Benefit-Cost Analysis Supplementary Documentation

Bridge Investment Program

Improving Rural Bridges in Northwest Oklahoma Project

Circuit Engineering District 8

September 8, 2022

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Benefit-Cost Analysis Supplementary Documentation

1. Executive Summary

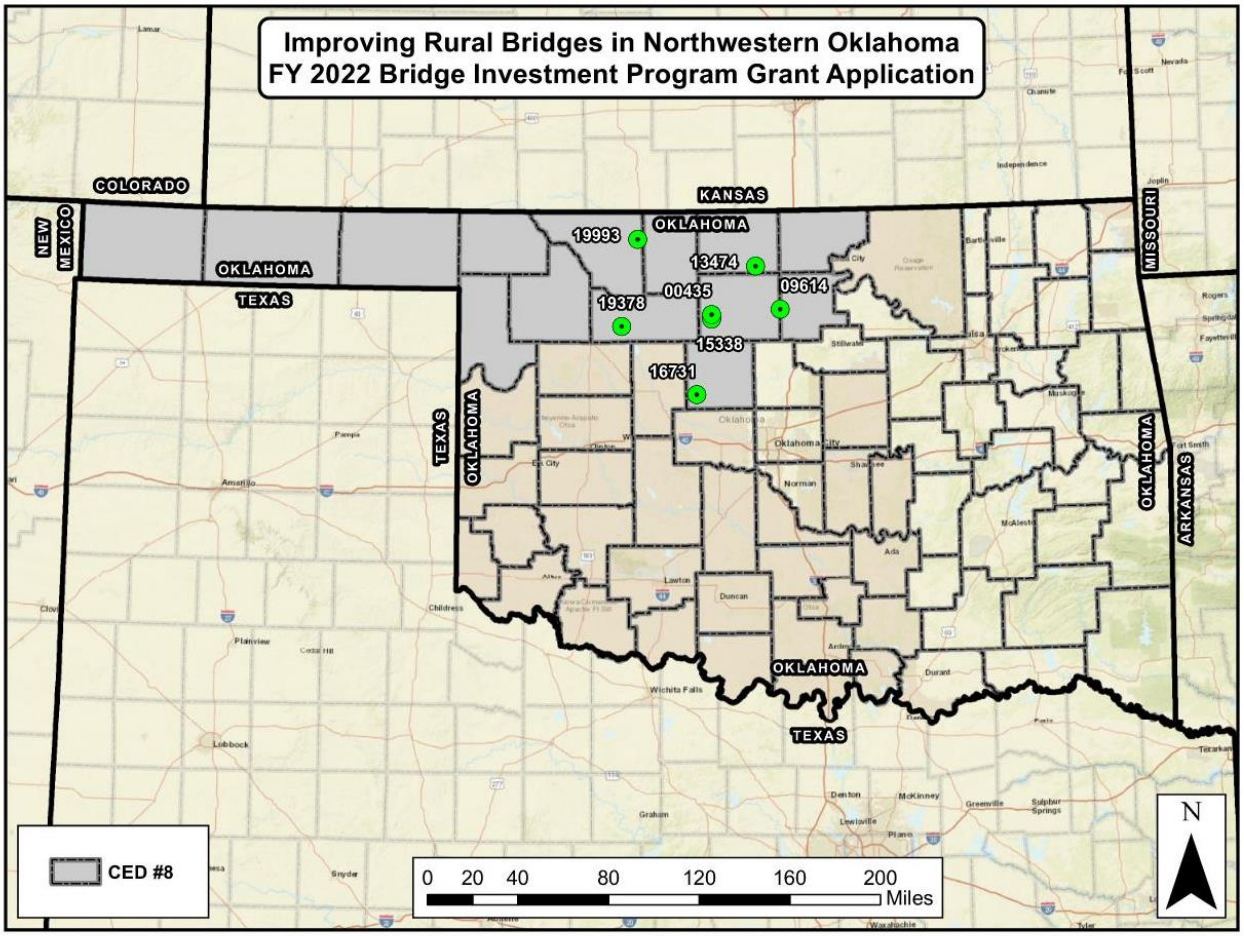
The Benefit-Cost Analysis conducted for this grant application compares the costs associated with the proposed investment to the benefits of the project. To the extent possible, benefits have been monetized. A qualitative discussion is also provided when a benefit is anticipated to be generated but is not easily monetized or quantified.

The project for which this BIP grant is requested is the replacement of seven bridges located in Garfield, Grant, Major, Noble, Kingfisher, and Woods Counties, Oklahoma, referred to as the Improving Rural Bridges in Northwest Oklahoma Project. The Project will contribute to the functioning and growth of the regional economy by providing a safe and efficient transportation network for the region's agricultural and energy businesses, as well as local residents. These industries often require heavy, oversize vehicles to utilize narrow county roads and bridges. Many of these bridges do not have the structural capacity to carry these heavy vehicles and in many cases are posted for load restriction. While intended to enhance safety and protect drivers, these postings are frequently ignored, particularly if a vehicle would have to make a lengthy detour.

Currently the bridges are between 15 and 23.6 feet in width, 6 have 2 lanes, and 1 is a single lane bridge. The bridges are in fair or poor condition, and all are rated as structurally deficient or functionally obsolete. All the bridges included in this package have been load posted to heavy traffic for some time. It is anticipated that if no action is taken, all the bridges will be closed permanently to all traffic by 2037 and all traffic will have to take detour routes of between 3 and 14 miles.

The proposed Project will replace the existing bridges on the same alignment with new, wider structures. All new bridges will be 26 feet in width except for the bridge in Kingfisher County, which will be 40 feet wide to accommodate the higher traffic volume. Six of the seven bridges will be replaced with pre-stressed concrete beam bridges of similar design. The seventh bridge will be replaced with recycled steel beams from ODOT's removal of the I-40 Crosstown Expressway in Oklahoma City in 2012. A map of the locations of the bridges is provided below.

Figure 1: Map of Proposed Bridge Locations



A table summarizing the changes expected from the project, and the associated quantified benefits, is provided below.

Table ES- 1. Summary of Project Infrastructure Improvements and Associated Benefits

Current Status or Baseline & Problems to be Addressed	Changes to Baseline / Alternatives	Type of Impacts	Population Affected by Impacts	Economic Benefit/Impact	Summary of Results
The seven selected bridges overseen by CED #8 for this project are in fair or poor condition, have deficient horizontal clearances, and are load posted. Without this reconstruction work, all bridges would close by 2037.	The purpose of the Project is to eliminate the bridge deficiencies and restore safe crossings that are up to today's design standards for width and traffic loads. CED #8 intends to construct this project as a bundle, letting all seven bridges as a single project to a single contractor.	Travel Time Savings	Local residents, students, and businesses (primarily commodity extraction and production)	Reduced drive time yields more efficient delivery, supply of goods, and savings for businesses.	**$19.1**
		Vehicle Operating Costs	Local residents, students, and businesses (primarily commodity extraction and production)	Reduced vehicle operating costs confers monetary savings to individuals, businesses, and the local school districts	**$18.7**
		Maintenance Costs	Counties in CED #8	Reduced maintenance costs over project lifetime	**$0.003**
		Emission Costs	Local residents and businesses, and surrounding communities	Reduction in social costs of emissions	**$2.0**
		Safety Benefits	Local residents, students, truck drivers	Reduction in social accident costs	**$3.8**
		Quality of Life	Local residents, local businesses, general public	Improved quality of life; better transportation network for personal and business/commercial-related travel.	Not quantified
		Residual Value	Counties in CED #8	Improved asset for future years	**$0.7**
		Innovation	Local contracting businesses, CED #8	Lower construction costs required for the project	Not quantified

Note: All monetary values in the table above are in millions of 2020 discounted using a real discount rate of 7 percent.

The period of analysis used in the estimation of benefits and costs is 37 years, including roughly 7 years of project development and construction and 30 years of operations. Total project construction costs are estimated at $14.1 million in 2022 dollars. In addition, $795,830 has been encumbered to date on various tasks related to project development. For this BCA, all costs were de-escalated to 2020 dollars using the GDP deflator. The total (undiscounted) project costs are estimated at $13.8 million (including previously incurred costs).

All relevant data and calculations used to derive the benefits and costs of the project are shown in the BCA model that accompanies this grant application. Based on the analysis presented in the rest of this document, the project is expected to generate $44.3 million in discounted benefits with $9.2 million in discounted development and construction costs, using a 7 percent real discount rate. Therefore, the project is expected to generate a Net Present Value of $35.1 million and a Benefit/Cost Ratio of 4.8 as shown below in Table ES- 2.

Table ES- 2: Summary of BCA Outcomes, in Millions of 2020 Dollars *

Project Evaluation Metric	Undiscounted	Present Value at 7% Discount Rate	Present Value at 3% Discount Rate
Total Benefits	$239.5	$44.3	$110.5
Total Costs	$13.8	$9.2	$11.5
Net Present Value	$225.7	**$35.1**	$99.0
Benefit / Cost Ratio	17.4	4.8	9.6
Internal Rate of Return (%)	18.6%		
Discounted Payback Period	12.9 years		

In addition to the monetized benefits, the project is expected to generate benefits that are more difficult to quantify. A brief description of those benefits is provided below

<u>Economic Competitiveness</u>

- Contribution to local economic development and growth. The package of bridges included in this application are located in rural counties highly dependent on the agricultural and energy industries. Closure of these bridges would impact commercial trucks and rural communities' accessibility and ease of transit. The bridges' replacement would serve to maintain and/or grow the economic competitiveness of these communities.

<u>Quality of Life:</u>

- Improved quality of life will be realized for local and regional residents due to increased mobility and higher vehicle capacity. Additionally, added bridge width and guardrails will improve safety and accessibility for non-motor vehicle road users.

<u>Innovation:</u>

- Bundling multiple bridge projects together can generate cost savings in construction, through economies of scale. CED #8 will coordinate utility relocation and leverage its statutory rights of way to minimize project delays.

2. Introduction

This document provides detailed technical information on the economic analyses conducted in support of the grant application for the Improving Rural Bridges in Northwest Oklahoma Project. The remainder of this document is organized as follows.

- Section 3, Methodological Framework, introduces the conceptual framework used in the BCA.
- 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 project is expected to generate.
- Section 5, General Assumptions, discusses the general assumptions used in the estimation of project costs and benefits.
- Section 6, Demand Projections, provides estimates of travel demand and traffic growth.
- Section 7, Benefits Measurement, Data, and Assumptions, outlines specific data elements and assumptions pertaining to the long-term outcome selection criteria along with associated benefit estimates.
- Section 8, Summary of Findings and BCA Outcomes presents estimates of the project's Net Present Value (NPV), its Benefit/Cost ratio (BCR) and other project evaluation metrics.
- Section 9, BCA Sensitivity Analysis, provides the results of the sensitivity analysis. Note that 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]

[1] While the models and software themselves do not accompany this appendix, they are provided separately as part of the application.
[2] USDOT, Benefit-Cost Analysis Guidance for Discretionary Grant Programs, March 2022.
[3] Ibid.

The specific methodology adopted for this application is based on the BCA guidance developed by USDOT and is consistent with the BIP program guidelines. In particular, the methodology involves:

- Establishing existing and future conditions under the build and no-build scenarios;
- Assessing benefits with respect to selection criteria identified in the Notice of Funding Opportunity (NOFO);
- 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 3 percent for sensitivity analysis); and
- Conducting a sensitivity analysis to assess the impacts of changes in key input assumptions.

4. Project Overview

4.1 Project Description, Current Conditions and Challenges

The bridges included in this Project are located in Garfield, Grant, Kingfisher, Major, Noble, and Woods Counties in northwestern Oklahoma. The bridges are in fair or poor condition, have outdated engineering design standards, and need reconstruction/replacement to address these deficiencies. These bridges generally serve rural communities, the agricultural and energy industries, and local traffic.

HDR conducted a Benefit Cost Analysis (BCA) for Circuit Engineering District #8 (CED #8) of Oklahoma for seven (7) bridges. The purpose of the Project is to eliminate these deficient bridges and restore safe crossings that are up to today's design standards for width and traffic loads. CED #8 intends to construct this project as a bundle, letting all seven bridges as a single project to a single contractor.

The Project bridges are currently rated as structurally deficient and/or functionally obsolete and in critical need of replacement. All the bridges are already load posted to heavy traffic. It is anticipated that if no action is taken, the bridges will be closed to all traffic by 2037, forcing all traffic to take detours of varying lengths. The proposed Project will replace the existing bridges on the same alignment with new structures that are wider, generally 26 feet in width[4]. The new bridges proposed in this Project would also provide long-term resiliency to extreme weather events. The new bridges will be designed to accommodate the 100-year storm and minimize overtopping.

[4] NBI 16731 in Kingfisher County will be 40 feet wide.

The Project will also increase efficiency of the movement of people and goods by avoiding bridge closure and lengthy detours and thus improving local transportation connectivity.

4.2 Base Case and Alternative

The Base Case for the Project is defined as the No-Build scenario. The No-Build scenario reflects the continuation of current conditions. All the bridges are rated as either structurally deficient or functionally obsolete, with all earning sufficiency ratings at or below 50 (out of 100). It is anticipated that most will be closed to the general traffic by 2032. Some maintenance will continue after closure for the remainder of the study period. Bridge closure will force traffic traversing these bridges to use alternative routes which are longer and result in additional travel time, travel costs, vehicle emissions, and road crashes.

The Build scenario assumes that the bridges will be replaced with new structures as planned and discussed above, avoiding permanent closures, traffic detours, and related travel costs. For the purposes of this analysis, bridge construction is assumed to occur in order of the estimated closure dates as shown in Table 1 below.

Table 1: Bridge Closures and Construction Years

Bridge Number	Closure Year	Construction Year
19738	2030	2026
19993	2032	2026
15338	2032	2027
435	2029	2026
13474	2027	2026
16731	2037	2027
9614	2023	2025

4.3 Types of Impacts

The replacement of the bridges will avoid the impeding permanent bridge closures, which would force vehicles currently using the bridge to take alternative routes (i.e. detour) resulting in an increase in vehicle miles of travel and travel costs. Replacement of the deficient bridges can then be expected to generete significant travel time savings benefits to travelers as well as vehicle operating costs and environmental emissions savings. In addition, the project will help avoid costly bridge maintenance that would have to continue even after bridge closure.

4.4 Project Cost and Schedule[5]

Total future project development and construction costs are estimated at $14.1 million in 2022 dollars. In addition, $795,830 has been encumbered to date on various tasks related to project development. For the purpose of this BCA, all costs were de-escalated to 2020 dollars using the

[5] All cost estimates in this section are in millions of dollars of 2020 and account for the savings due to combining of all bridges into one bundle. The assumed savings rate is 10 percent.

GDP deflator.[6] The adjusted cost is $13.8 million in 2020 undiscounted dollars and $9.2 million discounted at 7% as shown in Table 2 below.[7] Preliminary design is currently underway and is expected to be completed by September 2023. Environmental studies and NEPA documentation have been completed for one bridge and are underway on five others. NEPA activities are anticipated to be complete on all bridges by March 2024. Construction will start in September of 2025 and be completed by September 2027.[8] Over the project life-cycle total operations and maintenance (O&M) costs are estimated at $328,000. O&M costs include inspection, painting, joint repair, approach repair, and deck replacement over 30 years after bridge opening. Under No Build scenario certain maintenance costs will also be incurred (estimated at $1,500 annually). These costs were netted of to derive net impact on O&M costs (Section 7.4 provides further discussion). Table 2 shows an incremental O&M cost of about $40,000 over the project life undiscounted and a cost saving of about $3,000 discounted at 7 percent.

Table 2. Summary of Costs, Millions of 2020 Dollars

	Over the Project Lifecycle		
	Undiscounted	**Discounted at 7%**	**Discounted at 3%**
Development and Construction Costs	$13.8	$9.2	$11.5
Net O&M Cost Impact (No Build less Build)	-$0.04	$0.003	-$0.01

4.5 Effects on Selection Criteria

The main benefit categories associated with the project are mapped into the selection criteria set forth by USDOT in the Notice of Funding Opportunity in the table below. The table below presents this mapping with an indication whether the corresponding benefits were monetized In this BCA.

Table 3. Benefit Categories and Expected Effects on Selection Criteria

Selection Criteria	Description	Monetized
Economic Competitiveness	Travel time savings from continued use of a more efficient route relative to a detour route	Yes
	Reduced vehicle operating costs (including vehicle wear and tear and fuel) due to continued use of a more efficient route	Yes
State of Good Repair	Reduced maintenance costs relative to the No Build scenario	Yes
Emissions	Reduced GHG emissions due to continued use of a more efficient route	Yes
	Reduced CAC emissions due to continued use of a more efficient route	Yes
Safety	Reduced accident costs from trucks and automobiles due to continued use of a more efficient route	Yes
Quality of Life	Improved quality of life through improved mobility for local residents and businesses.	No

[6] The adjustment amounted to dividing 2020 costs by the deflator index of 1.0710 based on the GDP deflator for the years 2020 – 2022 (Office of Management and Budget of the White House, Table 10.1, https://www.whitehouse.gov/omb/historical-tables/)
[7] In this BCA, the previously incurred costs were equally distributed over the years 2020-2022.
[8] Construction of each individual bridge is expected to take about 4 months.

Selection Criteria	Description	Monetized
Innovation	The project realizes economies of scale and other cost savings due to bundling and leveraging the district's right of ways	No

5. General Assumptions

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

The monetized benefits and costs are estimated in 2020 dollars with future dollars discounted in compliance with BIP 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 2020 dollars;
- The period of analysis begins in 2020 and ends in 2056. It includes project development and construction years (2020 – 2027) and 30 years of operations (2027 – 2056);
- A constant 7 percent real discount rate is assumed throughout the period of analysis. A 3 percent real discount rate is used for sensitivity analysis;
- Travel demand and benefits are inputs to the BCA and assumed to be fully realized starting in 2027 (no ramp-up);
- All bridges have an expected lifespan of 75 years with the exception of NBI No. 09614, which has an expected lifespan of 50 years; and
- Unless specified otherwise, the results shown in this document correspond to the effects of the Full-Build alternative, replacement of all bridges.

6. Demand Projections

The traffic forecast is a critical component of the benefit-cost analysis as most of the benefits depend on the change in vehicle miles of travel between the Base Case / No-Build and Build scenarios.

Current 2020 traffic volumes crossing the evaluated bridges, including the share of truck traffic, as well as estimates of future (for year 2040) traffic were provided by CED #8. Annual traffic volumes were then interpolated from these two figures using the implied average annual rate of growth. The assumptions are presented in Table 4 below.

Table 4. Assumptions Used in the Estimation of Traffic

NBI Bridge No.	2020 ADT	2040 ADT	Average ADT Growth Rate	Share of Truck Traffic
19738	100	160	2.38%	25%
19993	120	192	2.38%	25%
15338	100	160	2.38%	15%
435	100	160	2.38%	15%
13474	50	80	2.38%	15%

NBI Bridge No.	2020 ADT	2040 ADT	Average ADT Growth Rate	Share of Truck Traffic
16731	2,400	3,840	2.38%	50%
9614	24	38	2.32%	15%

7. Benefits Measurement, Data, and Assumptions

This section describes the measurement approach used for each quantifiable benefit or impact category identified in Table 3 and provides an overview of the associated methodology, assumptions, and estimates.

7.1 Safety Benefits Impacts

Safety benefits include reduction in expected number of crashes due to avoidance of incremental VMTs related to detours when the bridges are closed. The condition of these bridges has affected the safety and reliability of school bus routes, postal routes, and emergency services. All of the bridges are currently load posted, meaning that heavier vehicles such as school buses and fire trucks cannot cross. In addition, the new bridge structures will be wider than the existing structures. This improvement in road geometry may then contribute to an additional reduction in accidents under the Build scenario.

7.1.1 METHODOLOGY

Crash rates and crash statistics on the bridge and detour route were provided by ODOT's Collision Analysis and Safety Branch. These were applied to the annual traffic volume to forecast total number of crashes. The distribution of crashes by accident type (fatal, injury, property damage only) was assumed based on these crash statistics.

Safety benefits impacts were then estimated based on the number of accidents, by type, expected under No-Build versus the Build scenario and monetized using the social values of accident cost by type recommended by USDOT.

7.1.2 ASSUMPTIONS

The assumptions used in the estimation of safety benefits are summarized in the table below.

Table 5. Assumptions Used in the Estimation of Safety Benefits

Variable Name	Unit	Value	Source
Average fatality per Thousand Miles by Vehicle	fatalities/thousand miles	Varies by bridge	Calculated from data obtained from Oklahoma State Department of Transportation on Vehicle Miles Travelled and Total Fatalities + Injuries for crashes from 2011 - 2021.
Average injury, by type per Thousand Miles by Vehicle	Injuries/thousand miles	Varies by bridge	Calculated from data obtained from Oklahoma State Department of Transportation on Vehicle Miles Travelled and Total Fatalities + Injuries for crashes from 2011 - 2021.
O - No Injury	$	$3,900	

Variable Name	Unit	Value	Source
C - Possible Injury	$	$77,200	Treatment of the Economic Value of Preventing Fatalities and Injuries in Preparing Economic Analyses (2021)
B - Non-Incapacitating	$	$151,100	
A - Incapacitating	$	$554,800	
K - Killed	$	$11,600,000	
U - Injured (Severity Unknown)	$	$210,300	

7.1.3 BENEFIT ESTIMATES

Table 6 shows that the proposed project will result in a safety benefit of $3.8 million discounted at 7 percent, or $18.6 million in undiscounted dollars.

Table 6. Estimates of Safety Benefits, Millions of 2020 Dollars

	Undiscounted	Discounted at 7%	Discounted at 3%
Safety Benefit	$18.6	$3.8	$9.0

7.2 Economic Competitiveness

Economic Competitiveness criteria for BIP grants include impacts such as improving the efficiency of movements of goods and people leading to a reduction in the costs of doing business and burden of commuting as well as improvements in overall well-being.

The rehabilitation of the proposed bridges is expected to have significant economic competitiveness impacts aligned with the above description of these merit criteria. They can be grouped under two categories of impacts:

(1) Travel time savings, and

(2) Vehicle operating costs savings.

The first category captures the reduced travel time for automobiles, buses, and trucks under the Build scenario due to the avoided detours after bridge closure. The avoided detours also save some vehicle operating costs which represent the second category of benefits.

7.2.1 METHODOLOGY

<u>Travel Time Savings</u>

Estimation of travel time savings due to avoidance of detours requires determination of a travel route that vehicles are currently taking when crossing the bridge and that they would likely take when the bridge closes entirely.

The travel routes (and their length) were provided by CED #8 and assessed using a planning level approach by considering the next best and suitable travel path in the local area after a bridge is closed. The distance that would have to be travelled with the bridge opened was then netted off of that detour route. The resulting incremental travel distances (per vehicle-trip) are shown in the table below. Route travel time was estimated by dividing the length of the route by an assumed detour speed of 45 miles per hour.

Table 7: Incremental Detour Length, by Bridge

Bridge No.	Detour length (mi)
19738	14.0
19993	12.0
15338	4.0
435	4.0
13474	9.0
16731	4.0
9614	3.0

Total travel times were calculated as the product of route travel time and the volume of vehicles. The detour route is expected to be longer than the typical route. Therefore, the difference in total travel time between the detour route and the typical route represents travel time savings under the Build scenario. As a conservative approach, it was assumed that only 80 percent of the usual traffic will take the detour and be affected by the incremental travel time and costs. This reflects the idea that some travelers may find other routes for their particular destinations with a minimal impact on the total distance and time travelled. The travel time savings were calculated separately for autos and trucks and monetized using value of time recommended by USDOT. The specific assumptions are shown in Table 8 below.

Vehicle Operating Costs Impacts

Vehicle operating cost savings were calculated for the incremental vehicle miles of travel due to detours as the product of the vehicle miles and the out-of-pocket travel costs for items such as fuel and maintenance. This cost was measured in terms of dollars per mile recommended by USDOT and was assumed to be constant over the analysis period.

7.2.2 ASSUMPTIONS

The specific assumptions used in the estimation of travel time savings and out-of-pocket travel cost are summarized in the table below.

Table 8. Assumptions Used in the Estimation of Economic Competitiveness Benefits

Variable Name	Unit	Value	Source
Light Duty Vehicle Operating Cost	$	$0.45	American Automobile Association, Your Driving Costs – 2020 Edition (2020)
Truck Operating Cost	$	$0.94	American Transportation Research Institute, An Analysis of the Operational Costs of Trucking: 2020 Update
Bus Operating Cost	$	$0.97	Alleghany County Public Schools, School Bus Per-Mile Operating Cost Analysis, October 6, 2015 (Inflated to 2020$)
Share of trucks	%	Varies	CED#8 Engineer Estimates
Truck Value of Travel Time	$	$32.00	

Variable Name	Unit	Value	Source
Car Value of Travel Time	$	$16.20	US DOT Benefit Cost Analysis Guidance, 2022
Average Vehicle Occupancy	# of people per vehicle	1.67	
School Bus Occupancy	passengers per vehicle	12.13	FHWA Methodology Report: Developing a Statistically Valid and Practical Method to Compute Bus and Truck Occupancy Data (May 2019)
Share of vehicles taking detour	%	80%	Assumed
Detour speed	mph	45	Assumed

7.2.3 BENEFIT ESTIMATES

The estimated benefits of economic competitiveness outcomes are shown in Table 9. Total economic outcome benefits over the analysis period amount to $208.6 million in constant 2020 dollars or $37.8 million in dollars discounted at 7 percent. The benefits are approximately equally distributed between travel time savings and vehicle operating cost savings.

Table 9. Estimates of Economic Competitiveness Benefits, Millions of 2020 Dollars

	Undiscounted	Discounted at 7%	Discounted at 3%
Vehicle Operating Cost Savings	$104.0	$18.7	$48.1
Travel Time Savings	$104.6	$19.1	$48.6
Total	**$208.6**	**$37.8**	**$96.7**

7.3 Environmental Protection Impacts

The replacement of the seven bridges in this Project is expected to have an impact on vehicle emissions and emissions costs due to the avoidance of additional vehicle miles of travel associated with the longer detour route. This section presents the methodology and assumptions.

7.3.1 METHODOLOGY

Emissions impacts were calculated for the incremental vehicle miles of travel due to detours as the product of these vehicle miles of travel and the social cost of vehicle emissions (dollars per mile). That cost was calculated using vehicle emissions rates (grams of emission per mile) and social cost of emission for various categories of air pollutants (dollars per ton of emissions) recommended by USDOT. Auto and truck emission rates were adopted from the Environmental Protection Agency's MOVES model. This analysis focuses on Criteria Air Contaminant (CAC) emissions (NOx, SO_2, and PM2.5) and Greenhouse Gases (i.e., CO_2). The speed assumed for the calculations is 45 mph. The BCA spreadsheet model provided with this application contains full details of the calculations of cost per mile, including the specific emission factors assumed for each pollutant. Per US DOT BCA Guidance, carbon emissions are discounted at a fixed rate of 3%, while all other contaminants may be discounted at either the 7% rate or the 3% sensitivity discount rate.

7.3.2 ASSUMPTIONS

The assumptions regarding the emission factors and social cost of emissions per VMT are shown in Section 10 – Supplementary Data Tables. The volume and cost vary by year and type of vehicle.

7.3.3 BENEFIT ESTIMATES

Total environmental benefits over the analysis period amount to $4.8 million in constant 2020 dollars or $2.0 million in dollars discounted at 7 percent as shown in the table below.

Table 10. Estimates of Environmental Benefits, Millions of 2020 Dollars

	Undiscounted	Discounted at 7%	Discounted at 3%
Total Environmental Savings	$4.5	$2.0	$2.1

7.4 State of Good Repair Savings

The Project bridges are now well beyond their design life spans. Without replacement or reconstruction, the structures will be closed permanently.

7.4.1 METHODOLOGY

CED #8 assessed annual operating and maintenance costs of the structures in the No Build and Build scenarios. After closure of each bridge, maintenance costs will be limited to signs and barricades at the closed bridges estimated at $1,500 annually. Under Build, these expenditures will not be required, and are replaced with ongoing O&M costs under the Build scenario. The estimates of the benefits are calculated by subtracting the Build O&M costs from the No Build O&M costs, dependent upon the assumed construction schedule.

7.4.2 ASSUMPTIONS

The specific assumptions used in the estimation of maintenance costs savings are summarized in the table below.

Table 11. Total O&M Costs in the No Build Case over 2020-2050, 2020 Dollars

Bridge No.	No Build Costs	Build Costs
19738	$40,500	$15,000
19993	$37,500	$52,000
15338	$37,500	$52,000
435	$42,000	$15,000
13474	$45,000	$75,000
16731	$30,000	$104,000
9614	$51,000	$15,000
Total	**$283,500**	**$328,000**

7.4.3 BENEFIT ESTIMATES

The estimated benefits of maintenance costs savings are shown in Table 12. This table as well as as Table 11 show that total undiscounted Build maintenance costs are higher than the Build costs. However, with a discount rate of 7 percent, a saving of $3,196 is realized over the project life.

Table 12. Estimates of Maintenance Costs Savings, 2020 Dollars

	Undiscounted	Discounted at 7%	Discounted at 3%
Maintenance Cost Savings	-$44,500	$3,196	-$10,426

7.5 Residual Value of Assets

7.5.1 METHODOLOGY

The residual value of capital assets at the end of the study period is estimated using a straight-line depreciation method and represents the remaining useful life of infrastructure and other long-lived assets. To calculate this value, the ratio of useful years remaining and total useful life was applied to the total project capital costs.

7.5.2 BENEFIT ESTIMATES

Table 13 shows the project is estimated to have a residual value of $0.7 million in 2020 dollars discounted at 7%.

Table 13: Estimates of the Residual Value of Assets, Millions of 2020 Dollars

	Undiscounted	Discounted at 7%	Discounted at 3%
Residual Value	$7.8	$0.7	$2.7

8. Summary of Findings and BCA Outcomes

The tables below summarize the BCA findings. Annual costs and benefits are estimated over the study period (37 years from 2020 to 2057). As stated earlier, construction for all bridges is expected to be completed by 2027. Benefits accrue during the operation of the project (over the years 2027-2056).

Table 14. Overall Results of the Benefit Cost Analysis, Millions of 2020 Dollars*

	Undiscounted	Discounted at 7%	Discounted at 3%
Total Benefits	$239.5	$44.3	$110.5
Total Costs	$13.8	$9.2	$11.5
Net Present Value (NPV)	$225.7	**$35.1**	$99.0
Benefit Cost Ratio (BCR)	17.4	4.8	9.6
Internal Rate of Return (IRR)	18.6%		
Discounted Payback Period (DPP)	12.9 years		

*Unless indicated otherwise

Considering all monetized benefits and costs, the estimated internal rate of return of the project is 18.6 percent. With a 7 percent real discount rate, the $9.2 million investment would result in

$44.3 million in total benefits, net present value of $35.1 million and a Benefit/Cost ratio of approximately 4.8. With a 3 percent real discount rate, the Net Present Value of the project is $99 million, for a Benefit/Cost ratio of 9.6.

The table below compiles all project benefits evaluated. The vast majority of project benefits (at 85 percent) is accounted for by travel time savings and vehicle operating cost savings. Reduction in accident costs accounts for about 9 percent of the overall benefits. Maintenance cost savings account for less than 1 percent, while environmental cost savings account for about 4.5 percent. Residual value of assets accounts for approximately 1.5 percent of total benefits.

Table 15. Overall Benefits, Millions of 2020 Dollars

Benefit Categories	Over Project Lifecycle		
	Undiscounted	Present Value at 7%	Present Value at 3%
Travel Time Savings	$104.6	$19.1	$48.6
Vehicle Operating Cost Savings	$104.0	$18.7	$48.1
Reduction in Accident Costs	$18.6	$3.8	$9.0
Environmental Cost Savings	$4.5	$2.0	$2.1
Maintenance Cost Savings	-$0.04	$0.003	-$0.01
Residual Value of Assets	$7.8	$0.7	$2.7
Total Benefits	**$231.7**	**$44.3**	**$107.8**

9. BCA Sensitivity Analysis

The BCA outcomes presented in 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 sensitivity analysis was conducted with respect to changes in the value of travel time, value of statistical life, capital cost estimate, and annual O&M. The changes in the value of statistical life and capital cost estimate are the parameters that have the greatest impact on net present value.

The outcomes of the quantitative analysis for the changes in value of travel time, value of detour length, capital cost estimate, and rate of growth in traffic estimate 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. The BCA for the project is robust with strong performance even in situations when key input values change in the direction that reduces net benefits. In all situations examined, BC ratio remains at the level of 3.1 or more.

Table 16. Quantitative Assessment of Sensitivity, Summary

Parameters	Change in Parameter Value	New NPV	% Change in NPV	New B/C Ratio
Value of Travel Time	Reduce value of travel time by 25%	$30.3	-14%	4.3
	Increase value of travel time by 10%	$39.8	14%	5.3
Capital Costs	Reduce capital costs by 25%	$37.0	6%	6.2
	Increase capital costs by 40%	$31.9	-9%	3.5
Rate of growth in traffic	Reduce rate of traffic growth by 2%	$19.0	-46%	3.1
	Increase rate of traffic growth by 1%	$46.5	32%	6.0
Rate of traffic taking detour	Decrease by 15%	$27.0	-23%	3.9
	Increase by 5%	$37.8	8%	5.1

10. Supplementary Data Tables

This section contains additional tables of assumed and calculated values used in the CBA benefits categories described in Section 7.

Table 17: Emissions Factors for Trucks, Grams per Mile 2020-2050

Year	CO_2 Emission Factor	NO_X Emission Factor	$PM_{2.5}$ Emission Factor	SO_2 Emission Factor
2020	2351	9.6	0.2	0.01
2021	2310	9.3	0.2	0.01
2022	2270	9.0	0.2	0.01
2023	2231	8.7	0.1	0.01
2024	2192	8.5	0.1	0.01
2025	2154	8.2	0.1	0.01
2026	2116	8.0	0.1	0.01
2027	2080	7.7	0.1	0.01
2028	2043	7.5	0.1	0.01
2029	2008	7.3	0.1	0.01
2030	1989	7.2	0.1	0.01
2031	1969	7.2	0.1	0.01
2032	1950	7.1	0.1	0.01
2033	1932	7.1	0.1	0.01
2034	1913	7.0	0.1	0.01
2035	1895	7.0	0.1	0.01
2036	1876	6.9	0.1	0.01
2037	1858	6.9	0.0	0.01
2038	1840	6.8	0.0	0.01
2039	1823	6.8	0.0	0.01
2040	1819	6.8	0.0	0.01
2041	1815	6.8	0.0	0.01
2042	1811	6.8	0.0	0.01
2043	1807	6.7	0.0	0.01
2044	1803	6.7	0.0	0.01
2045	1800	6.7	0.0	0.01
2046	1796	6.7	0.0	0.01
2047	1792	6.7	0.0	0.01
2048	1788	6.7	0.0	0.01
2049	1785	6.7	0.0	0.01
2050	1784	6.7	0.0	0.01

Emission factors for years 2051-2056 were assumed to be the same as for 2050.

Table 18: Emissions Factors for Passenger Vehicles, grams per mile 2020-2050

Year	CO_2 Emission Factor	NO_X Emission Factor	$PM_{2.5}$ Emission Factor	SO_2 Emission Factor
2020	455	0.17	0.003	0.003
2021	444	0.14	0.003	0.003
2022	434	0.12	0.003	0.003
2023	424	0.10	0.003	0.003
2024	414	0.09	0.002	0.003
2025	404	0.07	0.002	0.003
2026	395	0.06	0.002	0.003
2027	385	0.05	0.002	0.003
2028	376	0.04	0.002	0.003
2029	368	0.04	0.002	0.002
2030	364	0.03	0.002	0.002
2031	360	0.03	0.002	0.002
2032	356	0.02	0.002	0.002
2033	353	0.02	0.002	0.002
2034	349	0.02	0.002	0.002
2035	346	0.01	0.002	0.002
2036	342	0.01	0.002	0.002
2037	339	0.01	0.002	0.002
2038	335	0.01	0.002	0.002
2039	332	0.01	0.002	0.002
2040	331	0.01	0.002	0.002
2041	330	0.01	0.002	0.002
2042	330	0.01	0.002	0.002
2043	329	0.01	0.002	0.002
2044	328	0.01	0.002	0.002
2045	328	0.01	0.002	0.002
2046	327	0.00	0.002	0.002
2047	326	0.00	0.002	0.002
2048	326	0.00	0.002	0.002
2049	325	0.00	0.002	0.002
2050	325	0.00	0.002	0.002

Emission factors for years 2051-2056 were assumed to be the same as for 2050.

Table 19: Social Costs of Emissions, dollars per ton, 2020-2050

Emission Type	NO_x	SO_2	$PM_{2.5}$	CO2
2020	$15,135	$40,263	$726,284	$50
2021	$15,600	$41,500	$748,600	$52
2022	$15,800	$42,300	$761,600	$53
2023	$16,000	$43,100	$774,700	$54
2024	$16,200	$44,000	$788,100	$55
2025	$16,500	$44,900	$801,700	$56
2026	$16,800	$45,700	$814,500	$57
2027	$17,100	$46,500	$827,400	$58
2028	$17,400	$47,300	$840,600	$60
2029	$17,700	$48,200	$854,000	$61
2030	$18,100	$49,100	$867,600	$62
2031	$18,100	$49,100	$867,600	$63
2032	$18,100	$49,100	$867,600	$64
2033	$18,100	$49,100	$867,600	$65
2034	$18,100	$49,100	$867,600	$66
2035	$18,100	$49,100	$867,600	$67
2036	$18,100	$49,100	$867,600	$69
2037	$18,100	$49,100	$867,600	$70
2038	$18,100	$49,100	$867,600	$71
2039	$18,100	$49,100	$867,600	$72
2040	$18,100	$49,100	$867,600	$73
2041	$18,100	$49,100	$867,600	$74
2042	$18,100	$49,100	$867,600	$75
2043	$18,100	$49,100	$867,600	$77
2044	$18,100	$49,100	$867,600	$78
2045	$18,100	$49,100	$867,600	$79
2046	$18,100	$49,100	$867,600	$80
2047	$18,100	$49,100	$867,600	$81
2048	$18,100	$49,100	$867,600	$82
2049	$18,100	$49,100	$867,600	$83
2050	$18,100	$49,100	$867,600	$85

Social costs of emissions for years 2051-2056 were assumed to be the same as for 2050.