives

The Base Case for the 250 bridges entails the bridges closing at some point during the 30-year operational period of analysis. The year in which each bridge closes depends on the current age of the bridge and what type of construction is scheduled for the bridge: replacement, rehabilitation, and re-decking.

For bridges that are scheduled for replacement and are less than 50 years old, the following rules govern when the closure of the bridge will take place in the Base Case:

- Bridges with no Poor or Serious condition for deck, superstructure, or substructure will be closed in 2043;
- Bridges with Poor condition for deck, superstructure, or substructure will be closed in 2038;
- Bridges with Serious condition for one category, deck, superstructure, or substructure will be closed in 2028; and
- Bridges with Serious condition for two categories, deck, superstructure, or substructure will be closed in 2023.

For bridges that are scheduled for replacement and are more than 50 years old, the following rules govern when the closure of the bridge will take place in the Base Case:

- Bridges with no Poor or Serious condition for deck, superstructure, or substructure will be closed in 2033;
- Bridges with Poor condition for deck, superstructure, or substructure will be closed in 2028;
- Bridges with Serious condition for one category, deck, superstructure, or substructure will be closed in 2026; and

- Bridges with Serious condition for two categories, deck, superstructure, or substructure will be closed in 2022.

For bridges that are scheduled to be rehabilitated and are less than 50 years old, the following rules govern when the bridge will be closed in the Base Case:

- Bridges with no Poor or Serious condition for deck, superstructure, or substructure will be closed in 2048;
- Bridges with Poor condition for deck, superstructure, or substructure will be closed in 2043;
- Bridges with Serious condition for one category, deck, superstructure, or substructure will be closed in 2033; and
- Bridges with Serious condition for two categories, deck, superstructure, or substructure will be closed in 2028.

For bridges that are scheduled to be rehabilitated and are more than 50 years old, the following rules govern when the bridge will be closed in the Base Case:

- Bridges with no Poor or Serious condition for deck, superstructure, or substructure will close in 2038;
- Bridges with Poor condition for deck, superstructure, or substructure will close in 2033;
- Bridges with Serious condition for one category, deck, superstructure, or substructure will close in 2028; and
- Bridges with Serious condition for two categories, deck, superstructure, or substructure will close in 2024.

For bridges that are scheduled for re-decking, regardless of age or condition, each bridge is assumed to be closed by 2026.

For all 250 bridges in the Base Case, when the bridge closes, drivers are redirected to a detour route.[4] Some trips are considered to be discretionary, so the following rules apply to the percentage of personal vehicles and commercial vehicles assumed to take the detour:

- For bridges scheduled for replacement: half of the personal vehicles will take the detour, and 90 percent of the commercial vehicles will take the detour;
- For bridges scheduled for rehabilitation: no personal vehicles will take the detour and all commercial vehicles will take the detour; and
- For bridges scheduled for re-decking: no personal vehicles will take the detour, and all commercial vehicles will take the detour.

The alternative (Build Scenario), as described in Project Overview, includes replacement of 159 bridges, rehabilitation of 80 bridges, and re-decking of 11 bridges. Bridges will undergo

[4] The length of the detour route is given as the additional miles required to travel along the detour route as compared to using the bridge.

construction prior to the closure date of the bridge. This will mitigate the major traffic disruptions that would occur from closure of the bridges.

During the construction period for each work type, personal and commercial vehicles will be diverted to the same detour discussed in the Base Case. Based on the number of months that each work type takes for construction, the following assumptions are included in the model regarding the percent of drivers that take the detour:

- Replacement of the bridges is expected to last six months, or one half of the year, so during the year that construction takes place half of the annual traffic (personal vehicles and commercial vehicles) will take the detour;
- Bridge rehabilitation is expected to take four months, or one-third of the year, so during the year of construction one-third of annual traffic (personal vehicles and commercial vehicles) will take the detour; and
- Bridge re-decking is anticipated to last four months, or one-third of the year, so during the year that construction takes place one-third of annual traffic (personal vehicles and commercial vehicles) will take the detour.

### 4.2 Types of Impacts

The 250 bridges of the project will benefit the following categories of individuals:

- Truck drivers who travel through Missouri's major freight network;
- People that travel throughout Missouri for pleasure; and
- Rural communities who would otherwise need to take excessively long detours for trips.

### 4.3 Project Cost and Schedule[5]

Project support costs will be incurred in 2019. Between 2020 and 2023, construction will be staggered for all 250 bridges. The total discounted capital costs of the 250 bridges are approximately $341.7 million. Capital costs include construction costs and miscellaneous costs such as design and construction engineering. The breakdown of capital costs is provided in Table 1.

**Table 1: Project Cost Summary for 250 Bridges, in Millions of 2017 Dollars**

| Cost Type | Cost, Discounted at 7 Percent |
|---|---|
| Construction Costs | $264.6 |
| Project Support (Utilities, Permits, Design, and Construction Engineering) | $77.1 |
| TOTAL | $341.7 |

[5] All cost estimates in this section are in millions of 2017 dollars, discounted to 2017 using a 7 percent real discount rate.

### 4.4 Disruptions Due to Construction

The 250 bridges will be closed to traffic during construction. Replacement of the bridges will result in a six month closure, rehabilitation will result in a four month closure, and re-decking will result in a four month closure.

When the bridges are closed to traffic, drivers must take a detour route. Based on the rules outlined in Section 4.1 Base Case and Alternatives, a percentage of drivers will take the detour route while the remaining portion of drivers are assumed to not take the trip while the bridge is closed. The BCA model estimates the additional travel required for drivers taking the detour in the Build scenario.

### 4.5 INFRA Merit Criteria

The main benefit categories associated with the project are identified in Table 2 and align with Criterion #1 (Support for National and Regional Economic Vitality) as stated in the INFRA program's NOFO.

**Table 2: Benefit Categories and Expected Effects on Selection Criteria for 250 Bridges**

| Benefit or Impact Categories | Description | Monetized | Quantified | Qualitative |
|---|---|---|---|---|
| Travel Time Savings | Construction of the 250 bridges will eliminate the need for drivers to use detour routes when the bridges close. | Y | Y | |
| Vehicle Operating Costs Savings | Fuel and non-fuel cost savings to the users. Non-fuel costs include all vehicles operating cost other than fuel (e.g., maintenance and repair, depreciation). | Y | Y | |
| Emissions Savings | Reduction in air pollution due to reduced distances required to travel. | Y | Y | |
| Residual Value of Bridges | Bridges will be constructed to a service life beyond the 20-year period of analysis/ | | | Y |
| Accident-Related Cost Savings | Reduction in property losses, injuries, and deaths due to reduced distances required to travel. | | | Y |
| Travel Time Reliability | Increased travel time reliability due to eliminating the need for detours around bridges. | | | Y |

# 5. General Assumptions

The BCA measures benefits against costs throughout a period of analysis beginning at the start of construction and including 30 years of operations.

The monetized benefits and costs are estimated in 2017 dollars with future dollars discounted in compliance with INFRA requirements using a 7 percent real rate, and sensitivity testing at 3 percent.

The methodology makes several important assumptions and seeks to avoid overestimation of benefits and underestimation of costs. Specifically:

- Input prices are expressed in 2017 dollars;
- The period of analysis begins in 2019 and ends in 2053. It includes project development and construction years (2019 - 2023) and 30 years of operations;[6] and
- A constant 7 percent real discount rate is assumed throughout the period of analysis.

# 6. Demand Projections

Missouri Department of Transportation has estimated average daily traffic for each of the 250 bridges in a given base year and future year when submitting bridge data to the National Bridge Inventory. For purposes of the 250 bridges BCA, these average daily traffic figures are annualized and interpolated to a base year of 2020 and future year of 2040. The annual average daily traffic volumes for 2020 and 2040 are then adjusted based on the rules governing the percentage of drivers that are assumed to use the detour as detailed in Section 4.1 Base Case and Alternatives.

The annual average daily traffic can be found in the BCA model in the Bridge Data tab.

# 7. Benefits Measurement, Data and Assumptions

## 7.1 Benefits Measurement, Data and Assumptions

This section describes the measurement approach used for each benefit or impact category identified in Section 4.2 Types of Impacts and provides an overview of the associated methodology, assumptions, and estimates.

### LIST OF BENEFITS ANALYZED

The benefits analyzed for the remaining 250 bridges include:

- **Travel Time Savings:** Captures the reduced time required for travel as a result of replacing, rehabilitating, or re-decking each bridge, thus eliminating the need for drivers to take a lengthy detour route. Travel time savings will be realized by drivers of both personal vehicles and commercial vehicles.
- **Vehicle Operating Cost Savings:** Captures fuel cost savings and non-fuel cost savings (e.g., tire wear and tear, maintenance costs, and depreciation) for drivers of personal and

[6] Construction of the 250 bridges is staggered between 2020 and 2023. Bridges begin to accrue benefits in the year during which the bridge is assumed to be closed.

commercial vehicles as a result of eliminating the need for drivers to take detour routes around closed bridges.

- **Emission Cost Savings:** The proposed improvements will reduce emissions by reducing the distance drivers need to travel along detour routes as a result of bridge closures. As a result of the proposed improvements, emissions will decrease for pollutants such as carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxides ($NO_x$), fine particulate matter (PM2.5), sulfur dioxide ($SO_2$), and carbon dioxide ($CO_2$).

### METHODOLOGY

The methodology used for estimating each of the benefits listed is presented below:

- **Travel Time Savings:** Calculated based on the VHT in the No Build and Build scenarios, as estimated by bridge, using the decision rules regarding bridge closure age and percentage of drivers of personal and commercial vehicles taking the detour described in Section 4.1 Base Case and Alternatives. Using these rules, the BCA model calculates the VHT as the additional hours driven by personal and commercial vehicles when taking the detour route. Average vehicle occupancy, annual person-trips, and percent trucks are also input into the model. The model multiplies the number of additional hours driven by personal vehicle drivers and commercial vehicle drivers by their corresponding vehicle occupancy rates and values of time to calculate travel time costs. The difference between the additional hours required for detours in the No Build and the Build scenario is the travel time savings.
- **Vehicle Operating Cost Savings:** Calculated based on the VMT in the No Build and Build scenarios, as estimated by bridge, using the decision rules regarding bridge closure age and percentage of drivers of personal and commercial vehicles taking the detour described in Section 4.1 Base Case and Alternatives. The model also uses an assumed speed of 55 miles per hour. Fuel costs are calculated by multiplying VMT by fuel consumption per mile and by fuel price for both the No Build and Build scenarios. Non-fuel cost is calculated by multiplying VMT by non-fuel per-mile cost (which accounts for maintenance and other vehicle ownership costs) for the No Build and Build scenarios. The difference in additional fuel and non-fuel costs associated with taking the detour between the No Build and Build scenarios is the vehicle operating cost savings.
- **Emissions Cost Savings:** Calculated based on the VMT in the No Build and Build scenarios, as estimated by bridge, using the decision rules regarding bridge closure age and percentage of drivers of personal and commercial vehicles taking the detour described in Section 4.1 Base Case and Alternatives. The model also uses an assumed speed of 55 miles per hour. The model calculates running emissions by multiplying the VMT by the speed and the associated emission costs. The difference in emissions costs related to taking the detour between the No Build and the Build scenarios is the emissions cost savings.

  There are six types of emissions measured in the analysis: carbon monoxide (CO), volatile organic compounds (VOC), nitrogen oxide ($NO_x$), fine particulate matter (PM 2.5), sulfur dioxide ($SO_2$), and carbon dioxide ($CO_2$). Emissions per mile travelled for these pollutants were estimated using EPA's MOtor Vehicles Emissions Simulator

(MOVES) as found in Cal-B/C. The emissions are monetized using values consistent with those found in NHTSA's Final Regulatory Impact Analysis of the CAFE for MY2017-MY2025 Passenger Cars and Light Trucks and in the USDOT *Benefit-Cost Analysis Guidance for Discretionary Grant Programs, December 2018.* Since Cal-B/C Corridor estimates impacts in US short tons, the monetization values for US short tons have been used.

### ASSUMPTIONS

The assumptions used in the estimation of economic benefits for the project are summarized in Table 3.

**Table 3: Assumptions Used in the Estimation of Economic Benefits**

| Benefit Categories | Variable Name | Unit | Value | Source / Notes |
|---|---|---|---|---|
| Travel Time Savings | Average Vehicle Occupancy (Automobiles) | Persons per vehicle | 1.68 | USDOT *Benefit-Cost Analysis Guidance for Discretionary Grant Programs.* December 2018. |
| | Average Vehicle Occupancy (Trucks) | Persons per vehicle | 1.00 | |
| | Share of Trucks | Percentage | 1-46% | MoDOT calculated, each bridge has a unique percentage within the range specified. See 'Bridge Data' worksheet, column N. |
| | Travel Time Cost (Automobiles) – All Purposes Local | Dollars per hour | $16.10 | USDOT *Benefit-Cost Analysis Guidance for Discretionary Grant Programs.* December 2018. |
| | Travel Time Cost (Trucks) | Dollars per hour | $28.60 | |
| Vehicle Operating Cost Savings | Fuel Cost (Retail Gasoline) - Automobiles | Dollars per gallon | $2.03 | Annual Energy Outlook, 2017 Release, US Energy Information Administration (EIA). Fuel Cost excludes Federal and State taxes. |
| | Fuel Cost (Retail Diesel) - Trucks | Dollars per gallon | $2.25 | |
| | Vehicle Operating Cost (Non-Fuel Cost) – Automobiles | Dollars per mile | $0.29 | HDR Computation based on USDOT *Benefit-Cost Analysis Guidance for Discretionary Grant Programs.* December 2018. |
| | Vehicle Operating Cost (Non-Fuel Cost) – Trucks | Dollars per mile | $0.56 | |
| Emission Cost Savings | Volatile Organic Compounds (VOC) | Dollars per short ton | $2,000 | USDOT *Benefit-Cost Analysis Guidance for Discretionary Grant Programs.* December 2018. |
| | Nitrogen Oxides ($NO_x$) | Dollars per short ton | $8,300 | |
| | Fine Particulate Matter (PM) | Dollars per short ton | $377,800 | |
| | Sulfur Dioxide ($SO_2$) | Dollars per short ton | $48,900 | |
| | Carbon ($CO_2$) | Dollars per short ton | $0.91 | |

### AGGREGATION OF BENEFIT ESTIMATES

Table 4 presents the benefit estimates by benefit categories for the 250 bridges over the lifecycle of the project.

**Table 4: Estimates of Economic Benefits for the 250 Bridges, Millions of 2017 Dollars**

| Benefit Category | Over the Project Lifecycle | |
|---|---|---|
| | In Constant Dollars | Discounted at 7% |
| Travel Time Savings | $14,198.1 | $2,934.4 |
| Vehicle Operating Cost Savings | $12,476.0 | $2,554.5 |
| Emissions Cost Savings | $150.1 | $28.7 |
| **Total Benefits** | **$26,824.2** | **$5,517.5** |

# 8. Summary of Findings and BCA Outcomes

The tables below summarize the BCA findings for the **250 bridges portion** of the project. Annual costs and benefits are computed over the lifecycle of the project (30 years). As stated earlier, construction of the 250 bridges is staggered over the course of four years and is expected to be completed by 2023. Benefits accrue based on the year in which the bridge closes. This year varies for each bridge based on the closure rules outlined in Section 4.1 Base Case and Alternatives.

**Table 5: Overall Results of the Benefit Cost Analysis for the 250 bridges, Millions of 2017 Dollars**

| Project Evaluation Metric | 7% Discount Rate |
|---|---|
| Total Discounted Benefits | $5,517.5 |
| Total Discounted Costs | $341.7 |
| Net Present Value | $5,175.8 |
| Benefit / Cost Ratio | 16.15 |

Considering all monetized benefits and costs, with a 7 percent real discount rate, the $341.7 million investment for the 250 bridges portion of the project would result in $5,517.5 million in total benefits and a Benefit/Cost ratio of approximately 16.15.

# 9. BCA Sensitivity Analysis

The BCA outcomes presented in the previous sections rely on a large number of assumptions and long-term projections, both of which are subject to considerable uncertainty.

The primary purpose of the sensitivity analysis is to help identify the variables and model parameters whose variations have the greatest impact on the BCA outcomes: the “critical variables.”

The sensitivity analysis can also be used to:

- Evaluate the impact of changes in individual critical variables – how much the final results would vary with reasonable departures from the “preferred” or most likely value for the variable; and

- Assess the robustness of the BCA and evaluate, in particular, whether the conclusions reached under the "preferred" set of input values are significantly altered by reasonable departures from those values.

The outcomes of the quantitative analysis for the 250 bridges using a 7 percent discount rate are summarized in the table below. The table provides the percentage changes in project NPV associated with variations in variables or parameters (listed in row), as indicated in the column headers.

For example, increasing the assumed speed from 55 miles per hour to 70 miles per hour leads to a $538.8 million reduction in the NPV while maintaining a BC ratio of 14.57.

**Table 6: Quantitative Assessment of Sensitivity, Summary**

| Parameters | Change in Parameter Value | New NPV | Change in NPV | New B/C Ratio | Source / Notes |
|---|---|---|---|---|---|
| Base results | Full Build (7% Discount Rate) | $5,175.8 | $0.0 | 16.15 | No Change to the Model |
| Value of Travel Time | Lower Bound of Range Recommended by US DOT | $4,417.5 | -$758.4 | 13.93 | Automobile: $11.45 and Truck: $22.86. HDR Computation from BUILD BCA Guidance |
| | Upper Bound of Range Recommended by US DOT | $5,769.5 | $593.7 | 17.88 | Automobile: $19.37 and Truck: $34.34. HDR Computation from BUILD BCA Guidance |
| Fuel Costs | EIA Low-Case Scenario | $5,022.9 | -$152.9 | 15.70 | Gasoline: $1.47 and Diesel: $1.55. HDR Computation from 2017 Annual Energy Outlook, EIA. Net of Federal and State taxes. |
| | EIA High-Case Scenario | $5,453.5 | $277.7 | 16.96 | Gasoline: $3.10 and Diesel: $3.49. HDR Computation from 2017 Annual Energy Outlook, EIA. Net of Federal and State taxes. |
| AVO Factor | More Conservative Parameter | $4,226.3 | -$949.5 | 13.37 | Change in AVO factor from 1.68 to 1.00 for cars. |
| Minimum Detour Length of 5 miles | Less Conservative Parameter | $8,483.5 | $3,307.7 | 25.83 | Change in Minimum Detour from 0.62 to 5.00. |
| Maximum Detour Length of 5 miles | More Conservative Parameter | $1,564.6 | -$3,611.2 | 5.58 | Change in Maximum Detour from 130.00 to 5.00. |
| Detour Speed | Higher Speed | $4,637.1 | -$538.8 | 14.57 | Increase in the speed from 55 to 70 mph. |
| Number of Analysis Years | More Conservative Parameter | $3,253.0 | -$1,922.8 | 10.52 | Decrease in the number of benefit years from 30 to 20. |
| Capital Cost Estimate | Increase in Construction Cost | $5,007.8 | -$168.0 | 10.82 | Increase in construction cost by 50%. |