SEATTLE DEPARTMENT OF TRANSPORTATION

WEST SEATTLE HIGH-RISE BRIDGE SAFETY PROJECT

COST-BENEFIT ANALYSIS REPORT

FINAL

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FINAL

PROJECT NO.: 160424C
DATE: OCTOBER 2020

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October 19, 2020

Ms. Heather Marx
Seattle Department of Transportation
700 Fifth Avenue
Seattle, WA 98104

Subject: West Seattle High-Rise Bridge - Cost-Benefit Analysis

Dear Ms. Marx:

Please find the Cost-Benefit Analysis Report conducted as part of the West Seattle High-Rise Bridge Safety project enclosed. This report is intended to support the City as it makes the decision related to rehabilitation and/or replacement. As we understand through discussions with the City, the CBA is just one element out of many in making that decision. As such, the CBA presents findings in the form of value indices, which is a measure of return on investment, but does not provide any recommendations or conclusions.

The CBA was conducted in an accelerated time frame and with limited information due to the emergency nature of the work. As such, we needed to make a number of assumptions. Understanding the limitations and impacts of these assumptions within the CBA is important. We conducted sensitivity studies on key assumptions, and have provided a list of limitations and key next steps, at the end of this document (Sections 6 and 7).

Thank you for giving WSP the opportunity to support the City on this project. Should you have any questions as you review or use the document, please contact me via email at greg.banks@wsp.com or by phone at 253.906.3757.

Sincerely,

Gregory A. Banks

Gregory A. Banks, PE, SE
Project Manager

XXX:GAB:nb
Attachment

WSP ref: 160424C

TABLES

FIGURES

APPENDICES

EXECUTIVE SUMMARY

Because of observed accelerating crack growth in the West Seattle High-Rise Bridge (WSHB), the Seattle Department of Transportation (SDOT) made the decision to close the bridge to traffic on March 23, 2020, commencing the West Seattle High-Rise Bridge Safety Project. This project, which is part of a larger program, comprises designing and installing an intelligent monitoring system, conducting non-destructive testing, developing an emergency response plan, designing and constructing bridge stabilization measures, and conducting a cost-benefit analysis (CBA) — the results of which are presented herein.

Project Overview

SDOT did not make the decision to close an arterial route upon which the people of West Seattle and the region depend lightly. Its closure has disrupted lives, as well as the mobility of freight, services, and goods through the region. The closure has negatively impacted already marginalized communities. It has affected the maritime industry and the operations of the Port of Seattle. The closure's effects cannot be understated, nor can the consequences, should the bridge have failed during rush hour. From the outset, that this has been a public safety project. It continues to be a public safety project.

The intelligent monitoring system and non-destructive testing determined that it is technically feasible to continue further investigating if the bridge can be rehabilitated to restore live traffic. The bridge's continued positive responses to ongoing stabilization work and the findings of the structural assessment of further rehabilitation and retrofit concepts, echo that feasibility. However, there remain key stabilization work activities, including the release of the restrained lateral bearing at Pier 18 and the installation and tightening of the external post-tensioning system. These measures, to be completed in the coming month, are import to confirm these trends hold true.

The purpose of the CBA is to provide objective information and context to help the City decide between investing in further rehabilitation of the existing bridge or pivoting towards a replacement structure. The methodology incorporated multiple alternatives within that apparent binary choice. We assessed five alternatives using both quantitative and qualitative analyses for value determination and for risk and cost. Section 6 presents findings in the form of value indices (performance divided by cost, with costs inclusive of monetized risk).

WSP conducted the CBA on an accelerated schedule. We needed to make several assumptions, including selecting five conceptual alternatives based on apparent low cost. As such, the CBA does not represent a type, size, and location (TS&L) study. Should the ultimate decision be to replace the bridge, we anticipate that the City would explore yet-to-be-determined alternatives, some of which may be similar to the concepts presented here, but some of which will be different in type, size, and location, as well as in construction means and methods and material composition. Section 7 provides a detailed list of considerations for future studies that were beyond the scope of this CBA, because, as important as the findings are, so, too, is an understanding of what was not considered but should be in future studies.

This CBA addresses some of the questions we have all grappled with since March 23 – What long-term impacts will this closure have? Can the City afford to wait for a replacement? What is the life span of a rehabilitated structure? What benefits does rehabilitation offer? What benefits does replacement offer? While the purpose of this report is to objectively present the benefits and drawbacks of multiple alternatives, to help inform the decision to rehabilitate or replace the bridge, its findings will not, and should not, dictate that decision.

The CBA is, in fact, just one factor in this decision, focused on helping to support decisions being made around public safety and technical risk. The decision will also be informed by external exigencies and current events, by the recommendation of the asset owner, SDOT, as well as by the guidance provided by the Technical Advisory Panel (TAP) and Community Task Force (CTF). Ultimately, the imminent decision to rehabilitate or replace the structure will be a City decision based on a value judgment for the safety and well-being of the people of Seattle.

The Cost-Benefit Analysis

While not a perfect tool, the CBA did allow us to draw several conclusions using the assumptions outlined in Section 1. Section 2 discusses the five alternatives evaluated, with concept drawings, descriptions, and estimated timelines. Figure A below summarizes the alternatives.

Scheme	Scenario	Description
Shoring	1	Temporary Shoring to Restore Live Load (3 to 5 years)
Strengthening	2	Direct Strengthening to Restore Live Load (40 years)
	~~3~~	~~Partial Superstructure Replacement to Restore Live Load (15 to 50 years)~~
Replacement	4	Accelerated Superstructure Replacement (75 years)
	5	Accelerated Bridge Replacement (75+ years)
	6	Immersed Tube Tunnel (75+ years)

Figure A – Alternatives Evaluated

Section 3 outlines how we qualitatively evaluated each alternative using weighted attributes (selected by the CTF, the TAP, SDOT, and WSP during the CBA process) to develop an overall performance score. Figure B illustrates how we developed the overall performance score for each alternative.

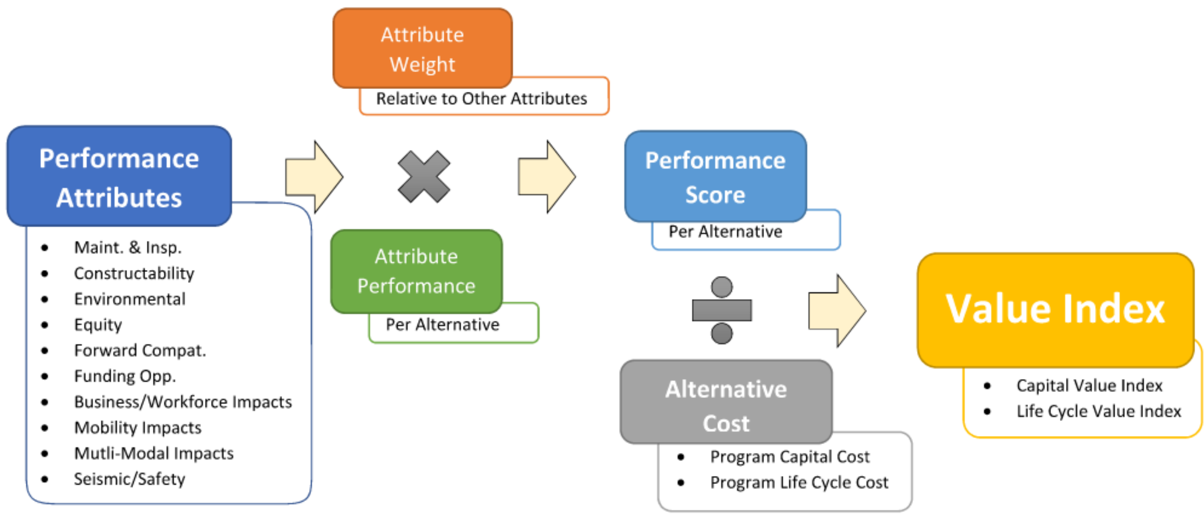


Figure B – Evaluation Process

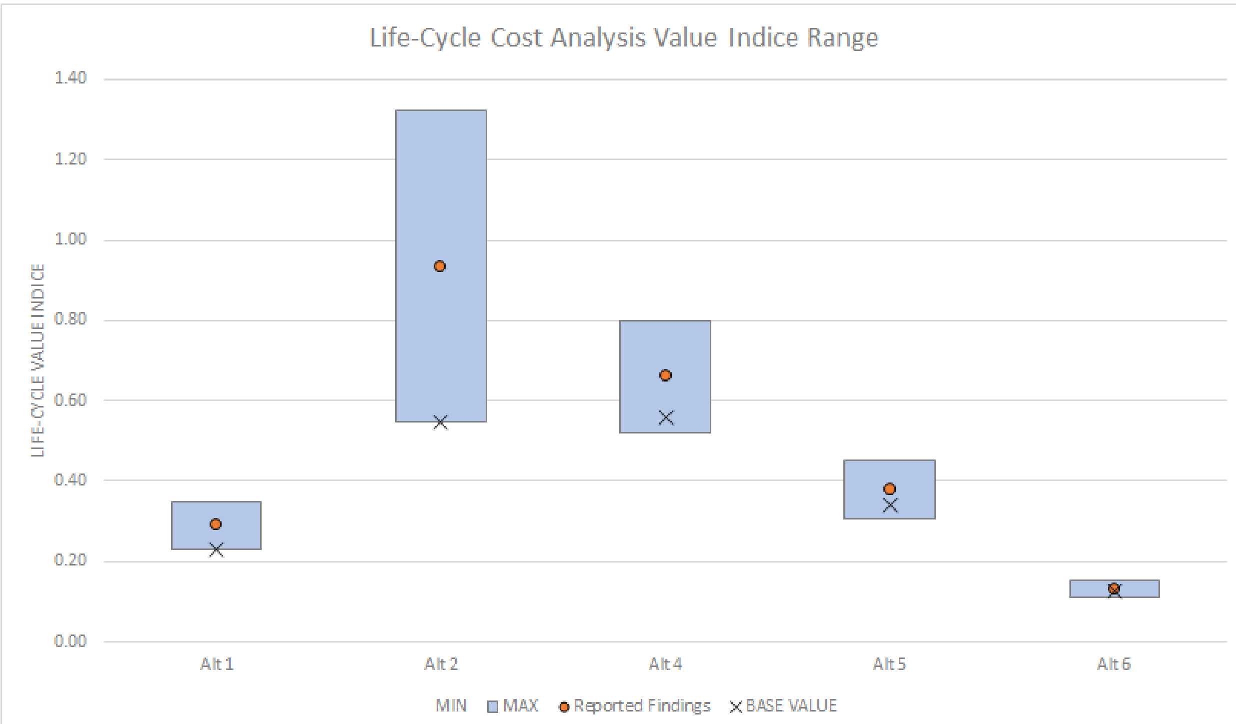
Section 4 details how we developed and calculated rough-order-of-magnitude conceptual costs for each alternative's initial capital project costs and life cycle costs, and presents costs developed from the base assumptions informed by SDOT's input. Section 5 highlights the primary risks we identified and discusses how we monetized some of them.

Section 6 puts all the information together – the performance scores divided by costs, inclusive of monetized risks, to develop the CBA findings, or "value indices." These value indices represent the overall return on investment for each alternative (higher values represent a better return on investment). Value indices are presented as a "base value," without considering assumptions on key variable sensitivity, and also as "reported findings," which do consider assumptions on key variable sensitivity (reported average values).

Figure C shows us how the inputs – performance and cost – resulted in value indices for both the "base values" and "reported findings" for each alternative, while Figure D shows the potential range in the value indices based on the sensitivity studies.

Alternatives	Performance		Capital Costs		LCCA Costs		LCCA Value Index	
	Base CBA	Reported Findings	Base CBA	Reported Findings	Base CBA	Reported Findings	Base CBA	Reported Findings
Alt 1	360	362	$125.1M	$124.8M	$1,558.9M	$1,248.8M	0.23	0.29
Alt 2	500	500	$233.4M	$98.8M	$916.0M	$535.1M	0.55	0.93
Alt 4	563	550	$736.3M	$773.3M	$1,005.7M	$833.4M	0.56	0.66
Alt 5	527	509	$1,246.8M	$1,337.1M	$1,542.7M	$1,341.4M	0.34	0.38
Alt 6	362	345	$2,713.3M	$2,780.5M	$2,821.M	$2,630.6M	0.13	0.13

Figure C – Summary of Base CBA Values and Reported Findings (Value Indices)



NOTES:

- Higher value indices represent better returns on investment.
- X's –base values; value indices based solely on assumptions within the CBA.
- Orange Dots – reported findings; average value indices based on findings of the sensitivity studies conducted.
- Blue Bars – potential range in value indices based on the sensitivity study findings.

Figure D – Range in Summary of Findings Values

Section 7 then highlights some of the limitations of the CBA and suggests areas where further study is necessary. The CBA had to choose five alternatives to compare, but we recognize that there are many options within the repair and replace categories. We recommend that a TS&L study investigate other options, as well as other considerations. For example, while the CBA qualitatively and quantitatively addressed socioeconomic impacts in multiple attributes (Equity, Mobility Impacts, and Multimodal Impacts) in Section 3, they were not included in monetized risks, capital costs, or life-cycle costs.

1 INTRODUCTION

The WSHB is a multi-span concrete bridge comprising prestressed concrete multi-girder approaches and twin cast-in-place, post-tensioned segmental concrete box girders (Figure 1 and Figure 2). The structure was constructed using balanced cantilever segmental techniques in the early 1980s and placed into service in 1984.

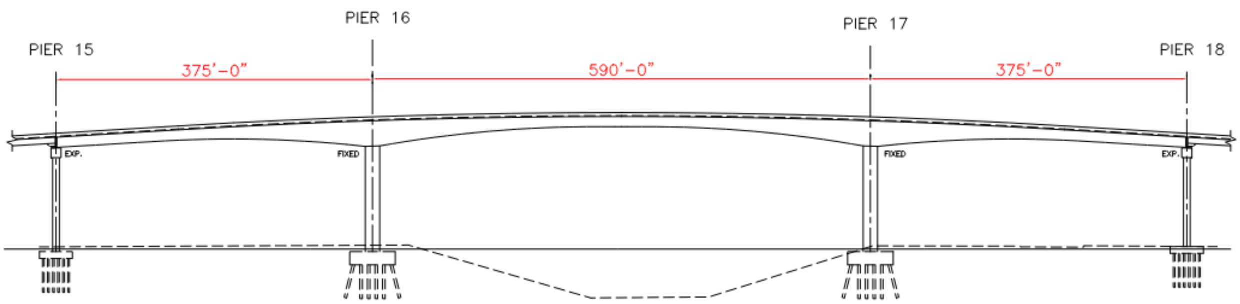


Figure 1. Elevation of Main-Span Segmental Box Unit

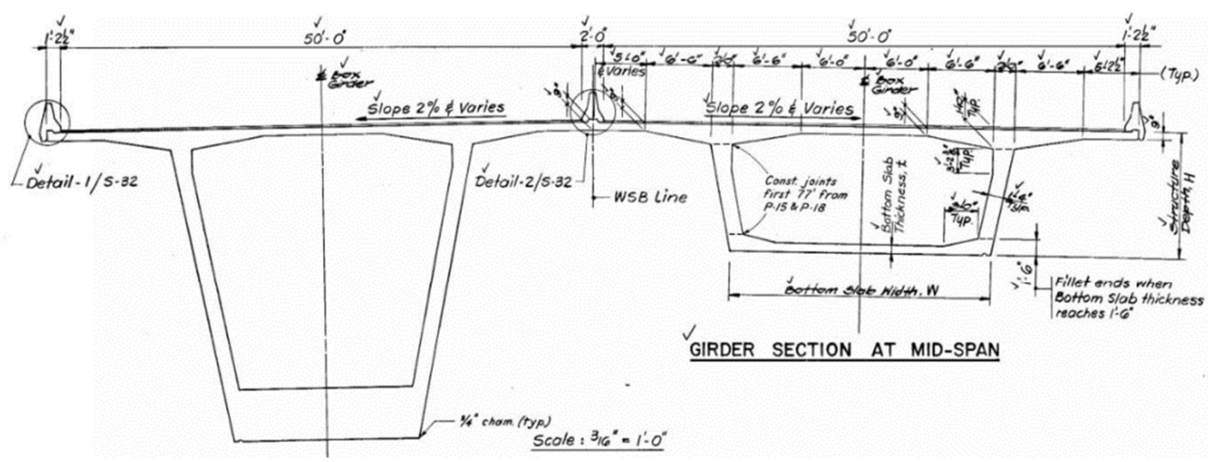


Figure 2. Cross-Section Views of Twin Box Girders, near Pier Table (left) and near Midspan (right)

In May 2019, the City asked WSP to perform a federally mandated load rating of the bridge with consideration to the effects of the known cracking. SDOT had observed limited hairline cracking for many years, first noting unusual cracking in 2013, near the quarter points of the main span (i.e., Joint 38). This cracking was seen at four primary locations. SDOT hired a national consulting firm in 2013 to investigate the cracking and its implication on safety. They concluded that the cracks were not a safety issue, although they did recommend that SDOT set up some monitoring and undertake epoxy injection of the larger cracks. SDOT completed this work in the summer of 2019.

In March 2020, while in the process of load rating the WSHB, the inspection team (WSP and SDOT) discovered rapid crack propagation in the webs of the bridge's main span. The City closed the bridge on March 23, 2020 as a public safety measure because of this rapid crack propagation – combined with the sensitivity of the analysis findings; the observation that the detailing within the distressed region of the bridge would not permit force transfer mechanisms upon which standard code provisions rely to form; and the unknown condition of the post-tensioning and cracking within the bridge.

From the analytics conducted up through February 2020, we learned that the bridge capacity was sensitive to the amount of degradation the bridge had experienced. We did not know the widths of the cracks prior to epoxy injection. With the bridge continuing to crack, SDOT determined that leaving the bridge in its current state was unsafe: thermal loads and force redistribution within the bridge were causing further degradation, jeopardizing the bridge's ability to carry its own self-weight. Removal of live load alone did not remove the crack propagation problem, further validating the decision to close the bridge.

Since the bridge closure in March 2020, multiple activities have been conducted concurrently, as illustrated in Figure 3 and discussed further below.

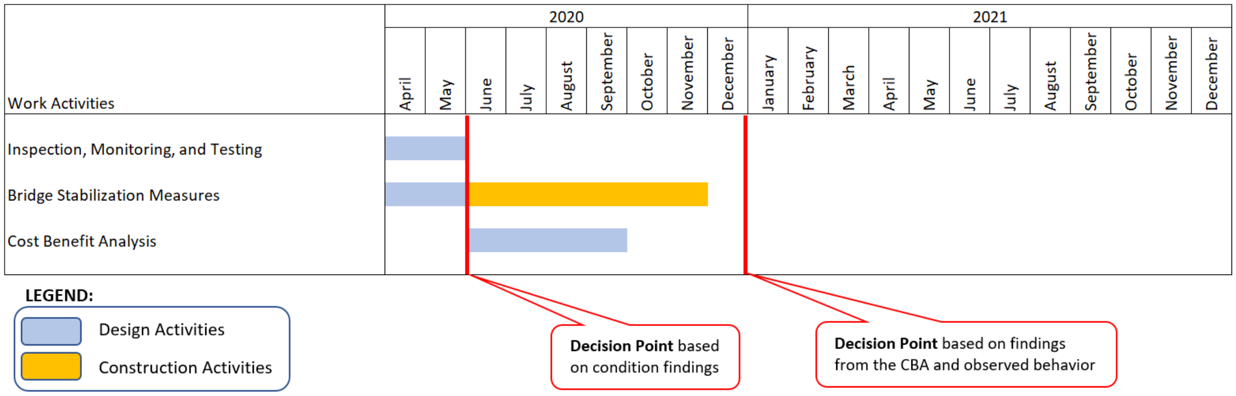


Figure 3. Timeframe of Work

Reconnaissance: The team learned about the condition of the bridge and how it was behaving. This work included:

— Daily field inspections
— Installation of an automated bridge monitoring system
— Holistic analysis of data from an automated bridge monitoring system
— Non-destructive testing of concrete cracks and post-tensioning to identify voids and measure crack depths

We conducted field inspections daily for months until the automated structural health monitoring system came online on May 18, 2020 and enough data was accumulated to be validated/understood. Visual field inspections, including crack mapping and width measurements, continue on a biweekly basis to better understand the condition of the bridge relative to the automated structural health monitoring system. The automated structural health monitoring system has allowed us to correlate our analytical modeling to environmental loadings. This has in turn allowed us to correlate bridge behavior to historic environmental data and gather an understanding of how seasonal (thermal) effects impact the bridge. In addition, we have been able to correlate analytical predictions to actual measured data for the specific work activity loadings occurring as part of the bridge stabilization measures. These correlations provide confidence that the bridge behavior is predictable and give a better understanding of the magnitude of force redistribution that has occurred within the structure.

We completed the non-destructive testing in the first part of June. This milestone marked the first decision point in the project and answered the question, "Is there anything systemic that would technically preclude further investigation into repair/rehabilitation options?"

The non-destructive testing yielded encouraging results regarding the condition of the various types of cracking. It did not identify any corrosive conditions of the post-tensioning grout; any widespread void patterns with the post-tensioning ducts; or any corrosion of the post-tensioning strands. The sample set of tests would indicate that the bridge is likely not suffering from systemic problems beyond the crack propagation between Piers 15 and 18, in the main span and end spans.

As information is received in real time through the biweekly in-person inspections and 24-hour monitoring system, we learn more about the bridge and how it is behaving, allowing us to make more informed decisions. What we have learned to date has yielded confidence that the bridge behavior is predictable and that it is technically feasible to rehabilitate the bridge and restore its remaining service life, or more. However, we will continue to perform reconnaissance work to see if trends change as we finalize stabilization measures this fall.

Bridge Stabilization: WSP designed stabilization measures to provide a missing link through the distressed regions of the bridge to allow the bridge to resist loads as it was originally intended, arrest further crack growth, and remove unintended restraints to bridge movements. Bridge stabilization measures currently being constructed include:

— Construction/installation of carbon fiber reinforced polymer (CFRP) sheets and external post-tensioning
— Construction of Pier 18 transverse bearings restraint release

The bridge stabilization design was released for construction on June 5, 2020, and construction started soon thereafter. With the monitoring system online, we continue to watch how the bridge reacts during bridge stabilization measure implementation, and, as Figure 3 shows, we will continue to do so for a period of time after construction.

Cost-Benefit Analysis (CBA): The team developed a spectrum of remedial action concepts with the purpose of illustrating the benefits and drawbacks of each alternative. The CBA included developing:

- Bridge demolition concepts
- Temporary shoring concepts
- Near- and longer-term rehabilitation concepts
- A preliminary seismic assessment
- Replacement concepts

1.1 OBJECTIVE OF THE COST-BENEFIT ANALYSIS

The objective of the CBA is to evaluate the benefits, drawbacks, and rough-order-of-magnitude (ROM) costs of multiple alternatives to determine whether it would be in the City's best interest to further rehabilitate the existing bridge or immediately pivot towards a replacement. WSP developed the CBA within the limits of the assumptions documented in Section 1.3 of this report.[1] However, recognizing the preliminary nature of the work and the scope/schedule limitations placed on the study, we conducted sensitivity studies to understand the implications of the established assumptions, and help inform key next steps as the project moves forward.

The CBA examines three different schemes (shoring, rehabilitation, and replacement), comprising six different alternatives that have been developed based on preliminary engineering work and the continued monitoring of the bridge. The CBA calculated initial capital costs, life-cycle costs, and risks for each of the six alternatives.[2] It also evaluated each alternative using a variety of quantitative and qualitative measurables.

Ultimately, the CBA is a planning study intended to help inform, but not dictate, the decision to further invest in rehabilitating the existing bridge or pivoting towards a replacement structure.

1.2 SCOPE

The CBA investigated multiple variables to illustrate the benefits and drawbacks of rehabilitation and replacement alternatives. As previously noted, the purpose is to objectively provide the City with information pertinent to the decision as to whether to further invest in rehabilitating the existing structure or pivot towards a replacement. Its findings illustrate the alternative yielding the apparent best return on investment within the context of the CBA; however, this may not necessarily be the best return on investment with consideration to the wider context of the City.

ALTERNATIVES DEVELOPMENT

The CBA began with five alternatives, all of which were on-alignment and fit the same grade/profile as the current bridge. In response to community feedback, the study adopted a sixth alternative – an immersed tube tunnel (ITT). This is the only alternative that deviates from the current alignment and grade/profile. During this process, we also eliminated the third alternative, a partial superstructure replacement, from consideration as it was determined that it was not the apparent low-cost option for a rehabilitation alternative. Section 2 of this report includes full alternative descriptions and details of each concept.

WSP chose five representative alternatives based on apparent low cost to fit within the scope and schedule confines of the CBA. There exist other options within each category, many conceptually mentioned within the appendices that could and should be further explored or developed.

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[1] It should be noted that SDOT, TAP, and CTF input was invaluable in WSP's development of the CBA. The Port of Seattle and Northwest Seaport Alliance were other important contributors.
[2] All costs are ROM costs. They are estimates based on historic data, similar projects, and City-specified rates of discount and inflation. All costs are calculated in 2021 dollars.

CONCEPTUAL DESIGNS

Sketches for each alternative include demolition options, shoring options, future construction considerations, and potential right-of-way needs for the alternatives. WSP developed the concepts with sufficient detail to support associated ROM cost estimates.

ATTRIBUTES AND MEASURABLES

With guidance from the TAP and the CTF, SDOT and WSP developed a list of ten attributes to define the performance of the alternatives.[3] For each attribute, subject matter experts from the TAP, SDOT, and WSP defined measurables that quantify the differences (positive and negative) between each of the alternatives. The attributes were first compared relative to each other using direct input from the advisory groups to determine attribute weight factors. Subject matter experts then scored each alternative relative to the others for each attribute, based on the measurable results.

COST ESTIMATES

For each alternative, WSP developed ROM estimates for initial capital cost (inclusive of monetized risk items) and for life cycle costs. Life cycle costs include allowances for initial capital investments, operation and maintenance costs, inspection costs, and future repair/rehabilitation costs.

RISK REGISTER

Many risks, challenges, and opportunities lie within each alternative. The risk register identifies those risks; qualitatively assesses each one based on the likelihood of occurrence and its impact; identifies how the risk will be addressed, monitored, and controlled; and determines whether the risk is monetized or not. The risk register is considered a "living document" – risks are added as they are identified, throughout the life of the project.

COST-BENEFIT ANALYSIS REPORT

Beyond the measured data captured in the attributes, costs, and risks exist the nuances inherent in a project of this magnitude, which affects as many people as it does. Subject matter experts have prepared this report to provide a qualitative study, and contextual information, to support the quantified portion of the analysis within the scope and schedule of the CBA.

1.3 ASSUMPTIONS

This CBA is founded on certain assumptions:

- The CBA does not quantitatively assess off-alignment bridge replacement alternatives.[4]
- The approach structures are beyond the scope of this study. The CBA does not assess their vulnerabilities, nor does it include any associated costs.
- An apparent low-cost approach dictated the development of alternatives. For the replacement alternatives, a type, size, and location (TS&L) study should be conducted to determine the actual layout and type of the replacement alternatives.
- A future TS&L study should conduct detailed constructability reviews for replacement alternatives.
- The WSHB corridor will be closed during construction of a given alternative.
- Construction closure durations are cumulative for a given alternative.[5]
- Sound Transit will have an independent Duwamish Crossing for light rail by 2032.
- Preliminary geotechnical input was limited to pile axial capacities, preliminary lateral soil design parameters (including liquefaction considerations), and preliminary seismic hazard information. See Appendix B.

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[3] Reference TAP CBA Part 1 Recommendation memorandum and City/WSP response memorandum for background discussions.

[4] Alternative 6, the Immersed Tube Tunnel, would necessitate replacing the approach structures and matches neither the existing alignment nor grade/profile, but we have not included those costs in this CBA. The ITT should be explored in greater depth in the TS&L study that will follow upon this CBA.

[5] Alternatives 1 and 2 each assume two phases of construction: one for the initial shoring or rehabilitation; one for the eventual replacement.

- A preliminary corrosion assessment was used to define assumptions for the condition of the existing foundations.
- Seismically, the rehabilitated bridge will have an operational classification of "normal," while a replacement bridge will have an operational classification of "essential."[6]
- Alternative 2 (direct rehabilitation) includes additional external post-tensioning and CFRP sheets, beyond that which is taking place during stabilization work.
- Alternative 4 (superstructure replacement) is assumed to be a girder structure composed of either steel tub girders or concrete box girders. Following an apparent low-cost approach, WSP eliminated other structure types, such as extradosed, cable-stayed, or network tied-arch superstructures. For cost purposes, the CBA assumed a concrete box girder.
- Immersed Tube Tunnel Assumptions – See Appendix L for an in-depth discussion of ITT assumptions.
- "Year one" for life cycle cost analysis (LCCA) is 2021. The LCCA extends to 2100. A salvage value was assigned to alternatives with remaining service life beyond the year 2100.
- The CBA does not capture all COVID-19-specific impacts.
- The CBA does not capture the costs of Reconnect West Seattle, of rehabilitating or replacing the approach structures, or of any other projects associated with the West Seattle Bridge Program.
- Socioeconomic impacts are qualitatively addressed as they pertain to general trends between alternatives. Certain measurables within each attribute are quantified.
- WSP based costs for civil/roadway, utilities, general traffic, and general preparation costs on rough metrics associated with the structure cost, and not on quantified values for specific items of work.
- Only Alternative 1 assumes a $300,000 lump sum for an intelligent transportation system.
- Each alternative assumes a $300,000 lump sum signal modification cost.
    - Mobilization: 10 percent
    - Other variable (soft) costs: 30 percent. These costs represent expenditures on owner management and administration, design engineering, construction administration and inspection, third-party reviews, utility relocations/protections, and other costs.
- The Forward Compatibility attribute assumes that the existing 6 percent approach grades can accommodate future Sound Transit light rail.

1.4 PROCESS

SDOT outlined the CBA as a step in the decision-making process after the corridor was closed in late March 2020. The CBA commenced in tandem with the design and construction of the bridge stabilization measures; the design and deployment of a comprehensive structural health monitoring system; and the non-destructive testing. By the nature of this process, inputs into the CBA were dynamic, becoming more informed with time.

1.4.1 DEFINITION (DECISION MATRIX)

At the beginning of this process, following the WSHB closure, SDOT identified the CBA as a key factor in determining next steps. The CBA's aim is to provide answers to a number of questions posed as a means of arriving at key decisions and extracted from the project's decision matrix document (see Table 1 below). As defined, the objective of the CBA was to help make informed decisions as it pertains to further investment in rehabilitating the existing structure or pivoting towards replacement of the bridge. Although the questions are not necessarily directly addressed within the CBA, the CBA provides the supporting information necessary to objectively address these questions and corollaries. As noted in Table 1, some of these questions are outside the scope of this CBA; however, the CBA provides a firm foundation and basis for answering them as part of future planning studies or a TS&L study.

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[6] "Essential" in this sense refers to the WSDOT Bridge Design Manual operational category. Alternative 2 was classified as normal; however, preliminary seismic analysis indicates that it meets the essential bridge performance defined for the replacement alternatives.

Table 1. Decision Matrix shows the key questions we started with, as well as some of the answers developed during the CBA process

Key Questions	CBA-Determined Answers
1. Can the bridge be rehabilitated sufficiently to allow a return to full capacity for an additional 10+ years at approximately 25% of the replacement cost?	1. Yes (see Section 4).
2. What other potential deficiencies exist?	2. None identified. Further investigation of other parts of the substructure and approach could yield different results.
3. How many more years of useful life would the bridge have?	3. Estimated to be 40 years.
4. What is the useful life of the approach structures?	4. Unknown.
5. What is replacement cost (In-Kind and Arterial Realignment)?	5. See Section 4.
6. What is rehabilitation cost?	6. See Section 4.
7. How would a replacement be constructed?	7. This requires further investigation in a TS&L study that includes constructability reviews.
8. What permits would be required to construct a replacement and demolish the existing structure?	8. This requires further investigation in a TS&L study.
9. Are columns and/or foundations structurally sound?	9. Preliminary analyses indicate that they are structurally sound.
10. Would superstructure replacement require temporary shoring?	10. In the concept explored here (Alternative 4), yes.
11. How would Sound Transit enter and exit the corridor?	11. This requires further investigation in a TS&L study.
12. Would a combined bridge be compatible with the other Sound Transit alignments being studied?	12. This requires further investigation in a TS&L study.
13. What are various funding/financing methods available?	13. See Section 3.2.6 Funding Opportunities

1.4.2 MULTIPLE ENTITY INVOLVEMENT

To avoid bias towards input from any one entity, multiple entities outside of WSP supported the CBA: the City, the TAP, and the CTF. Each entity has been integral to the CBA effort, providing direct input to the attributes used to define the value for each alternative and the importance of attributes relative to each other (i.e., the weighting).

While the CBA's intention is to be as inclusive of input as possible, subject matter experts from SDOT, the TAP, and WSP determined performance scores for each alternative, but the CTF did not. Because of the granularity and specificity of the measurables within each attribute, we felt that this was necessary to obtain accurate results.

1.4.3 CBA PHASES AND WORKSHOPS

The CBA entailed multiple phases. Each phase included workshops and discussions with the City, the TAP, and the CTF. A brief summary of the phases is as noted and further explored in Section 3:

- Phase 1 – Definition and Process: presentation of the proposed overall evaluation process and potential attributes to include in the evaluation. Solicited input on the attributes, and requested attributes be compared relative to each other to determine weight factors.
- Phase 2 – Findings: compared alternatives relative to each other, for each attribute, to determine overall alternative performance scores.
- Phase 3 – Reporting: conducted sensitivity studies based on the findings from Phase 2 to validate findings.

2 ALTERNATIVE DESCRIPTIONS

The CBA's purpose is to help inform the decision as to whether to rehabilitate or replace the damaged WSHB. WSP developed alternatives based on an apparent low-cost approach. Its intent is not to determine an alternative within those two scenarios; we anticipate that SDOT will further explore this in the TS&L study to be undertaken under a separate contract.

With a firmly established intent to help make a binary decision, WSP developed the CBA's alternatives with the assumptions outlined in Section 1.3. Critically, we initially developed the rehabilitate and replace alternatives to be compared directly against one another, so they were founded on the assumptions that all alternatives would be on-alignment (in the footprint of the current structure); would not change the approach structures or the bridge profile/elevation; and would not incorporate light rail (other than to determine whether the structure would or would not be able to accommodate it in the future).

ADDING THE IMMERSED TUBE TUNNEL ALTERNATIVE

Based on public feedback, WSP added an immersed tube tunnel (Alternative 6) to the CBA in July 2020. Because of the inherent differences between this and the other replacement alternatives (Alternatives 4 and 5), there are several crucial variances between Alternative 6 and Alternatives 4 and 5:

1. The tunnel is not on-alignment, as it would not be able to be placed on top of the existing bridge's foundations, even after demolition and excavation.
2. The tunnel requires significant modifications to or replacement of existing approach structures, because it is off-alignment and requires a downward rather than upward trajectory.
3. The tunnel requires different permits and environmental considerations from an above-water replacement alternative.
4. The tunnel's massive components need to be cast off site and transported in by barge; a casting facility would likely need to be built, increasing cost and duration.
5. The tunnel is forward compatible because the section could be designed to include extra lane width and light rail if desired. The tunnel concept explored here does not include light rail, as it is compared directly to other alternatives, which do not incorporate it.

Section 2.6 provides more detailed information on the immersed tube tunnel (ITT) concept. The major differences between the ITT and other replacement and rehabilitation alternatives are further explored throughout Sections 3, 4, 5, and 6.

Table 2. Alternatives

Scheme	Scenario	Description
Shoring	1	Temporary Shoring to Restore Live Load (3 to 5 years)
Strengthening	2	Direct Strengthening to Restore Live Load (40 years)
	~~3~~	~~Partial Superstructure Replacement to Restore Live Load (15 to 50 years)~~
Replacement	4	Accelerated Superstructure Replacement (75 years)
	5	Accelerated Bridge Replacement (75+ years)
	6	Immersed Tube Tunnel (75+ years)

2.1 ALTERNATIVE 1: TEMPORARY SHORING TO RESTORE LIVE LOAD

2.1.1 *ALTERNATIVE DESCRIPTION*

We considered several alternatives for temporary shoring. These included in-water supports, a below bridge K-frame, a below bridge truss, and an above bridge truss. Appendix G details all of the shoring concepts initially considered.

Due to the navigable channel below the bridge and the envelope of the swinging West Seattle Low Bridge (WSLB), it became evident that neither in-water supports nor the K-frame options were viable. While a truss under the bridge would not interfere with WSLB operations, its depth (approximated at 1/10 the span length) would reduce the navigable channel height by about 60 feet. WSP deemed this unacceptable because of its impacts on the maritime community and Port of Seattle industry. Potential impacts to Port of Seattle and maritime industry was a critical consideration for all alternatives. We therefore selected an above bridge truss system as the most practical solution for shoring.

Figure 4 below depicts the temporary shoring scheme. Trusses are cantilevered over the main piers to support the compromised segments in the main span. Each side of the bridge would have a series of four trusses, one over each box girder web. Because these trusses and the hardware to support the existing structure take up some of the roadway width, only between three and five lanes would be available for live load. This alternative would not be future compatible with light rail.

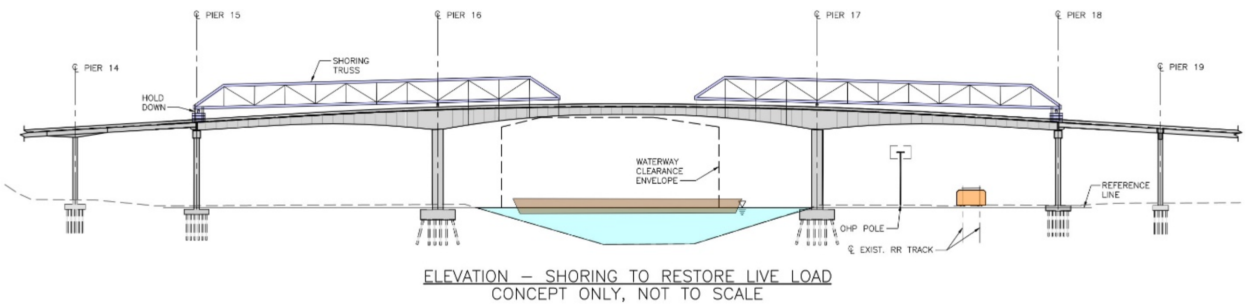

Figure 4. Alternative 1, Temporary Shoring Scheme

2.1.2 ALTERNATIVE LIFE CYCLE

Alternative 1 would restore live load to the bridge in 2024. The shoring concept depicted above is only an interim measure; it would allow live load to resume for five years while a replacement structure is planned (assumed for the CBA to be Alternative 5). The long initial duration for shoring is necessary because the structural steel would have to be custom designed and fabricated before being brought to the site and installed. It should be noted that shoring would not restore full traffic capacity; only between three and five lanes would be able to carry traffic.

Essentially, this is a two-phase construction project, with the first phase being designing and constructing the shoring, the second phase being designing and constructing the demolition and replacement structure (Alternative 5).

Because the CBA assumes that all bridge structures are on the same alignment, it also assumes that, after five years of restored live load, the shored bridge would be demolished, and a new bridge built in the same alignment with a 75-year design life. The CBA also assumes that, after 50 years, the new bridge would require direct strengthening. Direct strengthening would take one year and would not have long-duration traffic impacts. The condensed schedule below shows construction durations. Appendix F includes more detailed construction schedules.

Activity	Duration	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034-2082	2083	2084-2108
Design Shoring	0.5 Years																
Construct Shoring	3.25 Years																
Traffic on Shored Bridge	5 Years																
Construct New Bridge	3.67 Years																
New Bridge Service Life	75 Years																
Direct Strengthening	1 Year																

Figure 5. Construction Schedule for Alternative 1, Temporary Shoring Scheme

2.2 ALTERNATIVE 2: DIRECT STRENGTHENING TO RESTORE LIVE LOAD

2.2.1 *ALTERNATIVE DESCRIPTION*

The direct strengthening to restore live load (rehabilitation) concept consists of post-tensioning inside all spans of the box girders. The strengthening would restore capacity to the distressed regions so that live load could be restored to original condition for the bridge's remaining service life (40 additional years). The figure below depicts a preliminary concept for the post-tensioning.

Currently, the WSHB is undergoing stabilization work, which also includes external post-tensioning. It should be noted that this proposed alternative would require a more comprehensive version of current stabilization measures.

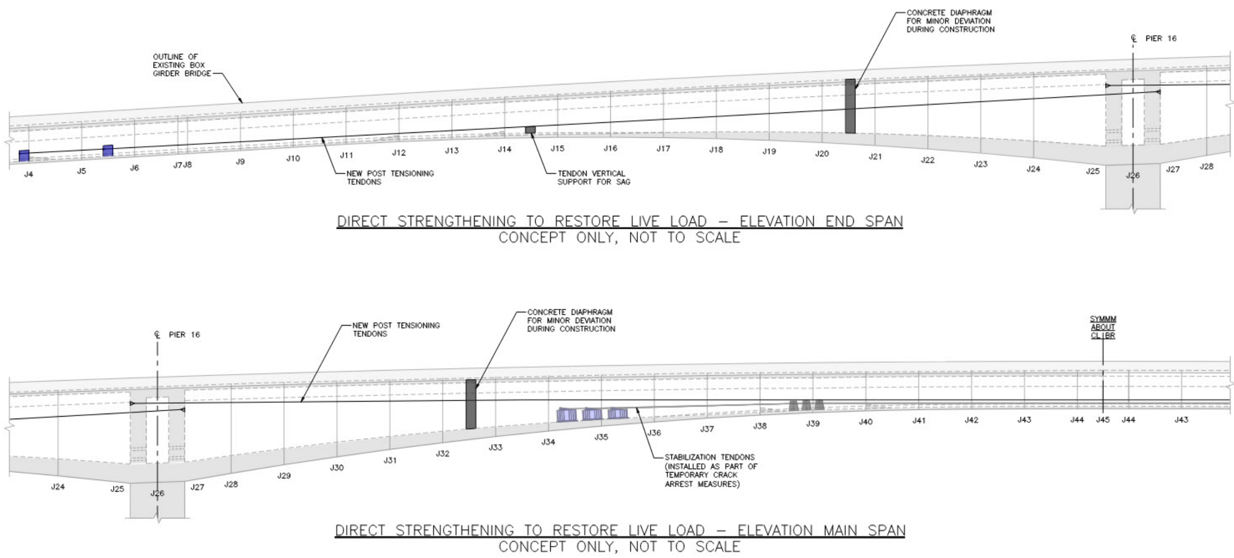

Figure 6. Alternative 2, Direct Strengthening to Restore Live Load

2.2.2 *ALTERNATIVE LIFE CYCLE*

Alternative 2 would restore live load to the bridge by 2022. The seismic assessment identified some local ground improvement needs at Pier 18. The CBA assumes that this work will be completed by 2032. In 2062, after an additional 40 years of service, it is assumed that the bridge would be replaced entirely. The condensed schedule below shows construction durations. Appendix F includes more detailed construction schedules.

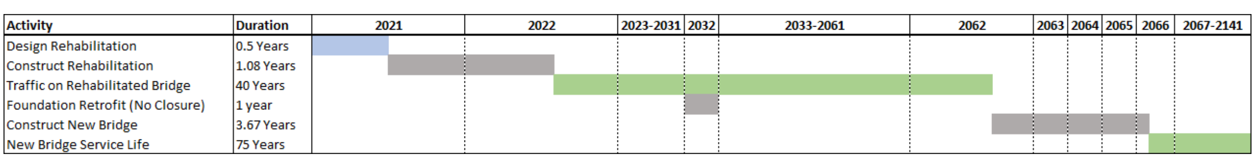

Figure 7. Construction Schedule for Alternative 2, Direct Strengthening to Restore Live Load

2.3 ALTERNATIVE 3: PARTIAL SUPERSTRUCTURE REPLACEMENT TO RESTORE LIVE LOAD

2.3.1 ALTERNATIVE DESCRIPTION

WSP eliminated the partial superstructure replacement to restore live load alternative during the CBA process, as we determined that it would be prohibitively difficult to make continuous connections between the concrete and the steel.

The partial superstructure replacement, depicted in the figure below, would involve demolishing the box girders between approximately the Joint 36 locations and replacing them with a steel box girder section. The steel box girder would be much lighter than the concrete section demolished and could be lifted from a barge. A concrete deck and barriers would be placed after connecting the steel section to the existing concrete box girders.

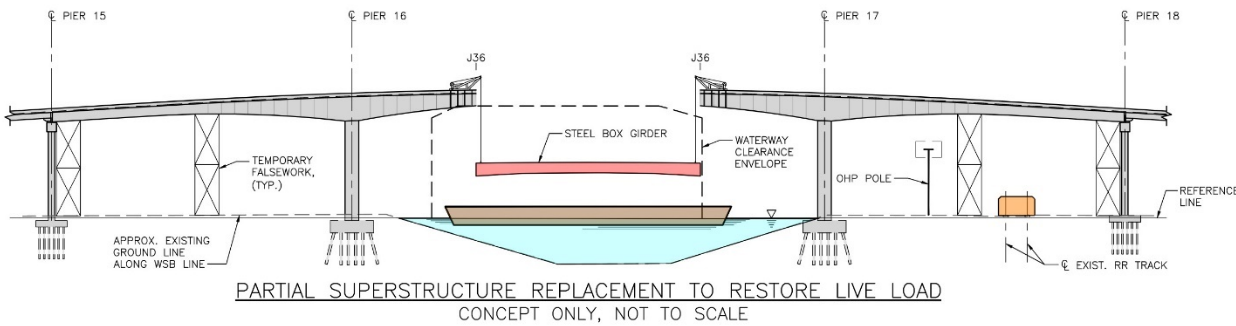

Figure 8. Alternative 3, Partial Superstructure Replacement to Restore Live Load

2.3.2 ALTERNATIVE LIFE CYCLE

WSP did not develop cost and schedule for this alternative because it was eliminated from consideration.

2.4 ALTERNATIVE 4: ACCELERATED SUPERSTRUCTURE REPLACEMENT

2.4.1 ALTERNATIVE DESCRIPTION

The on-alignment superstructure replacement involves demolishing the existing box girders between Pier 15 and Pier 18 and replacing it with another box girder superstructure, reusing the current foundations and substructure.

Figure 10 depicts how a superstructure replacement could be constructed using the balanced cantilever method, like its original construction. As with the current bridge, segments would be composed of cast-in-place post-tensioned concrete. Construction would require temporary falsework support.

If determined to be adequate for today's standards, the columns and main pier diaphragm reinforcement would be reused. Preliminary analyses indicate that the foundations would need some level of retrofit to support the new superstructure. However, unlike Alternative 2, which could accommodate a retrofit later, Alternative 4 would require a retrofit concurrent with superstructure replacement. Alternative 4 would be future compatible with light rail and restore traffic to its original capacity.

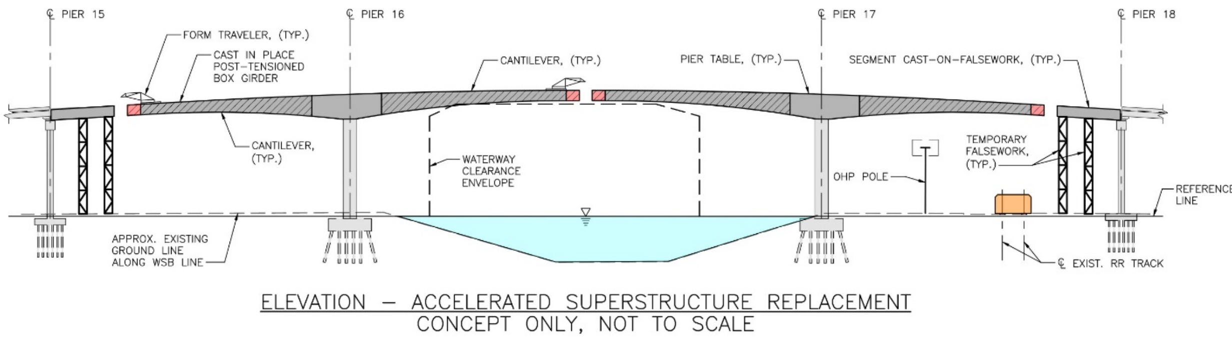

Figure 9. Alternative 4, Accelerated Superstructure Replacement

2.4.2 ALTERNATIVE LIFE CYCLE

Alternative 4 would restore full traffic by 2026, after design, demolition of the existing superstructure, and construction of the new superstructure. The CBA also assumes that, after 50 years, the new bridge would require direct strengthening. Direct strengthening would take one year and would not have long-duration traffic impacts. The condensed schedule below shows construction durations. Appendix F includes more detailed construction schedules.

Activity	Duration	2021	2022	2023	2024	2025	2026	2027-2075	2076	2077-2101
Design Superstructure Replacement	1.5 Years									
Construct Superstructure Replacement	3.83 Years									
New Bridge Service Life	75 Years									
Direct Strengthening	1 Year									

Figure 10. Construction Schedule for Alternative 4, Accelerated Superstructure Replacement

2.5 ALTERNATIVE 5: ACCELERATED BRIDGE REPLACEMENT

2.5.1 ALTERNATIVE DESCRIPTION

WSP considered on-alignment full bridge replacement options, such as steel tied arch, steel truss, extradosed, and cable-stayed bridge types. After comparing the relative costs, as well as potential locations and span configurations, WSP selected the cable-stayed option, comprising a steel tensioning system and prefabricated steel segments, as the best on-alignment full replacement alternative. This alternative would require new approach spans and would consist of a precast girder superstructure.

The figure below depicts how a main pylon could be constructed on the west side of the river to support a 700-foot span. If structurally adequate, Piers 15, 17, and 18 could be reused. It is assumed that each would require retrofit to their foundation systems, and costs and concepts were developed accordingly. This alternative would require a tie-down pier to the east of the existing Pier 14, and a new pier between existing Piers 17 and 18 to support the precast girder spans. Alternative 5 would be future compatible with light rail and restore traffic to its original capacity.

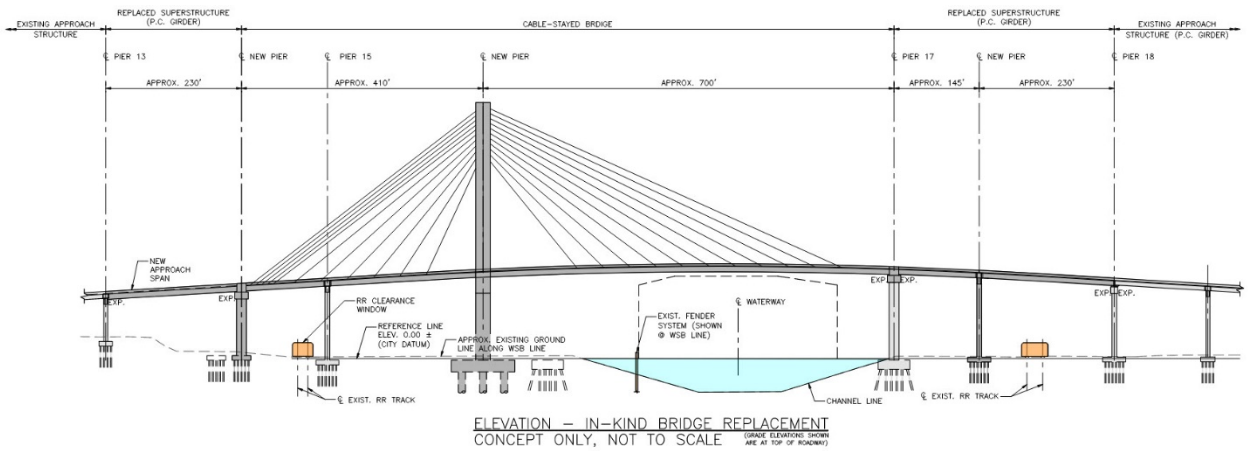

Figure 11. Alternative 5, Accelerated Bridge Replacement

2.5.2 ALTERNATIVE LIFE CYCLE

Alternative 5 would restore full traffic capacity in 2026, after design, demolition of the existing structure, and construction of the new bridge. The CBA also assumes that, after fifty years, the new bridge would require direct strengthening. Direct strengthening would take one year and would not have long-duration traffic impacts. The condensed schedule below shows construction durations. Appendix F includes more detailed construction schedules.

Activity	Duration	2021	2022	2023	2024	2025	2026	2027-2075	2076	2077-2101
Design Replacement Bridge	1.5 Years									
Construct Replacement Bridge	3.67 Years									
New Bridge Service Life	75 Years									
Direct Strengthening	1 Year									

Figure 12. Construction Schedule for Alternative 5, Accelerated Bridge Replacement

2.6 ALTERNATIVE 6: OFF-ALIGNMENT IMMERSED TUBE TUNNEL

2.6.1 ALTERNATIVE DESCRIPTION

WSP considered two immersed tube tunnel alignments, located to either the north or the south of the existing WSHB. The tunnels connect to the surface network via cut-and-cover and open-cut segments (see Appendix L for more information on tunnel concepts). WSP reviewed multiple alignments to the south and north of the existing corridor. Future studies should further evaluate the pros and cons of each alignment but, for cost estimating purposes, we chose the northernmost alignment to correlate with publicly presented alignments. There may be advantages to aligning the ITT to the south to minimize impacts with the railroad and Port of Seattle property.

The ITT segments would consist of reinforced concrete and be fabricated off site in a concrete casting basin facility. While not included in the CBA, if the tunnel included light rail, it is likely that a casting basin would need to be constructed, as there is no regional facility large enough to accommodate the fabrication of concrete tunnel segments of this magnitude.

After casting, each segment would be floated to the site prior to immersion and connection with adjoining segments. Cut-and-cover segments would also consist of reinforced concrete but would be constructed on site. A typical tunnel section and the tunnel profile for the north alignment are provided below.

While the tunnel could be built to accommodate light rail, the purpose of this CBA was to compare options as fairly as possible. Because the bridge replacement concepts discussed in the CBA are forward compatible with light rail but do not feature light rail, the tunnel concept advanced here does not include light rail, but we do consider the tunnel to be forward compatible with it (see Appendix L for more information).

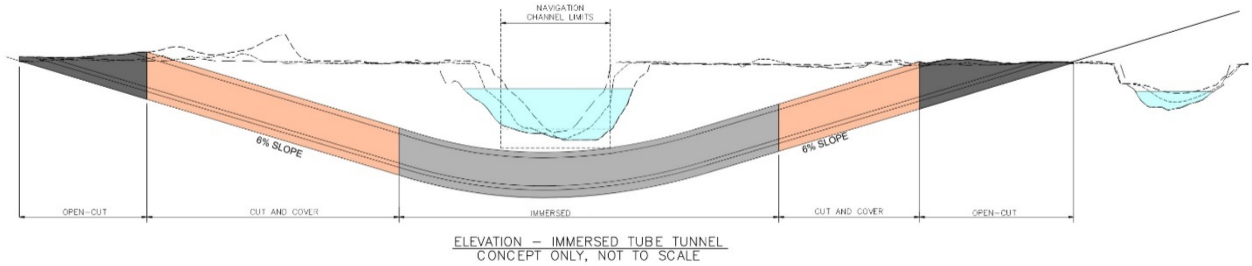

Figure 13. Alternative 6, Immersed Tube Tunnel

2.6.2 ALTERNATIVE LIFE CYCLE

It is anticipated that the tunnel would restore full traffic capacity at the beginning of 2030, depending on the required time to modify or realign existing infrastructure and make connections (orange bar appending the gray bar in the figure below). It is assumed that regular, ongoing operation and maintenance activities would be required.

Activity	Duration	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030+
Design and ROW/Easements	3.5 Years										
Construct Tunnel and Tie-Ins	5.5 Years										
New Tunnel Service Life	75+ Years										

Figure 14. Construction Schedule for Alternative 6, Immersed Tube Tunnel

3 PERFORMANCE EVALUATION CRITERIA

3.1 PERFORMANCE EVALUATION PROCESS

The findings of the CBA are presented as value indices, a measure indicating return on investment, and mathematically represented by dividing the performance score by the cost of a given alternative. This section of the report discusses the process for developing the alternative performance score, which is independent of cost.

The first step of the CBA assessed the rehabilitate and replace alternatives using a formal three-phase evaluation process:

1. Definition and process
2. Findings
3. Reporting

The CBA evaluation process used for the WSHB was developed, refined, and implemented in conjunction with Washington State Department of Transportation (WSDOT) on past WSDOT projects. The intent of this process is to minimize subjective evaluation of the alternatives.

Workshops with SDOT and WSP and meetings with the TAP and CTF refined the alternatives and key evaluation criteria. For example, during Workshop No. 2, SDOT and WSP discussed potential attributes, and decided to add another attribute (Equity) to the list. And, during the September 9 CBA presentation to the CTF, members of the task force raised concerns that the CBA was not capturing long-term workforce impacts, so WSP added another measurable to Business and Workforce Impacts (Section 3.2.7).

3.1.2 PERFORMANCE ATTRIBUTES

The City, the TAP, the CTF, and WSP together identified ten performance attributes that capture the unique benefits, or values, of each alternative relative to another.[7] The attributes identify non-monetary advantages and disadvantages. WSP eliminated any potential criteria which could be fully analyzed through cost impacts. Attributes are centered around the functional goals that address the needs of both the City and the community.

- Bridge Maintenance, Inspection, and Operations
- Constructability
- Environmental
- Equity
- Forward Compatibility
- Funding Opportunities
- Business and Workforce Impacts
- Mobility Impacts
- Multimodal Impacts
- Seismic/Safety

[7] Reference TAP CBA Part 1 Recommendation memorandum and City/WSP response memorandum for background discussions.

3.1.3 WEIGHTING OF PERFORMANCE ATTRIBUTES

Once we identified the ten performance attributes, along with how they are measured, the next step was to weight each individual attribute against the other attributes. SDOT, the TAP, and the CTF independently filled out the attribute matrix spreadsheet (Figure 15). The highest-ranking attributes were Mobility Impacts, Seismic/Safety, and Constructability. These attributes were then given the most weight for the next step of the CBA.

PERFORMANCE CRITERIA MATRIX

West Seattle Bridge Rehabilitation/Replacement Study

Which evaluation criterion contributes more to the overall success of the project?

		TOTAL	%
Bridge Maintenance, Inspection & Operation	A	14.4	8.8%
Constructability	B	17.5	10.6%
Environmental	C	14.0	8.5%
Equity	D	14.4	8.7%
Forward Compatibility	E	14.1	8.5%
Funding Opportunities	F	15.3	9.3%
Business and Workplace Impacts	G	14.6	8.8%
Mobility Impacts	H	22.7	13.8%
Multi-modal Impacts	I	15.5	9.4%
Seismic/Safety	J	22.5	13.7%
		55.0	100%

RATINGS FOR COMBINED SDOT/TAP/CTF

Figure 15. Blank Performance Attribute Weighting Matrix
Using blank matrices, SDOT, the TAP, and the CTF scored each attribute against the others for a subjective weighting system. See Appendix N for further details.

3.1.4 MEASURABLES

Within each attribute falls several measurables to quantify (and/or qualify) the value of each alternative in that particular context. These allow us to objectively measure the different components that subject matter experts chose as representative of each attribute. Depending on the unit of measure, results could be quantitative or qualitative.

Once data is input, subject matter experts give each alternative a score of 1, 3, 5, 7, 9 for each attribute, as defined in the following subsection.

3.1.5 PERFORMANCE RATINGS FOR ALTERNATIVES

For this evaluation, WSP used Alternative 2 (direct strengthening/rehabilitation) as the baseline for comparison with other alternatives. We gave the baseline alternative (Alternative 2) a performance rating of 5 for each attribute. For each of the other proposed alternatives, subject matter experts assigned a scalar value score of 1, 3, 5, 7, or 9 to each performance attribute based on the defined measurable criteria and compared to a baseline condition (Figure 16).

Table 3. Alternative/Baseline Rating Scale

Alternative / Baseline Rating Scale

Rating	Performance Attribute Scale
1	Baseline is strongly preferred
3	Baseline is moderately preferred
5	Baseline
7	Alternative is moderately preferred
9	Alternative is strongly preferred

Measurables	Unit of Measure	Alt #1 Shoring		Alt #2 Rehabilitation		Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
		5 Years (Shoring)	75+ Years (Alt 5)	40 Years (Rehab)	75+ Years (Alt 5)			
Inspection Requirements	Frequency & Level-of-Effort (High/Med/Low) Special Inspections (Yes/No)	6-12 Mo High Yes	12-24 Mo High Yes	6-12 Mo High No	12-24 Mo High No	24 Mo Med No	12-24 Mo High Yes	24 Mo Med Yes
Intelligent Transportation Systems Required	Yes/No	Yes	No	No	No	No	No	Yes
Structural Health Monitoring Systems Required	Yes/No How many systems required?	Yes 3	No	Yes 3	No	No	No	No
Painting/UV protection Required	Yes or No	No	Yes	Yes	Yes	No	Yes	No
SCORE	(1,3,5,7,9)			5.00				

Figure 16. Alternative 2 served as the baseline, receiving a 5 for every attribute (This figure shows the Seismic/Safety attribute for demonstration purposes.)

Specific items of measure for each attribute objectively assessed the difference between alternatives with respect to each attribute. Subject matter experts from SDOT, WSP, and the TAP independently rated each alternative relative to the baseline (see Figure 17). We then used these ratings to calculate overall performance scores and value indices (discussed further in Section 6).

VALUE MATRIX

West Seattle Bridge Rehabilitation/Replacement Study

Evaluation Criteria	Attribute Weight	Alternative	Performance Rating				Total Performance
			SDOT Avg	TAP	WSP	Average	
Bridge Maintenance, Inspection & Operation	8.8	Temporary Shoring to Restore Live Load (3 to 5 years)	5.00	1	5	3.67	32.1
		Direct Strengthening to Restore Live Load (15 to 40 years)	5.00	5	5	5.00	43.8
		Accelerated Superstructure Replacement (50 to 75 years)	8.33	7	7	7.44	65.1
		Accelerated Bridge Replacement (75+ years)	7.67	7	7	7.22	63.2
		Off-Alignment Immersed Tube Tunnel (75+ years)	3.67	3	3	3.22	28.2
Constructability	10.6	Temporary Shoring to Restore Live Load (3 to 5 years)	2.33	3	3	2.78	29.4
		Direct Strengthening to Restore Live Load (15 to 40 years)	5.00	5	5	5.00	53.0
		Accelerated Superstructure Replacement (50 to 75 years)	5.67	3	7	5.22	55.3
		Accelerated Bridge Replacement					

Figure 17. Subject matter experts from the TAP, SDOT, and WSP scored each alternative relative to each attribute to determine an average performance rating

3.2 PERFORMANCE

The following subsections discuss in greater detail each attribute's measurables and resulting values, as well as the performance of different alternatives with respect to each of the performance attributes. Within each attribute lies several "measurables" and "units of measure." Subject matter experts determined (a) what these measurables should be and (b) how to measure them. They then used various methodologies to calculate values for each of the five alternatives.

3.2.1 BRIDGE MAINTENANCE, INSPECTION, AND OPERATIONS

This attribute measures the services and systems necessary for the operation and preservation of the bridge and corridor, throughout the life cycle of each alternative. It seeks to answer the question: What will this rehabilitate/replace concept need over its lifespan in terms of operations, maintenance, and inspection?

Measurables	Unit of Measure	Alt #1 Shoring		Alt #2 Rehabilitation		Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
		5 Years (Shoring)	75+ Years (Alt 5)	40 Years (Rehab)	75+ Years (Alt 5)			
Inspection Requirements	Frequency & Level-of-Effort (High/Med/Low) Special Inspections (Yes/No)	6-12 Mo High Yes	12-24 Mo High Yes	6-12 Mo High No	12-24 Mo High No	24 Mo Med No	12-24 Mo High Yes	24 Mo Med Yes
Intelligent Transportation Systems Required	Yes/No	Yes	No	No	No	No	No	Yes
Structural Health Monitoring Systems Required	Yes/No How many systems required?	Yes 3	No	Yes 3	No	No	No	No
Painting/UV protection Required	Yes or No	No	Yes	Yes	Yes	No	Yes	No
SCORE	(1,3,5,7,9)	3.67		5.00		7.44	7.22	3.22

Figure 18. Bridge Maintenance, Inspection, and Operations attribute's measurables applied to all five alternatives

INSPECTION REQUIREMENTS

We examined the frequency and level of effort required for inspections, as well as the need for any special inspections. Alternative 4 performs best for this measure, as it requires only a medium level of effort, with 24 months between inspections from the outset and no special inspection requirements.

Alternative 6 also has 24-month inspections; however, the tunnel does require special inspections. Alternatives 1 and 2 would initially require a greater level of effort, with special inspections required every 6 to 12 months. Once these alternatives were superseded by their in-kind replacements (Alternative 5), those inspections would drop to every 24 months but would still require special inspections.

Alternative 5 performs moderately better than Alternatives 1 and 2 based on frequency of inspection. For this measurable, replacement (except for the tunnel) performs better.

INTELLIGENT TRANSPORTATION SYSTEMS REQUIRED

The only alternatives to require Intelligent Transportation Systems are Alternative 1 and Alternative 6, making rehabilitation (Alternative 2) or a bridge replacement (Alternatives 4 and 5) equally viable. Shoring and a tunnel replacement are less preferred.

STRUCTURAL HEALTH MONITORING SYSTEMS REQUIRED

If the existing superstructure elements remain in service (Alternatives 1 and 2), a number of systems would have to be installed to monitor the health of the rehabilitated or shored structure. Given the expense and manpower required to implement a structural health monitoring system, this makes replacement a better alternative for this measurable.

PAINTING/UV PROTECTION REQUIRED

Any structure containing structural steel elements, requires periodic painting. Alternative 5 (this would include Alternatives 1 and 2 eventual in-kind replacement) would need to be painted every 25 years. Before replacement, Alternative 2 would require painting every 10 years, as UV protection is required when using CFRP. Submersed elements of Alternative 6 would not require painting. As such, a replacement (specifically, Alternatives 4 and 6) is preferred for this measurable.

3.2.2 CONSTRUCTABILITY

The Constructability attribute measures the ease and efficiency with which each alternative can be built, relative to schedule and potential construction means and methods.

This attribute was the third highest ranked in the combined scores of the CTF, the TAP, and SDOT. It thus has the third highest weighting in the analysis. The constructability of each alternative was based on its impacts to the following measurables as discussed below. Subject matter experts from the TAP, SDOT, and WSP scored Alternative 4 (superstructure replacement) as the preferred alternative for this attribute, with an overall score of 5.22.

Measurables	Unit of Measure	Alt #1 Shoring		Alt #2 Rehabilitation		Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
		Immediate (Shoring)	Future (Alt 5)	Immediate (Rehab)	Future (Alt 5)			
Schedule Impacts	Duration of Construction	39	44	13	44	46	44	66
Complexity	Standard construction or complex	Complex	Complex	Complex	Complex	Standard	Complex	Complex
Specialty Contractors and Equipment	Are any required and if so how many	Yes, 2	Yes, 5	Yes, 3	Yes, 5	Yes, 5	Yes, 5	Yes, 6
Utility Relocations	Impacts on existing utilities, scope	Minor	Average	Minor	Average	Average	Average	Major
In-Water Work	Amount of in-water work and how many in-water windows are needed	None	Foundation Retrofit 2 Windows	None	Foundation Retrofit 2 Windows	Foundation Retrofit 2 Windows	Foundation Retrofit 2 Window	Tunnel Segments in Water 2 Windows
Demolition	Amount and complexity of demolition required	Complex & Truss Demo	Complex	Complex	Complex	Complex	Complex	Complex
Poor Soil Conditions	Is substantial foundation work required?	No	Yes	Yes	Yes	Yes	Yes	Yes
Staging/Laydown Area Required	Required footprint	Average	Large	Minimal	Large	Average	Large	Very Large
SCORE	(1,3,5,7,9)	2.78		5.00		5.22	4.11	2.11

Figure 19. Constructability attribute's measurables applied to all five alternatives

SCHEDULE IMPACTS

For each alternative, WSP estimated an approximate duration (shown in months), based on the work required and the potential risk for schedule delays.

Alternative 2 has the shortest initial schedule duration, as it does not require significant amounts of demolition or major construction of new bridge components. We can estimate durations based on similarities in work items to the current stabilization measures.

It is our understanding that federal funds could be used in rehabilitation or replacement of the bridge. This will likely require all permanent steel materials to be manufactured domestically. Therefore, alternatives that require much greater amounts of structural steel, such as the trusses required for the Alternative 1 shoring option or the steel superstructure used for the Alternative 5 cable stay, will have increased procurement duration, risk of delays, and risk of higher or unpredictable cost. Alternative 6, with a construction duration of 66 months, would have the greatest impact. It is likely that it would also run the greatest procurement risks, with the potential need to build an off-site casting basin for fabricating the components.

For this measurable, rehabilitation is preferred.

CONSTRUCTION COMPLEXITY

The complexity of each alternative is based on the use of standard construction methods. We consider an alternative to be more complex if the work requires less common or reliable means of construction, increasing the contractor's risk and/or costs.

For Alternative 1, the two trusses that would have to be constructed are larger than any locally constructed trusses in recent history, making this alternative complex. There is a wealth of local experience in the use of post-tensioning, and the similarity to the current work being performed reduces Alternative 2's risk. However, this work would still require retrofitting an existing structure, and retrofitting is complex.

Alternative 4 assumes that the means and methods for replacing the superstructure would be like those used to construct the existing bridge. However, balanced cantilever construction has become more common than in the early 1980s, and regionally, contractors are experienced in that method. Therefore, the construction of a new superstructure on existing foundations is somewhat complex, but the assumed means and methods are frequently used in the region. If future studies explore other superstructure replacement options, complexity could change accordingly.

Alternative 5 does not require as much reuse of the existing structure, making substructure work more traditional than retrofitting existing substructures. However, the concept features a cable-stay bridge which is somewhat regionally uncommon and has construction methods that are considered complex.

Alternative 6's construction is complex, because segments need to be set and leveled underwater. It is also complex because of the amount of temporary works and dewatering needed for the cut-and-cover portion, and the low frequency of similar projects in the region. In addition, the tunnel would require the construction of an entirely new structure, along with approaches.

For this measurable, rehabilitation, specifically Alternative 4, is preferred.

SPECIALTY CONTRACTORS AND EQUIPMENT

Any alternatives requiring post-tensioning, primarily Alternatives 2 and 4, would require specialty contractors. Alternative 2 would also require a specialty contractor for CFRP placement.

The construction methods for the cable-stay bridge proposed for Alternative 5 would require specialty contractors and materials. Ground improvements would likely be needed near the new foundations, consisting of groupings of large-diameter drilled shafts. Ground improvements and drilled shafts would both require specialty contractors and a fairly large footprint for mobilizing and storing construction equipment and materials.

Alternative 6 would require a contractor experienced in the construction methods needed for dredging the channel and setting and aligning the tunnel segments, as well as a specialty fabricator and facility for casting segments.

For this measurable, rehabilitation, specifically Alternative 4, is preferred.

UTILITY RELOCATION

As alternatives are only conceptual at this point, we have only considered utility impacts in a general sense. Future studies should further investigate specific impacts. For bridge superstructure work only, we expect that impacts would be less severe, giving an advantage to Alternative 2 as far as initial work items are concerned. We would expect Alternatives 1 and 4 to have greater impacts due to the amount of work outside of the box.

Alternatives 5 and 6 would have the greatest impact on existing utilities, as the new foundations would be large, and exact locations are yet to be determined. This is also assumed to be the case for any foundation work, such as foundation retrofits for Alternatives 2 and 4. For Alternative 6, it is expected that there will be utility conflicts both within the footprint of the tunnel alignment and those utilities that may be impacted by any anchors or similar methods that may be used to support excavation for the tunnel.

For this measurable, repair is preferred, but long-term impacts would be similar to replacement alternatives.

IN-WATER WORK

Any alternative that requires work below the wetted perimeter is by default more challenging because of the constraints that the river poses — from marine traffic to environmental considerations, such as fish migration. Alternatives 2 and 4 are expected to require some in-water work for foundation retrofits. The advantage of the new foundations Alternative 5 would require is they can be located further from the river, thus minimizing or eliminating permit constraints when working in or near the water. Alternative 6 requires the most in-water work as the channel would have to be dredged and then segments of tunnel sunk into place and connected. There is likely to be at least some disruption to river operations to perform this work; however, full extents of the disruption have not yet been assessed.

For this measurable, a full in-kind replacement is preferred.

DEMOLITION

Demolition would be over an active river, and all demolition activities would need to accommodate the operation of the adjacent swing bridge. The CBA’s current assumption is that any superstructure demolition would be top-down.

For Alternative 1, the shoring trusses could support the main span during demolition. For all the other alternatives, it is assumed that the demolition of the existing bridge superstructure would be performed in a reverse order of how it was constructed – balanced cantilever.

While several bridges in the region have been demolished over waterways and roadways, this would be one of the region’s first balanced cantilever bridges to be demolished, adding another level of uncertainty to this activity. Current work, such as post-tensioning and carbon fiber wrap, to stabilize the bridge could also add more complexity to structure demolition.

There is no clear “winner” for this measurable.

POOR SOIL CONDITIONS

As stated in the assumptions, a limited amount of geotechnical information is available for the site at this time. Unforeseen geotechnical conditions are likely to cause additional cost and schedule delay, adding risk to all alternatives. The more foundation work that an alternative requires, as well as expected increases in superstructure weight, can be anticipated to have greater impacts due to poor soil conditions. Alternatives 1 and 4 require that existing Piers 16 and 17 foundations be retrofit in the future. Poor soil conditions could have a large impact in these cases, as the options for strengthening existing structure are limited. Alternative 5 requires full replacement piers, which provide more opportunity to design for poor soils. However, this alternative would potentially require ground improvements, which can be costly and impact the schedule. Alternative 6 may require targeted ground improvements needed to support the final structure, and to reduce seepage and provide lateral excavation support during construction.

There is no clear winner for this measurable, as all alternatives are impacted by poor soil conditions in one way or another.

STAGING AND LAYDOWN AREAS REQUIRED

A minimal construction footprint is needed to perform the strengthening work for Alternative 2. Alternatives 1 and 5 would likely need larger laydown areas to facilitate the storage and erection of steel elements. Any work on the existing foundations (Alternatives 2 and 4) would require coffer cells with a large footprint to avoid existing battered piles. The construction footprint for Alternative 6 is an order of magnitude larger than any of the other alternatives, requiring direct impacts to most of the alignment, as the on-land portions will be constructed by cut-and-cover methods. It also requires a dedicated site for construction of the prefabricated elements.

Either rehabilitation or the superstructure replacement alternatives are preferred.

3.2.3 ENVIRONMENTAL

The Environmental attribute measures each alternative's potential adverse effects to the built or natural environments. Using the following measurables, it seeks to answer the question: What kind of temporary and permanent impacts will this rehabilitate/replace concept have on the Duwamish River and surrounding area?

Subject matter experts from the TAP, SDOT, and WSP scored Alternative 2 (rehabilitation) as the overall preferred alternative for this attribute (with the baseline score of 5), with Alternative 4 (superstructure replacement) a close second with a score of 4.78.

Measurables	Unit of Measure	Alt #1 Shoring	Alt #2 Rehabilitation	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
Noise and Vibration	Pile driving be required?	No	Yes	Yes	Yes	Yes
Duwamish Waterway	In-water work required? Proximity of construction ground disturbance to shoreline?	In-water work limited to temp barges during shoring and demolition Alt 5 Replacement includes foundation strengthening at Pier 17 which requires ground disturbance within the shoreline and waterway	In-water work limited to temp barges during rehabilitation and demolition Alt 5 Replacement includes foundation strengthening at Pier 17 which requires ground disturbance within the shoreline and waterway	In-water work limited to temp barges during demolition Alt 4 Replacement includes foundation strengthening at Piers 16 & 17 which requires ground disturbance within the shoreline and waterway	In-water work limited to temp barges during demolition Alt 5 Replacement includes foundation strengthening at Pier 17 which requires ground disturbance within the shoreline and waterway	Dredging in the West Waterway ITT requires in-water work to place the tunnel structure and riprap/backfill Ground disturbance within waterways and along shoreline
Section 4(f) Resources	Use of parks, recreation areas, trails, open space, wildlife refuges Proximity of construction to known archaeological sites and known historic structures listed or eligible for the National Register of Historic Places	No use of parks, trails, open space or wildlife refuges Potential use of Nucor Steel NHRP Building or Pacific Forge historic district for Shoring trusses and bridge replacement piers	No use of parks, trails, open space or wildlife refuges Potential use of Nucor Steel NHRP Building or Pacific Forge historic district for bridge replacement piers	No use of parks, trails, open space or wildlife refuges	No use of parks, trails, open space or wildlife refuges Potential use of Nucor Steel NHRP Building or Pacific Forge historic district for bridge replacement piers	Potential use of Terminal 18 public access park and public recreation area shore/fishing access across East Waterway
Emissions	Tons of greenhouse gas (from VMT) x construction duration	210,000 more tons	128,000 more tons	161,000 more tons	161,000 more tons	213,000 more tons
Wildlife Impacts	Timing and duration of construction proposed during falcon/great blue heron breeding season. Noise levels from construction activities (pile driving).	Three phases of construction, total 6-8 years High during pile driving (Alt 5)	Three phases of construction, total 5-6 years High during pile driving (Alt 5)	Two phases of construction, total 4-5 years High during pile driving	Two phases of construction, total 4-5 years High during pile driving	One phases of construction, total 8-9 years High during pile driving
SCORE	(1,3,5,7,9)	3.67	5.00	4.78	3.89	1.33

Figure 20. Environmental attribute's measurable applied to all five alternatives

NOISE AND VIBRATION

We measured the potential for adverse noise and vibration impacts for each alternative by whether construction would require pile driving. WSP selected pile driving as the measure for adverse noise and vibration effects, as it is a construction activity that typically produces high levels of noise and ground vibration. Pile driving reaches noise levels that can potentially impact surrounding neighborhoods.

Any foundation retrofit work, which would include driving new piles to strengthen the existing foundations at Piers 16 and 17, would require pile driving. Foundation retrofit work is proposed with Alternatives 2, 4 and 5; foundation retrofit work is not proposed with Alternative 1. Pile driving would also be required to construct the sheet pile wall shoring system necessary for excavation support for Alternative 6's immersed tunnel segment and the cut-and-cover/open-cut tunnel segment. Noise and vibration impacts would be greatest for the alternatives that require a foundation retrofit with pile driving (Alternatives 2, 4, and 5) and Alternative 6 that requires pile driving for the shoring system.

As noise and vibration would be high for Alternatives 2, 4, 5, and 6, shoring would have the least effect on the built and natural environments for this measurable. It should be noted that the replacement (Alternative 5) that will ultimately supersede shoring would be as impactful in the future as replacement would be now.

DUWAMISH RIVER

We measured adverse environmental impacts to the Duwamish River by whether in-water work would be required and by the proximity of ground disturbance to the shoreline during construction.

With the rehabilitation and replacement alternatives, we anticipate that construction activities in or on the Duwamish River would be limited to barges providing equipment or construction materials and/or removing materials (i.e., existing bridge segments). For these activities, barges would be located in the Duwamish River beneath the bridge only intermittently and for very short periods of time (i.e., hours). The tunnel alternative would require dredging within the West Duwamish River.[8] The immersed tube segment that would span the West Duwamish River would require extensive in-water work to construct and place the tunnel structure, as well as the riprap and backfill that would be placed on top of the tunnel. Even after construction was complete and the depth of the river back to preconstruction depths, regulating agencies could consider the tunnel as a new structure in the waterway.

In terms of proximity of ground disturbance to the shoreline, because of the existing location of Pier 17, near the top bank of the Duwamish River, the foundation retrofit work would likely include new piles that would either require in-water work or disturb the shoreline very near the waterline. Again, foundation retrofit work is proposed with Alternatives 2, 4, and 5 and not proposed with Alternative 1. With Alternative 5's new replacement span, the new bridge piers would be located further from the edge of the Duwamish River. With the tunnel alternative, construction of both the immersed tunnel segment and the open-cut tunnel segment would require ground disturbance within the shoreline of both the East and West Duwamish River.

This measurable indicates that shoring would have the least effect on the Duwamish River (the natural environment). It should be noted that the replacement (Alternative 5) that will ultimately supersede shoring would be as impactful in the future as replacement would be now.

SECTION 4(F) RESOURCES

Section 4(f) of the *U.S. Department of Transportation Act of 1966* provides special protection of publicly owned land of a park, recreation area, or wildlife and waterfowl refuge of national, state, or local significance, or land of an historic site of national, state, or local significance (as determined by the officials having jurisdiction over the park, area, refuge, or site) (49 United States Code Section 303).

A "use" is generally defined as a transportation activity or facility that permanently or temporarily acquires land from a Section 4(f) property, or that substantially impairs the important activities, features, or attributes that qualify the property as a Section 4(f) resource. Under Section 4(f), a use can be:

- **Permanent use**: Occurs when the transportation facility acquires or incorporates all or part of a Section 4(f) property.
- **Temporary use**: Occurs when the project temporarily occupies any portion of the resource (typically during construction), substantially impairing the resource.
- **Constructive, or indirect, use**: Occurs when the project is near the Section 4(f) resource and has effects that substantially impair the protected activities, features or attributes of a property.

This measurable evaluated potential adverse effects to Section 4(f) resources based on the temporary or permanent use of parks, trails, open space or wildlife refuges, and the proximity of construction to known archaeological sites or historic structures (those listed or eligible for the National Register of Historic Places [NRHP]).

According to City of Seattle maps, there are no publicly owned parks, recreation areas or wildlife refuges within the immediate vicinity of the existing bridge. There is a multi-use path along the southern side of the Spokane Street bridge, just north of the existing WSHB. Multiuse paths, or trails, that are part of an existing transportation system are typically exempt from Section 4(f). The Terminal 18 public access park is approximately 500 feet north of the bridge, along the east side of the West Duwamish River. Across the East Duwamish River, along the north side of SW Spokane Street there is a public shore access that is used for public recreation, including fishing.

The NRHP-listed Nucor Steel building is just south of the WSHB. The Nucor Steel building is also part of an area eligible for listing on the NRHP as a potential historic district – the "Pacific Forge Historic District."

With Alternative 1, the placement of shoring trusses on land beneath the existing bridge could have *temporary use* of the Nucor Steel property or the potentially eligible Pacific Forge Historic District. The foundation retrofit work

[8] While not assessed in the CBA, dredging for the tunnel has the potential to disturb hazardous materials in the Duwamish River, which is classified as a Superfund site. This renders Alternative 6 particularly worrisome from an environmental impact standpoint.

with Alternatives 2, 4, and 5 could also have a *permanent* or *temporary use* of the Nucor Steel property or the Pacific Forge Historic District. With all the alternatives, the new piers with the in-kind bridge replacement, when it occurs, may also have a potential use of these two Section 4(f) resources. The tunnel alternative could have a *permanent* or *temporary use* of both the Terminal 18 public access park and the public shore access across the East Duwamish River.

For this measurable, the replacement alternatives are preferred, as they have only one construction event that could result in a use of a Section 4(f) resource and that potential use would be limited to the area of a new pier.

AIR QUALITY

We measured air quality by evaluating the additional tons of greenhouse gas (GHG) emissions emitted because of increased vehicle miles traveled (VMT) from detour routes while the bridge is closed, as compared to the VMT if the bridge were open to traffic. This measurable took into account emissions from additional VMT for each phase and duration of construction by primary vehicle classification (personal vehicle, medium truck – 3 axle vehicle, and large truck – 4+ axle vehicle) and emissions profile. For Alternative 1, the estimated emissions were an additional 210,000 tons. Alternative 2 had an estimated additional 128,000 tons of emissions, and Alternatives 4 and 5 had an estimated additional 161,000 tons of emissions. Alternative 6 has an estimated 213,000 tons of emissions.

With the fewest tons of emissions, rehabilitation has the least impact on the built and natural environments for this measurable.

WILDLIFE IMPACTS

We measured the timing and duration of construction to identify potential impacts to wildlife, as this could impact the breeding season of falcons, which have been known to nest on the bridge, and great blue herons, with a known heron rookery in the greenway south of the bridge. As the exact duration of construction for the different work activities is not yet defined, we assessed construction impacts based on the number of phases of construction (i.e., demolition, shoring or strengthening, or replacement) and the total duration of construction. High levels of construction noise, such as from pile driving, can also disrupt wildlife, particularly nesting birds during the breeding season.

With Alternative 1, pile driving is not initially anticipated; however, three phases of construction are anticipated with a total construction duration estimated between six to eight years and eventual pile driving during the replacement. Alternative 2 anticipates three phases of construction over five to six years. Alternatives 4 and 5 assume two phases of construction, including foundation retrofit pile-driving work, with an estimated duration of construction between four to five years. Alternative 6 assumes only one construction phase; however, the total construction time is between eight and nine years. Alternative 6 would also include pile driving with high noise levels that can affect nesting birds.

As Alternatives 4 and 5 offer a shorter duration than Alternatives 1 and 6 and require two phases of work (instead of Alternative 2's three phases), replacement (with the exception of Alternative 6) is preferred for this measurable.

3.2.4 EQUITY

The City of Seattle has a long-standing Race and Social Justice Initiative, which is the City's commitment to eliminate racial disparities and achieve racial equity in Seattle. Most City departments, including SDOT, have a Race and Social Justice Initiative Change Team and use Racial Equity Toolkits to evaluate programs and projects using a broader equity lens.

The Equity attribute applies both quantitative and qualitative measurements to the rehabilitation and replace alternatives presented in the CBA, based on many of the underlying methodologies presented in the Racial Equity Toolkits. The WSHB closure impacts the surrounding area, including traffic movements, access to employment opportunities, and operating local businesses. The equity attributes are specific to impacts on marginalized communities, as determined by evaluating primary diversion routes during bridge closures. Sections 3.2.6 Funding Opportunities and 3.2.7 Business and Workforce Impacts cover revenue generation measures that can be based on regressive taxes and fees and impacts on employment and economic activity that often disproportionately impact lower-wage professions.

Using closure duration as the foundation for examining Equity attributes, the CBA looked at both how to best frame a definition of equity and identify specific measurables to capture incremental impacts that disproportionally affect historically and currently marginalized communities.[9] There are a number of potential sociodemographic factors that could be considered for an equity analysis: race, income status, disability, populations that do not speak English as their first language, among others.

Within the West Seattle peninsula and in South Seattle, the range of median household incomes and the demographic characteristics of their approximately 20 neighborhoods illustrate the diversity of affected populations. Compared to the median household income in Seattle, the median household income in neighborhoods around the WSB range from 47 percent below the city average in South Park to 21 percent above the city average in Alki Beach. The median household income in 12 neighborhoods is below the city average.

The change in traffic patterns could result in social externalities for neighborhood residents and local businesses. For example, the detour route over the First Avenue South Bridge diverts road traffic through three of four neighborhoods with the lowest median household income in the project area. This results in increased environmental and social impacts from the increase in passenger and truck traffic. In the long term, the accumulation of these impacts could result in undesirable effects on personal health, the degradation of the environment and physical infrastructure, decreased effectiveness of social services, and stagnant growth in property values (See Sections 3.2.6 Funding Opportunities, 4.2.6 Business and Workforce Impacts, 4.2.7 Mobility Impacts, and 4.2.8 Multimodal Impacts for further discussion of equity and economic impacts due to the bridge closure). Furthermore, components that may be attributed to work-related equity concerns, for example the impact of increases in travel time delay on independent owner-operators of commercial trucks serving the port, are assessed within the framework of the Business and Workforce Impacts.

Subject matter experts from the TAP, SDOT, and WSP scored Alternative 2 (rehabilitation) as the overall preferred alternative for this attribute, with a baseline score of 5.

The CBA's Equity attribute focused on race to examine the impact of the closure diversion routes through communities with relatively high percentages (23 to 89 percent) of people of color.[10]

Measurables	Unit of Measure	Alt #1 Shoring	Alt #2 Rehabilitation	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
Duration of Bridge Closure	Time to restore full capacity of bridge operations (years full closure starting 1/2021)	3 lanes: 2024 New Bridge: 2033 (7.42 years)	All lanes: 2022 New bridge: 2066 (5.25 years)	New bridge: 2026 (5.33 years)	New bridge: 2026 (5.17 years)	New Tunnel: 2030 (9 years)
Incremental Vehicle-Miles Traveled (VMT)	Incremental VMT during closure through marginalized communities	Higher	Low	Medium	Medium	Higher
Incremental Vehicle Travel	Incremental vehicular travel through marginalized communities (crossing the Duwamish Waterway)	85.3 million more trips	58.8 million more trips	62.5 million more trips	62.5 million more trips	82.5 million more trips
Incremental Travel Time	Cumulative PHT during construction through marginalized communities	Higher	Medium	Lower	Lower	Medium
Number of Construction Events / Community Disruption	Repeat closure events due to preservation or construction marginalized communities would experience 2021 to 2100	2 events within 3 years	2 events within 40 years	1 event	1 event totaling	1 event
SCORE	(1,3,5,7,9)	2.78	5.00	4.11	3.22	1.00

Figure 21. Equity attribute's measurable applied to all five alternatives

DURATION OF BRIDGE CLOSURE

The continued closure causes increased vehicular traffic using detour routes through marginalized communities. Because the overall closure duration was similar for Alternatives 2, 4, and 5 (even if in two phases), these were rated as better than Alternative 1, which would require two closures totaling 7.5 years, or Alternative 6, which would require one closure totaling 9 years.

For this measurable, rehabilitate and replace (except Alternative 6) have similar outcomes – the only difference is that part of the rehabilitation alternative's duration is projected to occur in 40 years.

[9] It should be noted that the Equity attribute captures primarily the impact of detour routes through marginalized communities. It does not delve into impacts on members of those communities who might see their travel times increase or find it more difficult or unreliable to get to work.
[10] A note on methodology: VMT differs based on the timing of the closure. It is assumed that light rail will be in service after 2032, reducing impacts on vehicle travel thereafter. As such, if a replacement were to be built for the rehabilitated bridge in 2066, the VMT would be lower than it is for a pre-2032 closure.

INCREMENTAL VEHICLE MILES TRAVELED[11]

This measurable is intended to capture associated incremental emissions – air quality impacts and GHG, road safety impacts, noise and other negative indirect externalities associated with vehicular travel. Again, this measure depends on both the duration of the bridge closure, as well as the timing of the closure. Vehicle miles traveled (VMT) are modeled by vehicle classification and aggregated for the incremental VMT measure.

With the highest overall closure duration, Alternative 6 has the highest incremental VMT through marginalized communities. While Alternatives 2, 4, and 5 have similar closure durations, Alternative 2's second phase is assumed to be in 2066, which would impact travelers less than in 2022 because one of the CBA's assumptions is that light rail would be available at that time, reducing reliance on vehicles.

In terms of incremental VMT through marginalized communities, rehabilitation is the better option.

INCREMENTAL VEHICLE TRAVEL

Similar to above, the unit of measure for this measurable, intended to capture the increased VMT through marginalized communities, is vehicle trips (all types) crossing the Duwamish River through diversion routes (through marginalized communities) multiplied by construction duration. With Alternatives 1 and 6 adding more than 80 million more trips through marginalized communities, Alternatives 4 and 5 adding 62.5 million more trips, and Alternative 2 adding 58.8 million more trips, rehabilitation is the more equitable option for incremental vehicle travel, with bridge replacement alternatives scoring similarly.

INCREMENTAL TRAVEL TIME

This measurable, which is also dependent on closure duration and timing, evaluates cumulative person hours traveled (PHT) through marginalized communities on SDOT diversion routes and PHT in the final configuration. PHT measures all travel time – pedestrian, transit, bicycle, and vehicle – while VMT captures only the distance traveled in vehicles, including longer distances due to diversion routes. The measurable is also intended to qualitatively capture incremental vehicular delays through marginalized communities. To derive PHT, we used the modeled vehicle hours traveled (VHT) based on vehicle classification (single occupant passenger vehicle (SOV), multiple occupant passenger vehicle (HOV+), medium truck, heavy truck) and adjusted for the average number of occupants per vehicle to derive aggregated PHT values.

With Alternatives 4 and 5 scoring Low, while Alternatives 1 scored High and Alternatives 2 and 6 Medium, the replacement alternatives (except the tunnel) are preferred for this measurable.

NUMBER OF CONSTRUCTION EVENTS/COMMUNITY DISRUPTION

This measurable evaluates how the number of repeated long-term construction events over time may impact marginalized communities over 75 years. Alternatives 1, with two events and 7.5 years' total closure, and 6, with one event and 9 years' total closure, have the greatest potential for community disruption. Alternative 2, with two events and 5.25 years' total closure, has the same overall duration as Alternatives 4 and 5, but the timing is different. It is assumed that light rail will be available for Alternative 2's second construction event, minimizing its impacts on marginalized communities.

As such, rehabilitation and replacement offer similar levels of disruption, with rehabilitation causing less disruption in the short term, but similar disruption in the long term.

A NOTE ON EQUITY

One of the CBA's key findings was that 59 percent of WSHB's current diversion routes are through communities with high representation of people of color (23 to 89 percent) (Figure 22). In some cases, the entire diversion route is through communities of color; in other cases, none of the diversion routes were, or a percentage of the route was. Overall, these communities are currently disproportionately impacted by the bridge closure. It should be noted that WSP recommends further study on impacts to marginalized communities' economies from more than a perspective focused on detour routes through the identified neighborhoods below.

[11] For more information on how we calculated VMT, see Section 3.2.8 Mobility Impacts.

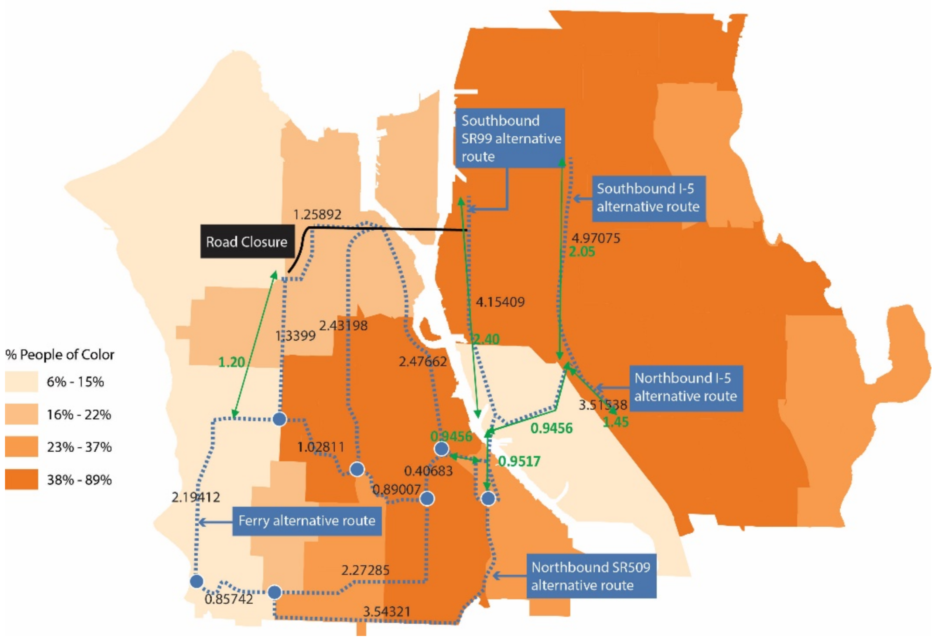

Figure 22. West Seattle Bridge Diversion Routes and Percentage of People of Color by Census Tract

After evaluating all alternatives with regards to these five measurables, we concluded that overall, Alternatives 2, 4, and 5 have the least impact on communities of color. This had to do with both a shorter closure duration and less VMT relative to Alternatives 1 and 6. Alternatives 1 and 6 rated as the least-preferred alternatives, in large part due to longer overall closure durations.[12]

For Equity in general, rehabilitation and bridge replacement alternatives are preferable to shoring and the tunnel replacement alternative.

3.2.5 FORWARD COMPATIBILITY

The Forward Compatibility attribute evaluates each alternative's ability to maintain the current lane configure, as well as each alternative's ability to accommodate light rail. It seeks to answer the questions: Will this rehabilitate/replace concept be compatible with Sound Transit light rail? Will it restore traffic capacity (weight and quantity) to the desired levels?

Subject matter experts from the TAP, SDOT, and WSP scored Alternative 5 (full replacement) as the preferred alternative for this attribute, with an overall score of 8.11.

Measurables	Unit of Measure	Alt #1 Shoring	Alt #2 Rehabilitation	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
Future Roadway Configurations	Maintain a minimum of existing configuration and improve design features (Year)	3 lanes 2024-2029 7 lanes starting 2033	7 lanes starting 2022 (less 2063-2066)	7 lanes starting 2026	7 lanes starting 2026	7 lanes Starting 2030
Accommodate Light Rail	Yes or No: Ability to accommodate light rail by 2032	No	No	Yes	Yes	Yes
SCORE	(1,3,5,7,9)	2.11	5.00	7.00	8.11	5.67

Figure 23. Forward Compatibility attribute's measurables applied to all five alternatives

[12] It is important to acknowledge that there are limitations to the equity framework and definition used in this analysis. A more robust equity analysis and framework that incorporates greater community input and other demographic factors is recommended for future studies.

FUTURE ROADWAY CONFIGURATIONS

This measurable evaluated the time it would take to achieve full standard lane/shoulder widths. To accommodate the necessary shoring structure, Alternative 1 would limit the entire structure to three to five lanes, until the bridge is replaced (opening in 2033). This is the only alternative that would not restore the full seven lanes. Alternative 2 would restore all seven lanes in 2022, which is sooner than both Alternatives 4 and 5. Alternative 6 would be built with all seven lanes, but it would not be open to traffic until 2030.

For this measurable, rehabilitation is preferred.

ACCOMMODATE LIGHT RAIL

Sound Transit's current plan is to build its own structure for the West Seattle to Ballard Light Rail Extension (WSBLE) However, noting the opportunity for synergy between agencies, this measurable examined the technical feasibility of adding light rail to the WSHB structure, now or before 2032, when it is assumed that the WSBLE would be complete. Coordination between Sound Transit and the City has commenced to determine if a joint structure is desired. To date, Sound Transit and SDOT have discussed:

- Design life
- Capital costs
- Sound Transit O&M cost data
- Geometric considerations (vertical curves)
- Seismic design spectra
- Design loads (any plans for future increase?)

In addition to these discussion topics, SDOT has requested the following items from Sound Transit to support the planning of a replacement structure:

- USCG Navigation Impact Report (NIR)
- Topographic surveys and mapping of the ground and waterway
- Geotechnical information logs and borings
- Environmental reports/studies
- Traffic data, forecasting, and modeling used for the WSBLE DEIS
- Preferred alignment drawings and cross sections
- Anticipated construction schedule
- List of planned temporary and permanent property acquisitions

For the purpose of the CBA, WSP assessed which alternatives could accommodate light rail. Alternatives 1 and 2 do not reconstruct the bridge superstructure until after 2032, while Alternatives 4, 5, and 6 would be able to accommodate light rail prior to 2032.

For this measurable, replacement is preferred.

3.2.6 FUNDING OPPORTUNITIES

The CBA reviewed 42 funding and financing options at the federal, state, and local level to compare the likelihood of funding for the rehabilitate or replace alternatives, based on the nature of each design. This attribute seeks to answer the questions: What funding will be available, and what will the potential funding burdens be on local resources and communities? Is this rehabilitate/replace concept eligible for federal, state, local, or emergency funding? See Appendix M for full data on funding opportunities and methodology.

The review focused on near-term (through 2030) funding or financing options. When a definitive answer can be given, such as with eligibility, that will be used. However, many qualitative criteria will be reviewed as high (5), medium (3), or low (1). Overall, none of the alternatives for replacement and/or rehabilitation proved to be significantly more or less favorable to securing funding, with the tunnel option scoring lowest.

Measurables	Unit of Measure	Alt #1 Shoring	Alt #2 Rehabilitation	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
Project eligibility	Yes or No: Count of eligible of funding sources (out of 42)	33	33	33	33	32
Funding revenue generation potential	Historical experience on revenue generation ranges	5.7	5.4	5.7	5.7	5.6
Stability of the funding source	Funding sources are scored based on known continuation, likely continuation, and likely elimination	6.2	5.9	6.2	6.2	6
Likelihood of funding	Historical experience on competitiveness of funding sources and successful probability ranges	1.8	1.7	1.8	1.8	1.7
Timing for availability	Availability of funding using ranges based on typical years to secure funds	6	5.5	6	6	5.8
Administrative requirements	Existing administrative structure in place, incremental requirements, no structure in place	7	6.6	7	7	6.8
Legal authority	Existing legal authority, Legal at the State level but City of Seattle is not authorized, no State or City authorization	7.9	7.5	7.9	7.9	7.7
Income and racial equity	Measure is progressive, progressive or regressive depending on implementation, or regressive	6.5	6.1	6.5	6.5	6.3
SCORE	(1,3,5,7,9)	5.22	5.00	4.78	4.33	3.67

Note: Values shown are the weighted 1 to 9 scores. We applied each measurable to each funding source and then aggregated those scores before applying them to each alternative.

Figure 24. Funding Opportunities attribute's applied to all five alternatives

ELIGIBILITY

This initial criterion evaluated whether each alternative would be eligible to receive funds from each of the identified funding sources. With 42 funding sources evaluated and 33 applicable and available for each of the alternatives, except Alternative 6 with 32 sources, there is no clear preferred alternative.

REVENUE POTENTIAL

This measurable looks at the estimated revenue a given funding source may yield. Revenue potential, coupled with other measurables within this attribute, can help the project sponsor determine whether a funding source is worth pursuing.

Revenue Potential Score

- (5) revenue potential equal to or greater than $75 million
- (3) revenue potential between $26 million and $74 million
- (1) revenue potential equal to or below $25 million

With Alternative 2 receiving a weighted score of 5.4, Alternative 6 receiving 5.6, and Alternatives 1, 4, and 5 each receiving 5.7, replace or shore are the slightly preferred choices for this measurable.

STABILITY/PREDICTABILITY

The predictability of a funding source is scored based on its known future revenue potential. For example, federal funding sources authorized in the FAST Act are only guaranteed through fiscal year 2021. It is possible that the future transportation act will create new requirements and different funding levels for each program, or it may dismantle a program all together. Similarly, other sources, such as gas taxes or value capture revenue, may fluctuate based on various market forces (i.e., lower gas tax revenues due to COVID-19 or vehicle fuel efficiency improvements).

Stability/Predictability Score

- (5) known continuation and stability of a funding source
- (3) likely continuation and stability but possible changes to a funding source
- (1) likely elimination of a program or no future funds available during the project period

With Alternative 2 receiving a weighted score of 5.9, Alternative 6 receiving 6.0, and Alternatives 1, 4, and 5 each receiving 6.2, replace or shore are the slightly preferred choices for this measurable.

LIKELIHOOD OF FUNDING

Looking beyond baseline eligibility, this criterion determines the likelihood of SDOT's securing funds in the near term for the project. This measurable evaluates the likelihood of securing federal discretionary funds by reviewing project competitiveness for each program and assesses the local political/voter appetite for any new fees or revenue sources that may require voter approval. It also determined if existing programs have the capacity to fund new projects, or if funds have already been dedicated to an established program of projects.

Likelihood of Funding Score

- (5) it is highly likely the project will secure funding through this source (~75% or greater)
- (3) it is possible to secure funding
- (1) it is highly unlikely the project will secure funding (~25% or lower)

With Alternatives 2 and 6 receiving a weighted score of 1.7, and Alternatives 1, 4, and 5 each receiving 1.8, replace or shore are the slightly preferred choices for this measurable.

TIMING FOR AVAILABILITY

The timing of funding availability is an important consideration in creating a realistic funding program for the next 10 years. Issues that could impact timing include legislative requirements (such as obligation periods and construction start date requirements), election cycles for new voter-approved levies, or existing funding commitments in approved multi-year capital plans.

Timing for Availability Score

- (5) funding is available within a year
- (3) funding will be available in the next 1 to 5 years
- (1) funding will be available in the next 5 to 10 years

With Alternative 2 receiving a weighted score of 5.5, Alternative 6 receiving 5.8, and Alternatives 1, 4, and 5 each receiving 6.0, replace or shore are the slightly preferred choices for this measurable.

ADMINISTRATIVE AND COLLECTION REQUIREMENTS

All funding sources require administrative oversight, some more than others. Most discretionary programs at the federal, state, and local levels come with a different set of reporting requirements, environmental requirements, and possible local match requirements. Some of these administrative processes can be burdensome for relatively small funding awards. An alternative source of funding, such as a new levy or value capture revenues, can come with a large administrative effort if the project sponsor is looking to create a new program. However, if funding is from an established revenue source, the administrative burden would not be significantly increased by this project.

Administrative and Collection Requirements Score

- (5) the fee or tax is already being collected at some level or otherwise has a low cost of collection/the project sponsor has a dedicated staff person who oversees grant reporting requirements
- (3) administration and collection requirements would entail some degree of incremental hours but not dedicated staff
- (1) administration and collection would require the creation of a costly new mechanism and/or involve many dispersed points of collection with higher associated staffing costs

With Alternative 2 receiving a score of 6.6, Alternative 6 receiving 6.8, and Alternatives 1, 4, and 5 each receiving 7.0, replace or shore are the slightly preferred choices for this measurable.

LEGAL AUTHORITY/AUTHORIZATION REQUIREMENTS

To implement each funding source, the state legislature may be required to authorize the use of the funding mechanism, and the City of Seattle must be authorized to either implement a new tax or fee, and/or be eligible to apply for a funding program administered through the federal or state government.

Legal Authority to Implement Score

- (5) authorized at the state level, and the City of Seattle has legal authority to implement a tax or fee and/or apply for a funding program
- (3) authorized within the state, but the City of Seattle is not directly authorized to use it and/or they must partner with another project sponsor to be eligible to apply for a funding program
- (1) not authorized within the State and, as such, City of Seattle has no authority to implement the tax or fee, and/or they are ineligible to apply for a federal or state funding program

With Alternative 2 receiving a weighted score of 7.5, Alternative 6 receiving 7.7, and Alternatives 1, 4, and 5 each receiving 7.9, replace or shore are the slightly preferred choices for this measurable.

EQUITY IMPACTS

Any funding strategy for the rehabilitation and/or replacement of the WSHB has to consider mitigating the impact on low-income households. Washington State has the most regressive tax structure in the nation, with a disproportionate tax burden falling on the lowest income groups. Any funding mechanisms for infrastructure should be evaluated within the context of reducing or mitigating the disproportionate burden on low-income households include user fees, tolls, property taxes, and sales taxes.

Equity Impact Score

- (5) progressive and burden increases with income level
- (3) measure is progressive or regressive, but the implementation of the measure could include items that would allow for the measure to be applied more regressively/progressively (examples: toll exemptions for low income users, corporate exemptions for a head tax)
- (1) regressive and disproportionately impacts low income communities

With Alternative 2 receiving a weighted score of 6.1, Alternative 6 receiving 6.3, and Alternatives 1, 4, and 5 each receiving 6.5, replace or shore are the slightly preferred choices for this measurable.

3.2.7 BUSINESS AND WORKFORCE IMPACTS

Business and Workforce Impacts is an attribute that demonstrates the criticality of the impacts on the maritime and Port of Seattle industries, among others. We evaluated impacts to vicinity businesses, including short- and long-term workforce impacts, based on the duration of closure, as well as additional construction impacts. While overall closure durations are similar for Alternatives 2, 4, and 5, Alternative 2 assumes that replacement construction would be in 2066, at which time light rail access would have an impact on vehicle travel.

Subject matter experts from the TAP, SDOT, and WSP scored the baseline, Alternative 2 (rehabilitation), as the overall preferred alternative for this attribute.

Measurables	Unit of Measure	Alt #1 Shoring	Alt #2 Rehabilitation	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
Bridge Closures Impacts	Trip reduction x discretionary spending per trip (could impact BIPOC-owned businesses)	Net reduction of $3.5 million	Net increase of $6.7 million	Net reduction of $0.9 million	Net reduction of $0.9 million	Net reduction of $2.2 million
Direct/Indirect Economic Construction from construction	Capital expenditures	7,451 FTEs	7,976 FTEs	6,766 FTEs	9,548 FTEs	15,108 FTEs
Temp Const. Easements	Number/duration of TCE's (could impact BIPOC-owned businesses)	1 TCE for 1 yr + Alt 5 TCEs for 3.67 yrs	1 TCE for 1 yr + Alt 5 TCEs for 3.67 yrs	1 large TCE for 3.83 yrs	2 TCEs for 3.67 yrs	Many TCEs for 5.5 yrs
Utility interruption	# of times impact utilities on and under bridge	For Demo and new bridge construction (Alt 5)	For Demo and new bridge construction (Alt 5)	For Demo and new bridge between piers 15-18	For Demo and new bridge between piers 13-18	Major permanent and temp impacts including overhead transmission lines over Duwamish as well as distribution lines.
Access impacts to local properties	Impacts to existing property access during construction and final configuration	No restrictions	Min. restriction during construction to S. Harbor Island via SW Manning	Potential restrictions to S. Harbor Island via SW Manning	Potential restrictions to S. Harbor Island via SW Manning	Severe restrictions to on Harbor Island and near west portal
Economic and Workforce Impacts on Regional Industry	50% Quantitative: VHT x economic value per VHT and jobs attributed to the change in economic output 50% Qualitative: Perceived risk of long-term construction closures	3,194 FTEs Low Risk	4,687 FTEs Medium Risk	2,071 FTEs Low Risk	2,071 FTEs Low Risk	2,867 FTEs Low Risk
SCORE	(1,3,5,7,9)	3.89	5.00	3.89	2.33	1.67

Note: FTE stands for full-time employee; this is a measurement of construction- and maintenance-related job creation.

Figure 25. Business and Workforce Impacts attribute's measurables applied to all five alternatives

We expect that the change in travel patterns due to the WSHB closure will affect how and where residents and commuters in West Seattle spend their household income on goods and services. The closure primarily affects commuter and personal trips between West Seattle and the rest of Seattle; the increase in trip length and travel time is expected to increase home-based work and local trips, while discouraging longer trips to other areas of Seattle.

Based on the traffic data detailed in the Mobility Impacts attribute, the change in trips associated with each alternative also represents a shift in spending behaviors throughout the Seattle area, affecting businesses and employment opportunities at the neighborhood level. Figure 26 shows several, though not all, of the local business areas in West Seattle that may be impacted; businesses east of West Seattle are also likely to be impacted by West Seattle residents' limiting discretionary trips.

The long-term changes in household expenditures throughout the Seattle area could significantly change the local economy, including business investment, business diversity, spending patterns, and employment opportunities and access. Latent effects of the closure could include a disruption in opportunistic spending, the interchangeability of retail purchases and value-added goods and services, and the shift from brick-and-mortar retail to online retail. For example, a shift from vehicle to pedestrian traffic in West Seattle could result in higher spending on local retailers, hospitality establishments, and service businesses by residents, but less spending by non-resident consumers.

In addition, the detour routes and changes in road congestion resulting from the closure could affect the supply chains of businesses operating in and around the West Seattle area, potentially resulting in long-term closures or reduced operations, specifically in the Duwamish valley. Negative impacts will likely disproportionately impact smaller businesses and independent operators who have less resources to mitigate the financial impacts from a long-term closure. According to a survey of truckers serving the Port of Seattle, conducted by the City of Seattle and Port of Seattle, 81 percent are independent owner-operators, many of whom associate with minority communities. The Business and Workforce Impacts attribute considers the disproportionate economic impact faced by smaller employers or independent operators through the business categories and income levels included in our quantitative analysis, as well as in the qualitative evaluation

It is important to note that many of the Business and Workforce Impacts could be viewed as positive or negative, as local businesses may see increased spending while businesses outside of the immediate vicinity could see decreases in spending.

BRIDGE CLOSURE IMPACTS

Using the breakdown of average household expenditures provided in the Consumer Expenditure Survey published by the Bureau of Labor Statistics, we can attribute an estimated 7 percent of expenditures of an average household in the West region to commuter and recreational trips between West Seattle and other areas of Seattle.

The affected population's annual expenditures were divided by the number of annual trips they would have taken, and an approximate dollar value per trip was calculated. We estimated average annual household expenditures at $69,981. Expenditure groups included food prepared by consumers on out-of-town trips; food away from home; gasoline, other fuels, and motor oil; fees and admissions; and apparel and services. We used these expenditures as a subset for estimating the impact – a total $9,589, or 13.7 percent of total annual household expenditures. Assuming an average of two wage earners per household in West Seattle, the average percent impact per household earner would be half or $4,829 (6.9 percent).

The average number of trips per household is 1,500, with approximately 45 percent attributed to local discretionary trips. Dividing the amount of expenditures per person by the number of trips results in an average expenditure per trip of $7.15. We then multiplied the dollar per trip amount by the net change in trips for each of the alternatives.

Alternative 2, the rehabilitation alternative, shows a net increase of $6.7 million, while both bridge replacement alternatives show a net reduction of $0.9 million. Alternative 1 shows a net decrease of $3.5 million, and the final replacement alternative, Alternative 6, shows a net reduction of $2.2 million.

In the case of this measurable, rehabilitation is the better option.

DIRECT/INDIRECT ECONOMIC CONSTRUCTION IMPACTS

The positive impacts of additional spending related to construction activities include direct and indirect employment and business expenditures in the regional economy. The analysis of the economic impact of construction activities, independent of the consumer spending changes outlined above, tracks the transactions linked to regional labor and materials expenditures. These direct expenditures on labor and materials support employment in the supplier market and the goods and services market. Direct expenditures are in turn supported by employee household expenditures, resulting in indirect employment and economic output.

Using the IMPLAN economic analysis software, we calculated direct and indirect employment, labor income, and economic output from construction-related expenditures for construction and operations of each alternative.

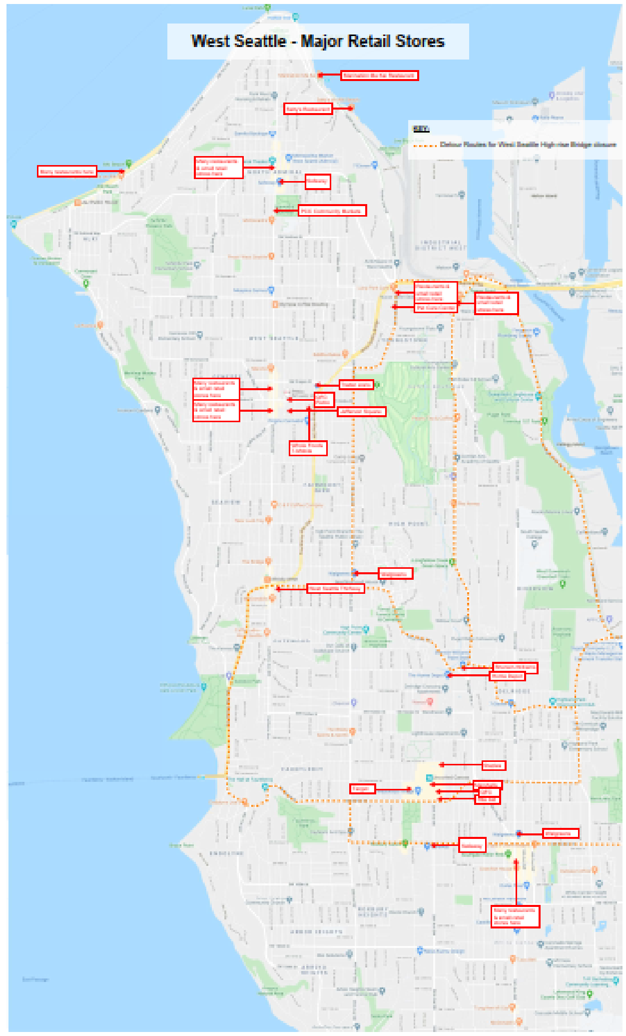

Figure 26. Major Retail Outlets in West Seattle

With the potential for 15,108 FTEs, Alternative 6 offers the greatest positive impacts, with Alternative 5, at 9,548 FTEs, as second best. With 6,766 FTEs, Alternative 4 offers the least. Alternatives 1 and 2 could bring, respectively, 7,451 and 7,976 FTEs.

For this measurable, full replacement is the best option, with the tunnel offering the most FTEs during construction.

TEMPORARY CONSTRUCTION EASEMENTS

The temporary construction easements (TCEs) measurable evaluated the assumed space necessary for construction, as well as an approximate construction duration for each alternative (Figure 27 to Figure 31). For all alternatives, we assumed that the space under the east approach would not require a TCE, while the west approach would. These evaluations did not consider waterway impacts.

Figure 27. Temporary construction easements that would be required for Alternative 1

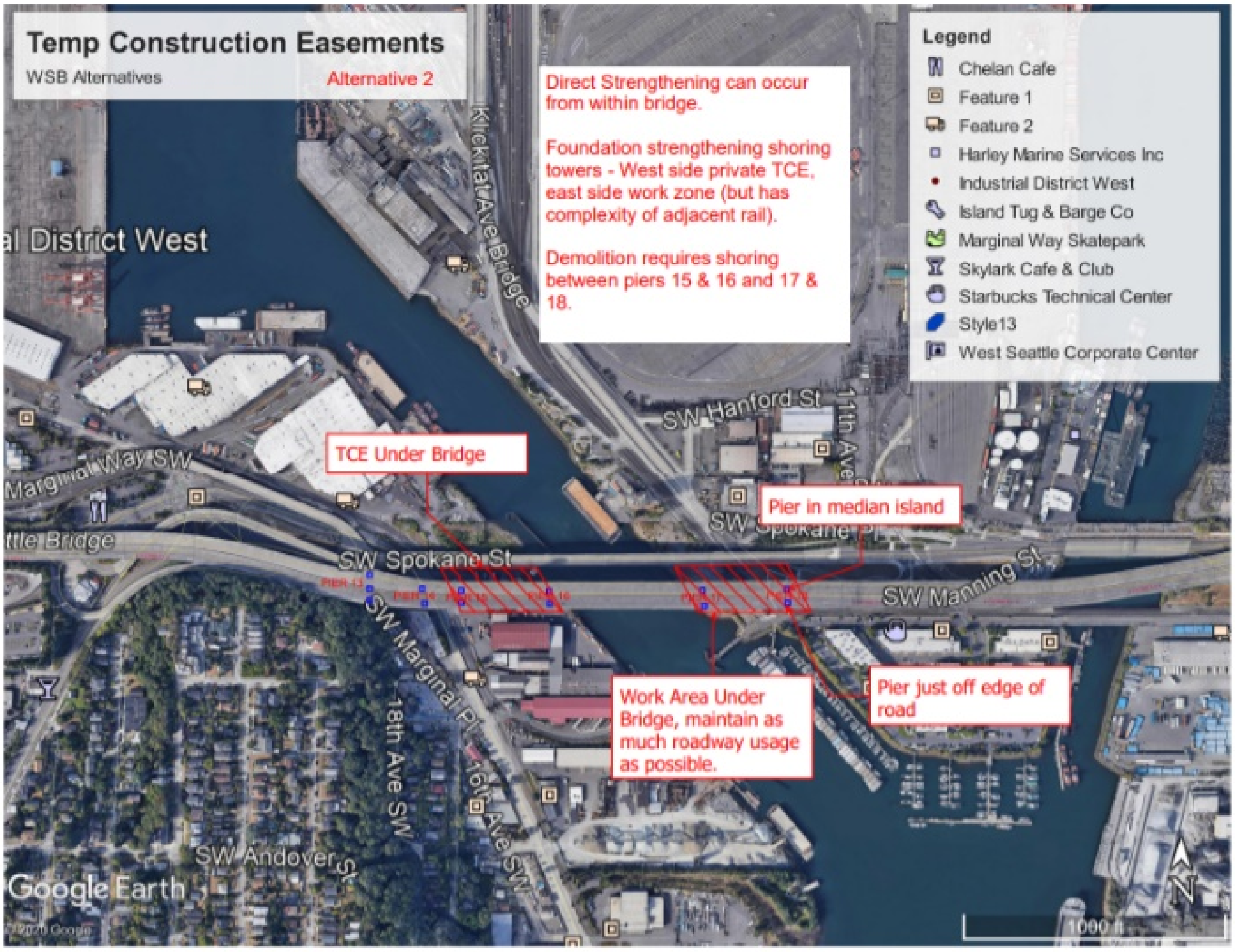

Figure 28. Temporary construction easements that would be required for Alternative 2

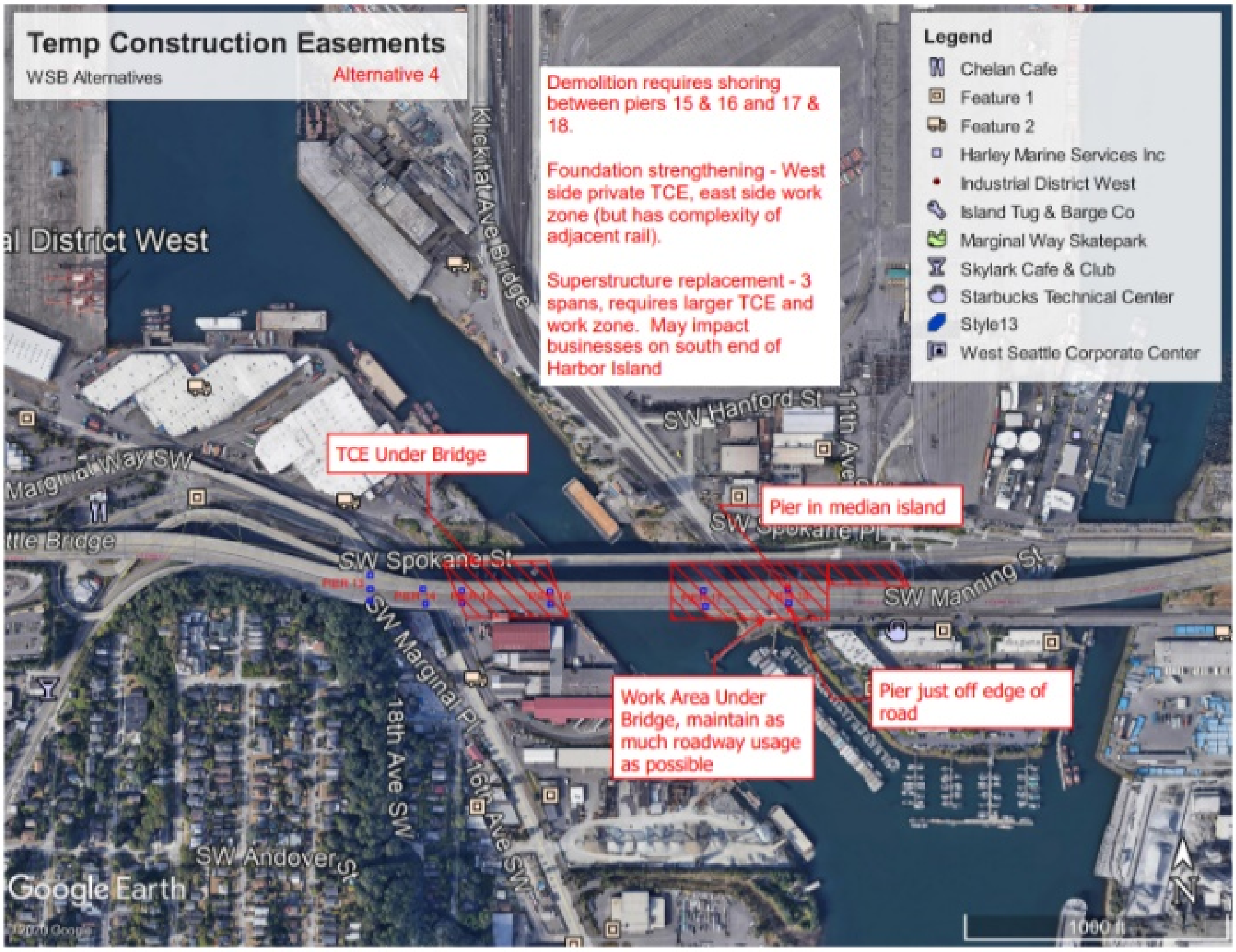

Figure 29. Temporary construction easements that would be required for Alternative 4

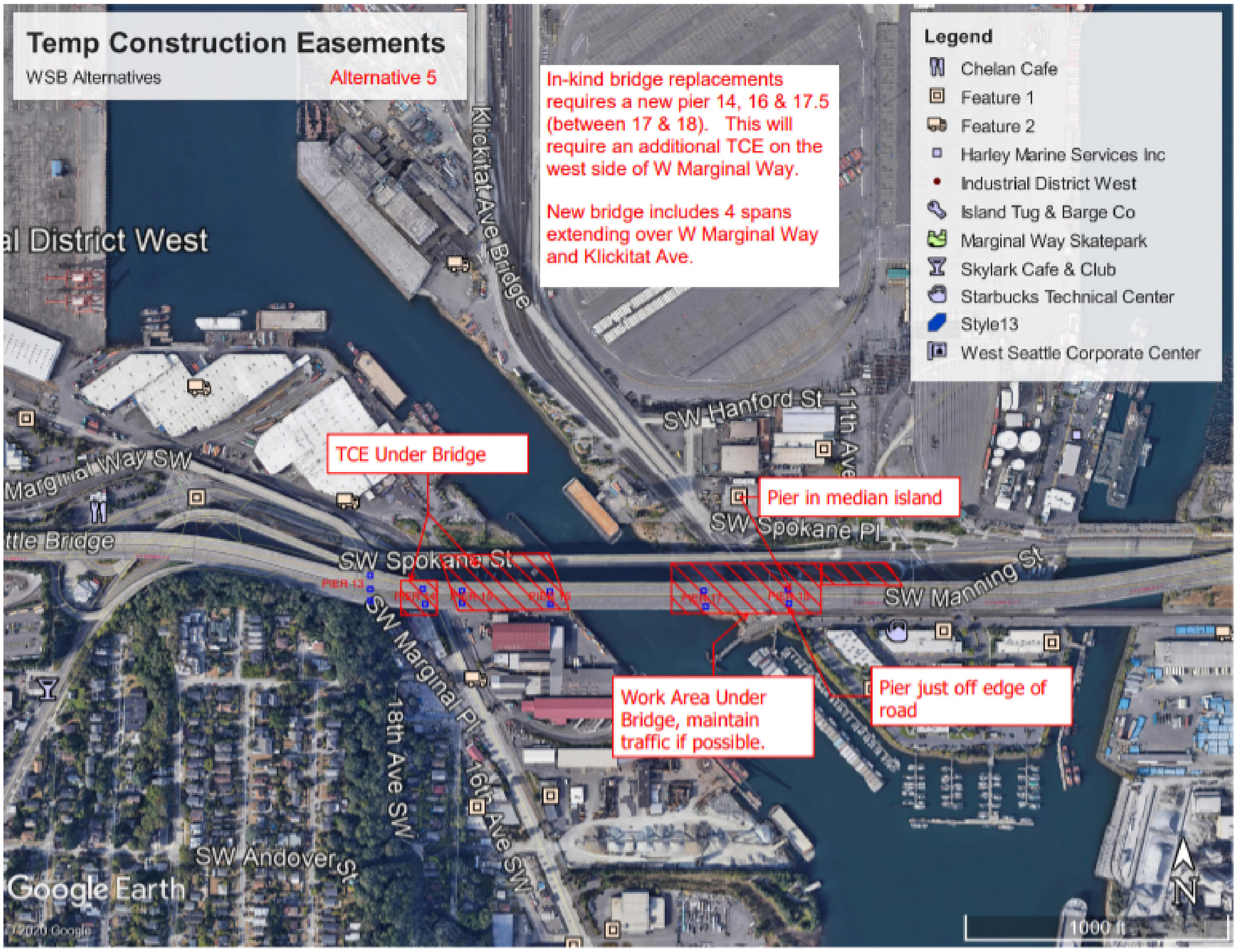

Figure 30. Temporary construction easements that would be required for Alternative 5

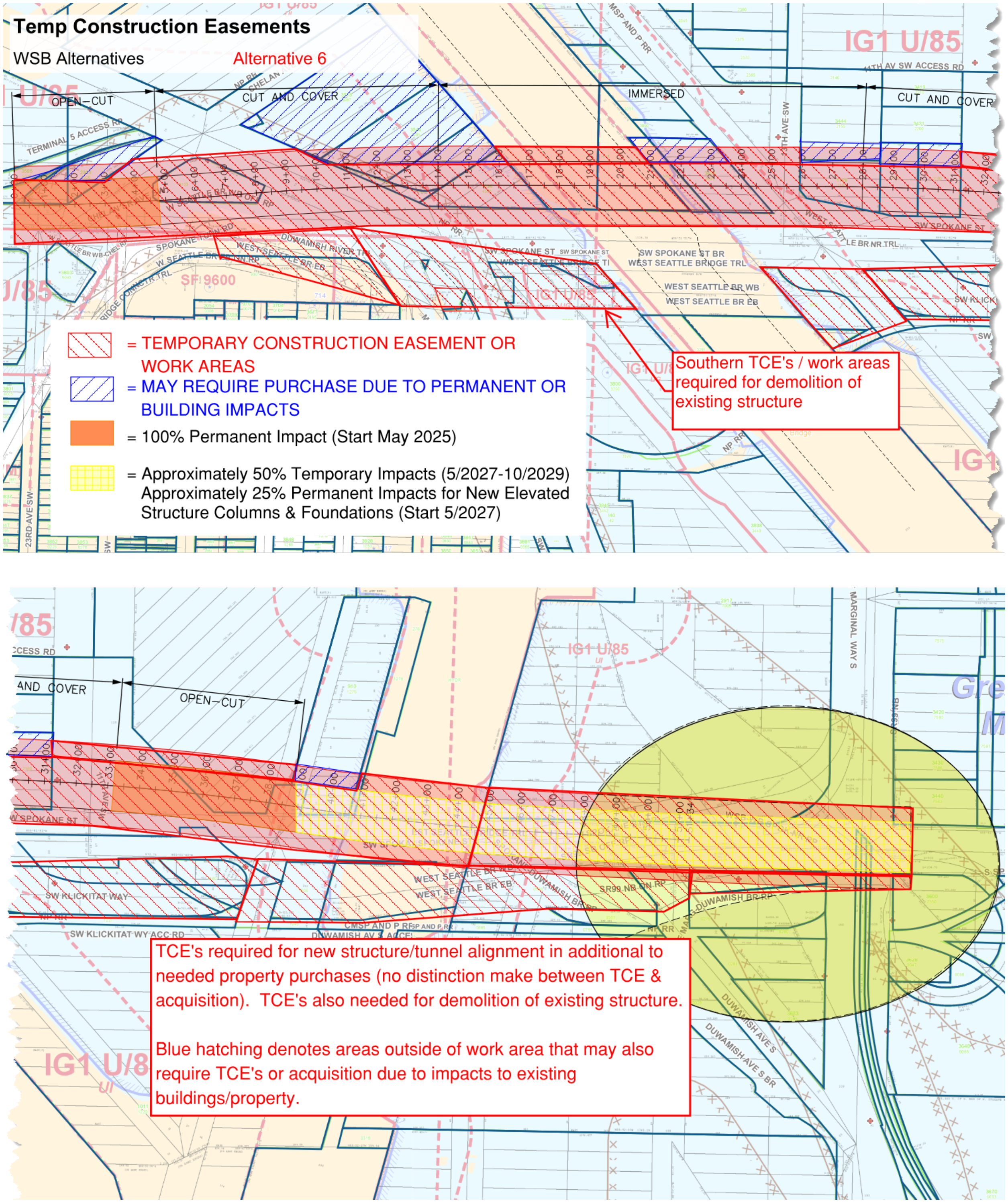

Figure 31. Temporary construction easements that would be required for Alternative 6

For Alternatives 4 and 5, the durations of 3.83 years and 3.67 years are very similar; however, Alternative 5 would require an additional TCE across West Marginal Way, as that alternative would require six spans rather than three. Alternatives 1 and 2 have similar TCE requirements: a TCE of one year for preliminary work, and then the same TCE requirements for Alternative 4 or 5. However, Alternative 1 would not require the same demolition TCE for shoring for the full bridge replacement, as demolition could occur from gantry cranes and a barge. Alternative 6 would require the most TCEs for the longest duration – multiple TCEs over an estimated 5.5 years.

For this measurable, replacement, with the exception of Alternative 6, is the better option.

UTILITY INTERRUPTION

Utility interruptions for the on-bridge utilities include the control cables for the Spokane Street swing bridge; WSHB navigation lights, power, drainage and fire protection; and fiber lines for various communication companies. The main power transmission crosses the Duwamish north of the bridges, and should therefore not be impacted; however, there are numerous overhead distribution lines on either end of the bridge that will likely be impacted (see Figure 32). The CBA did not investigate underground utilities on the east and west sides of the bridge. We assumed that early work would not impact utilities; however, the ultimate replacement of the bridge would.

The Alternative 5 bridge replacement (and thus Alternatives 1 and 2, which would require a first phase followed by a full replacement) would have more impact on utilities due to the expanded limits of construction. Alternative 6 would necessitate major permanent and temporary impacts utilities. Overhead transmission lines crossing the Duwamish, as well as distribution lines, would further complicate these impacts. Further evaluation is required to identify all underground utilities, and construction methods should be analyzed for a true comparison.

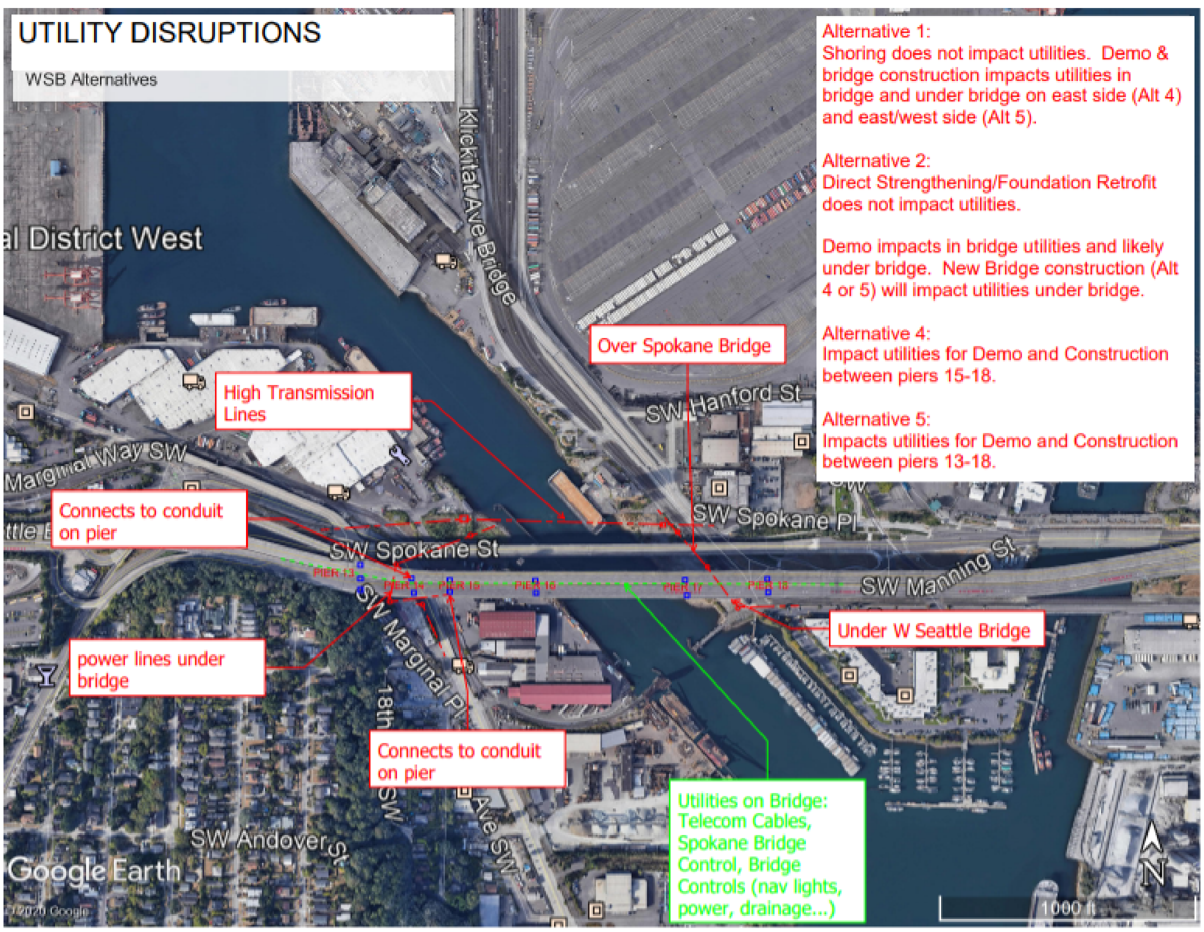

Figure 32. All alternatives require some level of utility disruptions, during demolition, construction, or both

With interruptions to utilities for demolition and new bridge construction in an expanded footprint, Alternatives 1, 2, 5, and 6 are the most impactful, while Alternative 4, with interruptions for demolition and construction between Piers 15 and 18, is less so. For this measurable, there is no clear winner between shore and replace (with the exception of Alternative 6).

ACCESS IMPACTS TO LOCAL PROPERTIES

This measurable evaluates impacts to property access during construction and then in final configuration. It should be noted that access impacts would also affect bicycles and pedestrians. We based these impacts on the TCEs assumed necessary for each alternative (see Figure 27 to Figure 31).

We assumed that the work zones for Alternative 2 would not extend into West Marginal Way or Klickitat Avenue, with no additional restrictions. However, the TCEs for Alternative 1, which requires shoring between Piers 15 and 16 and Piers 17 and 18, could impose some restrictions to South Harbor Island along SW Manning.

Alternatives 4 and 5 both include shoring extending into Klickitat Avenue, with Alternative 5 including a bridge replacement over Klickitat Avenue. While the south end of Harbor Island would still be accessible from the east side of the island, the west entrance via SW Manning would likely be closed or restricted. Alternative 1, as well as Alternatives 4 and 5, would likely require laydown space between Klickitat Avenue and 11th Avenue, impacting some elements of the WSHB Trail at the south end of Harbor Island. Future studies will need to further evaluate the trail connections. As it would keep current foundations, Alternative 4 would be less impactful to properties than Alternative 5.

Building the portals for Alternative 6 on Harbor Island and near the west portal would create severe restrictions to property access on both sides of the Duwamish River.

The results of this qualitative evaluation indicate that shoring or a bridge replacement is the preferred alternative for minimizing access impacts to local properties.

ECONOMIC AND WORKFORCE IMPACTS ON REGIONAL INDUSTRY

WSP developed this measurable, especially relevant to maritime industry, in conjunction with the CTF and SDOT after receiving feedback at the September 9 CTF meeting. The WSHB closure significantly impacts the movement of traffic throughout the region. Evaluating the specific near- and long-term economic impacts on the Port of Seattle and industry along the Duwamish River is crucial. We used a combination of quantitative and qualitative evaluation to assess the impact on the local industrial and maritime economy.

WSP evaluated regional models to understand and quantify impacts on the freight traffic that supports operations at the Port of Seattle and industry along the Duwamish River. The geography assessed for the metric included Harbor Island, Industrial District West (Terminal 5), and businesses on both banks of Duwamish River, extending south, to the First Avenue South drawbridge.

We established the geographic coverage based on the Puget Sound Regional Council’s (PSRC) 1K zonal system. Medium and heavy truck trip activity to and from the area served as a proxy to establish maritime business impacts. This included calculating the change in vehicle hours traveled (VHT) for medium and heavy trucks. Future studies could assess individual quadrants in the selected geography, based on overall results of truck VHT.

To capture travel time-related delays, we can use the USDOT standardized values for value of time for passenger vehicles and freight drivers cited in the WSHB Economic Impacts Memo.[13]

The Transportation Research Institute recommended a full marginal cost values, including the value of freight to be closer to $66.70 per hour of travel time in 2017 dollars. Furthermore, adjustments for freight vehicle value of reliability considers the incremental travel time built into delivery schedules to account for potential delay beyond the modeled VHT impacts. Using the 95th percentile delay, the National Cooperative of Highway Research Program Research Report 925 recommends $160 per shipment per hour or $9.40 per ton per hour.

Using the change in freight vehicle-hours traveled for each alternative and the value of time for freight truck drivers, we estimated that the annual economic cost resulting from travel delays would be between $0.7 million and $1.2 million per year. Adding the impact of the overall shipment costs would bring the annual costs to close to $3.0 to $4.0 million and with travel time reliability could potentially double the cost range, although further analysis would

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Vehicle Type	Value of Time ($2018/PHT)
Passenger Vehicles	$16.60/hour
Delivery Vehicles	$27.10/hour
Commercial Vehicles	$29.50/hour

be required to verify specific economic cost values. These do not include the travel delay for non-freight vehicles traveling through the project area.

The quantified economic impact of any change in freight traffic can be estimated using industry-level data from the IMPLAN economic impact analysis software and the forecasted changes in VHT. For the analysis, the economic output of industries operating on the Port of Seattle facilities in the Industrial District, Industrial District West and Harbor Island areas, including wholesale retailers, water transportation services and manufacturing services, can be proportionally attributed to the representative freight trips. The economic categories included are consistent with the economic categories evaluated by the City of Seattle as part of the Industrial Lands Land Use and Employment Study conducted in 2017. We measured the relative economic output attributed to the Port of Seattle and other industrial and commercial facilities on a per-unit basis of VHT; a change in the values for freight trips would be equivalent to a change in direct economic output by those businesses, which relates to the direct employment of those operations.

Economic Impact of West Seattle High-Bridge Closure - Summary

	Alternative #1	Alternative #2	Alternative #4	Alternative #5	Alternative #6
Total Economic Output in Study Area w/ Project (nominal $)	$1,334,571,000,000	$1,336,139,000,000	$1,335,622,000,000	$1,335,622,000,000	$1,334,908,000,000
Total Industry Employment in Study Area w/ Project (total job-years)	3,764,007	3,759,229	3,767,604	3,767,604	3,765,054
Estimated Total Economic Output Impacted by Freight Delays (nominal $)	$2,803,000,000	$1,235,000,000	$1,752,000,000	$1,752,000,000	$2,466,000,000
Average Annual Economic Output Impacted by Freight Delay	$200,214,768	$112,294,200	$250,290,476	$250,290,476	$246,557,774
Average Annual Impacted Economic Output per Freight Vehicle-Hour	$602.31	$251.29	$1,198.00	$1,198.00	$832.30
Estimated Total Employment Impacted by Freight Delays	10,227	15,005	6,631	6,631	9,181
Average Annual Employment Impacted by Freight Delay	731	1,364	947	947	918
Percentage of Annual Industry Employment in Study Area Affected by Freight Delays	0.9%	1.8%	1.2%	1.2%	1.2%
Estimated Total Change in Freight Vehicle-Hours	332,410	446,865	208,924	208,924	296,237
Annualized Change in Freight Vehicle-Hours	23,744	40,624	29,846	29,846	29,624
Total Economic Cost of Travel Delays (at $29.50/hour)	$9,806,087	$13,182,513	$6,163,246	$6,163,246	$8,738,979
Annualized Economic Cost of Travel Delays (at $29.50/hour)	$700,435	$1,198,410	$880,464	$880,464	$873,898

Figure 33. Economic Impact of WSHB Closure based on IMPLAN analysis

The overall impact of the freight delays on the percent of annual industry employment in the study area is relatively minor, at 1.8 percent in the worst-case scenario (Alternative 2). However, total economic output impacted by freight delays would be the highest under Alternatives 1 and 6, largely due to construction timing and duration.

The IMPLAN software evaluates only the total economic output and employee compensation of the businesses within the study area; therefore, it may not capture the total value of economic output if the businesses providing those goods and services are located outside of the study area. Further qualitative considerations were made based on the perceived risk on long-term employment of maritime businesses operating in the identified area.

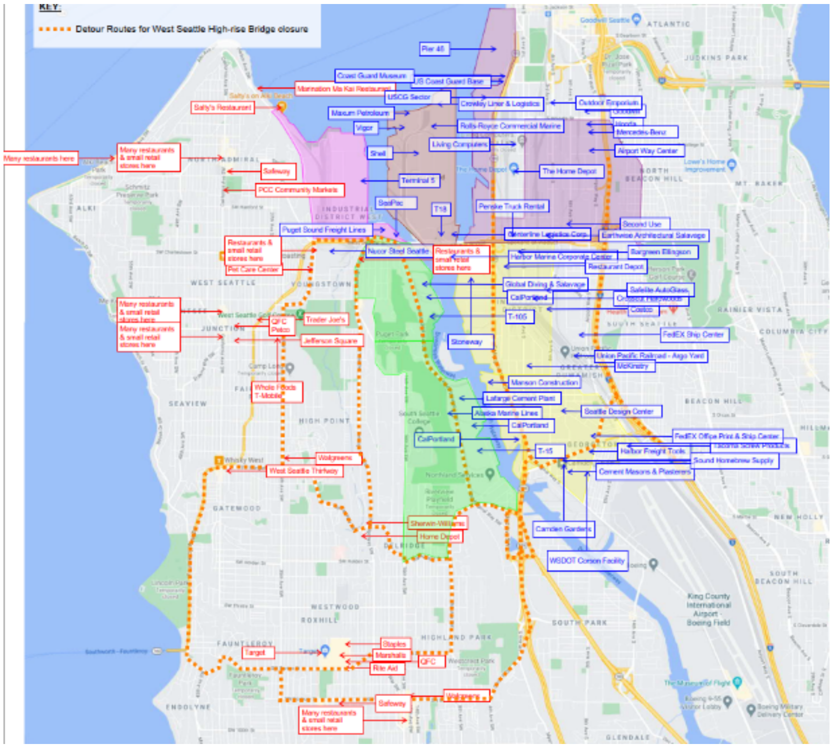

Figure 34. Map of Major Employers

We evaluated risk based on the closure duration and the perceived operational dependency on both the WSHB and the Lower Bridge. Figure 34 indicates the location of major employers with the specific subareas that were evaluated for changes in traffic patterns and increased VHT.

We determined that employers located in the yellow and green subareas were most at risk of long-term economic impacts from prolonged construction closures; however, some of the employers are in the construction sector and could potentially directly benefit from construction work. Employers on Harbor Island and the northeast and northwest subareas were the least exposed to long-term economic impacts, as they would see only minor changes to VHT based on the construction closures, and in some cases would benefit from lower VHT due to lower congestion as passenger vehicles reroute to other arterials.

Scoring was based on a 50 percent qualitative and 50 percent quantitative weighting, with the former based on impact to job losses as compared to the baseline Alternative 2, and the latter based on perceived risk, as measured by the number of businesses severely impacted by the anticipated closure durations in each of the identified subareas. Based on the results, Alternative 2 has the largest potential impact on jobs, as well as a medium risk of business closures. Alternatives 4 and 5 show the least potential impact on employment and a low risk of closures, and Alternatives 1 and 6 fell in between. In all of the alternatives, the southwest and southeast subareas were at the highest risk.

Replacement, with the exception of Alternative 6, is the preferred option for this measurable.

3.2.8 MOBILITY IMPACTS

The Mobility Impacts attribute seeks to measure the effects of construction and the bridge closure on regional mobility, including travel times, routes and mode shifts, as well as increased mobility once the crossing is reopened.[14]

[14] A note on methodology: For purposes of modeling traffic impacts from the WHSB closure, WSP leveraged the PSRC model using regional land use vision forecast (LUV.2), using the Puget Sound Gateway program with tolling, and the Sound Transit WSBLE service in 2032. WSP was able to validate model results with the Port of Seattle-provided Dynamic Traffic Assignment (DTA) model output. The PSRC outputs are

Subject matter experts from the TAP, SDOT, and WSP determined that the baseline, Alternative 2 (rehabilitation), was the overall preferred alternative for this attribute.

Measurables	Unit of Measure	Alt #1 Shoring	Alt #2 Rehabilitation	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
Travel Time	Cumulative PHT during construction and PHT in final configuration	42.9 million more hours	40.0 million more hours	30.1 million more hours	30.1 million more hours	40.3 million more hours
Travel Distance	VMT x duration during construction and VMT in final configuration	563.9 million more miles	353.6 million more miles	398.8 million more miles	398.8 million more miles	551.5 million more miles
Non-Vehicle Trips	Trips (mode shift to bikes from car) during construction. This is a health benefit.	60.9 million more bike/ped trips	45.7 million more bike/ped trips	44.1 million more bike/ped trips	44.1 million more bike/ped trips	58.3 million more bike/ped trips
Regional Mobility Impacts	Impacts to other regional construction projects. Does other construction occur when bridge is closed?	E Marginal: bridge closed; WSBLE: ½ during bridge closure	E Marginal: ½ during bridge closure; WSBLE: bridge open	E Marginal: bridge closed; WSBLE: bridge open	E Marginal: bridge closed; WSBLE: bridge open	E Marginal: bridge closed,; WSBLE: > ½ during bridge closure
Safety	Expected crashes/VMT on detour routes during WSHB/tunnel closure	553 more crashes	347 more crashes	391 more crashes	391 more crashes	541 more crashes
SCORE	(1,3,5,7,9)	3.00	5.00	4.11	3.89	2.33

Figure 35. Mobility Impact attribute's measurable applied to all five alternatives

TRAVEL TIME

Vehicle Person Hours Traveled: We calculated vehicle PHTs by multiplying the passenger volumes by mode with time spent traveling in the four-county PSRC region. This measure captures the effect of congestion/delay during peak periods. We calculated PHTs assuming a 2+HOV[15] occupancy factor of 2.4. We considered all auto modes in the PSRC model: SOVs[16], 2+HOVs, light trucks, medium trucks, and heavy trucks.

Transit Passenger Hours Traveled: We derived transit PHT by multiplying the transit passenger volumes on a transit segment with transit travel times in the four-county PSRC region. This measure accounts for transit mode shift and delays associated with the bridge closure. It includes both bus and rail passengers, as we expect that the bridge closure would impact rail passenger volumes as much as buses.

Bike and Pedestrian Hours Traveled: These hours primarily increase as a result of a mode shift to active transportation methods, including cyclists who have access to the lower bridge crossing, and increased pedestrian traffic as more work and recreational trips are occurring close to home. Increased bike and pedestrian PHT can be seen as a benefit.

The variance in travel time from the no-build base to the selected alternative base for the modeled years are annualized and then interpolated between years to derive an annual forecast. We made further adjustments for COVID-19 impacts on travel behavior and major capital projects that are anticipated to impact travel behavior to/from West Seattle, such as Sound Transit's West Seattle to Ballard Link Extension (WSBLE). Resulting annual variances are applied only for the years when the bridge is closed for construction.

While Alternatives 1, 2, and 6 have increases of approximately 41 million hours, Alternatives 4 and 5 see increases of approximately 30 million hours. For this measurable, replace (with the exception of Alternative 6) is the better option.

TRAVEL DISTANCE

Vehicle Miles Traveled: We calculated VMT by multiplying the daily vehicle volumes of a road segment with its mileage. It includes freeways, arterials, and local roads in the four-county PSRC region by the following auto modes: SOVs, 2+ HOVs, light trucks, medium trucks, and heavy trucks.

Transit Vehicle Miles Traveled: Similar to auto VMT except calculated for transit vehicles. This calculation includes only buses; for the purpose of this study, transit VMT does not include rail-car miles traveled. Again, increased transit use is often considered a positive effect. WSP recommends that rail-car impacts and VMT be explored in future studies.

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approximately 16 percent higher than the DTA results for the primary Duwamish crossings. The higher volumes used in the analysis are largely due to the DTA model's timing, which was developed in 2014, prior to the higher than expected growth experienced in the past six years.

[15] HOV=high-occupancy vehicle
[16] SOV=single-occupancy vehicle

Corridor Level VMTs: We estimated corridor-level VMTs for the identified detour routes. We then calculated daily VMTs by multiplying the corridor length with daily auto volumes at a representative location. Some corridors leading to the bridge will see a reduction in vehicular traffic due to the closure and could show a reduction in VMT.

Similar to travel time, the variance in travel distance from the no-build base to the selected alternative base for the modeled years is annualized and then interpolated between years to derive an annual forecast. We made further adjustments to account for COVID-19 impacts on travel behavior and major capital projects that are anticipated to impact travel behavior to and from West Seattle – such as the completion of Sound Transit's WSBLE (assumed to be complete by 2032). We applied the resulting annual variances only for the years when the bridge would be closed.

Alternative 1 increases travel distance by 564 million miles; Alternative 6 increases travel distance by 551.5 million miles; Alternatives 4 and 5 increase travel distance by 399 million miles; and Alternative 2 increases travel distance by 354 million miles. These results indicate that rehabilitation is the preferred alternative for the travel distance measurable.

NON-VEHICLE TRIPS

One of the more noticeable impacts from the combination of the WSHB closure and COVID-19 was the shift in transportation modes from driving to walking and biking. There is a quantified and monetized approach for calculating the health benefits from more active forms of transportation. For the purposes of this study, we used the non-vehicle trips calculated in the PSRC model as the basis for the non-vehicle adjustment factor and scoring.

Alterative 1 increases non-vehicle trips increase by 60.9 million trips. Alternative 6 sees non-vehicle trips increase by 58.3 million trips. Alternative 2 is slightly lower at 45.7 million, and Alternatives 4 and 5 are 44.1 million more trips.

This is a multifaceted measurable. On the one hand, increased non-vehicle trips are better for the environment from an emissions standpoint and better for humans from a health standpoint. However, an increase in non-vehicle trips also indicates that mobility via vehicle has been reduced.

Because of the complexity of the measurable, as well as the similarity in results for Alternatives 2, 4, and 5, this measurable has no clear "winner" as pertains to the rehabilitate versus replace decision.

REGIONAL MOBILITY IMPACTS

The Regional Mobility Impacts measurement evaluated how the timing of the WSHB closure could impact other regional projects due to more surface street traffic. For example, the CBA assumes that SDOT's East Marginal Way project will be in construction between 2021-2023, and that Sound Transit's WSBLE would be in construction between 2027-2032.[17] If the bridge is closed during work on these projects, the surface streets on either side of the Spokane Street lower ridge will likely see heavier-than-usual traffic.

Comparing the preliminary construction schedules for each alternative with the assumed construction periods for both the East Marginal Way and WSBLE shows that the WSHB would be closed during the East Marginal Way construction for Alternatives 1, 4, and 5. For Alternative 2, the bridge would be closed for only half of the East Marginal Way construction, which is more desirable.

For Alternatives 1 and 6, the WHSB would be closed for half of the construction for the WSBLE construction. Alternatives 2, 4, and 5 would be open during construction on that project, lessening the traffic impacts on nearby surface streets. Based on these assumed schedules, Alternative 2 would have less impact on construction of these other regional projects.

Rehabilitation is the preferred alternative for this measurable, as it would allow the WHSB to be open for half of East Marginal Way construction and all of WSBLE construction. Shoring and a tunnel replacement would be the most impactful, while bridge replacement would be in the middle.

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[17] SDOT's E Marginal Way project and Sound Transit's WSBLE project are not yet fully funded or in construction. WSP has assumed that they will be under construction during these years, but neither the projects nor the dates/durations are definitive as of October 2020. WSP recommends that future studies address this once more detail is known about these projects.

SAFETY

Subject matter experts evaluated safety by reviewing the existing collisions and five years of history along the City-identified diversion routes on the West Seattle side of the Duwamish River. We then applied the increase in VMT to identify the potential for additional crashes versus the crashes expected if the West Seattle bridge were open.

Safety was estimated as 541 more crashes with Alternative 6, 553 more crashes in Alternative 1, 347 in Alterative 2, and 391 more crashes in Alternatives 4 and 5. As such, both rehabilitation and replacement are safer than shoring, but rehabilitation is slightly safer than the bridge replacement options. Replacement Alternative 6 is less safe than shoring.

3.2.9 MULTIMODAL IMPACTS

The Multimodal Impacts attribute evaluates impacts to emergency vehicles, freight, and transit during construction, as well as impacts to pedestrians and bicycles in the final configuration. This attribute seeks to answer the questions: Does this replace/rehabilitate concept facilitate or improve the movement of people and goods by all modes? How will it impact current multimodal traffic?

Because the WSHB does not accommodate bicycles or pedestrians and is not expected to in the future, regardless of the alternative, all alternatives were scored the same for these measurements. Section 4.2.7 Business and Workforce Impacts *Access Impacts to Local Properties* evaluates potential impacts to bike and pedestrian access as a result of construction along West Marginal Way and Klickitat Avenue.

Subject matter experts from the TAP, SDOT, and WSP scored Alternative 4 (superstructure replacement) as the preferred alternative for this attribute, with an overall score of 6.78 relative to the baseline.

Measurables	Unit of Measure	Alt #1 Shoring	Alt #2 Rehabilitation	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
Incremental Transit Service during Construction	Increase transit capacity	1,280 daily units	753 daily units	982 daily units	982 daily units	1,283 daily units
Bicycle Traffic Accommodation	High/med/low (no bike accommodation on bridge)	Low	Low	Low	Low	Low
Pedestrian Traffic Accommodation	High/med/low (no ped accommodation on bridge)	Low	Low	Low	Low	Low
Emergency Access	Total Response time increase during construction	38 hours	27 hours	27 hours	27 hours	46 hours
Freight Mobility	High/med/low	422,000 hours	360,000 hours	295,000 hours	295,000 hours	397,000 hours
SCORE	(1,3,5,7,9)	4.11	5.00	6.78	5.89	4.67

Figure 36. Multimodal Impacts attribute's measurable applied to all five alternatives

INCREMENTAL TRANSIT SERVICE DURING CONSTRUCTION

The closure's effect on transit is specific to trip changes as relates to increased transit volumes and the incremental number of buses required to meet demand both in West Seattle and along critical bus routes that serve communities between West Seattle and downtown Seattle. We used full-capacity 60-foot buses or their double-decker equivalents as the unit measure. The projected commencement of the Sound Transit WSBLE in 2032 also changes the composition of transportation trips with most bus trips, and a large number of current SOV trips are anticipated to switch to light rail service. For Alternative 1, the incremental annual bus trips would be 1,280 daily units, and Alternative 6 is very similar at 1,283 daily units. Alternative 2 would see an increase of 753 daily units, and for Alternatives 4 and 5 there would be an increase of 982 daily units. The rehabilitation option (Alternative 2), with the lowest increase of daily units, is the preferred option for this measurable.

While overall transit is considered to be a benefit (by reducing vehicle use and associated congestion, emissions, and crashes) the Mobility Impacts measurable considers the incremental transit service levels during construction to be a partial offset of those benefits, representing the incremental cost of providing the necessary service levels to support the benefits. As such, Alternatives 1 and 6, with the highest increase in transit capacity, could be seen as the preferred options.

BICYCLE TRAFFIC ACCOMMODATION

We evaluated potential impacts to bicycle access as a result of construction along West Marginal Way and Klickitat Avenue under the *Access Impacts to Local Properties* measurement. See Section 4.2.7 Business and Workforce Impacts. For the purposes of the Multimodal Impacts attribute, all alternatives scored "Low," with no clear preferred alternative.

PEDESTRIAN TRAFFIC ACCOMMODATION

We evaluated potential impacts to pedestrian access as a result of construction along West Marginal Way and Klickitat Avenue under the *Access Impacts to Local Properties* measurement. See Section 4.2.7 Business and Workforce Impacts. For the purposes of the Multimodal Impacts attribute, all alternatives scored “Low,” with no clear preferred alternative.

EMERGENCY ACCESS

Information provided by SDOT for 2019 indicates that there were 2,097 emergency calls that could have used the WSHB (749 from Battalion 7, 54 from Ladder 11, and 1,294 from other calls). While we were not able to evaluate the exact route for each call, we did review the travel distance and assumed travel times between Fire Station 14 (near the intersection of Fourth Avenue South and South Horton Street) and the intersection of the WSHB and 35th Avenue SW. While not all emergency trips would have used these routes, we considered it to be a reasonable comparison route to assess the effects of the WSHB closure on emergency access and response.

Based on the distances, speed limits, and assumed delays at signalized intersections, rail crossings, and the Spokane Street lower bridge’s openings, it is estimated that an average trip using the WSHB would have taken 6.25 minutes, while an average trip using the Spokane Street lower bridge in combination with local streets would have taken approximately 15 minutes. See Figure 39 for the assumed routes.

We ranked each alternative based on closure durations and the cumulative increase in emergency vehicle response time during the closure.[18] With the longest closure period, Alternative 6 had the lowest score, with a 46-hour increase in emergency response time. Alternative 1 had a 38-hour increase, while Alternatives 2, 4, and 5 each had a cumulative 27 hours’ increase in emergency response time. Rehabilitation and replacement (with the exception of the tunnel replacement) have similar increases in emergency response time and are preferred to shoring, which has the poorest results.

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[18] The potential for an increase of emergency calls in the future was not considered in this study. WSP recommends that this be further explored in future studies.

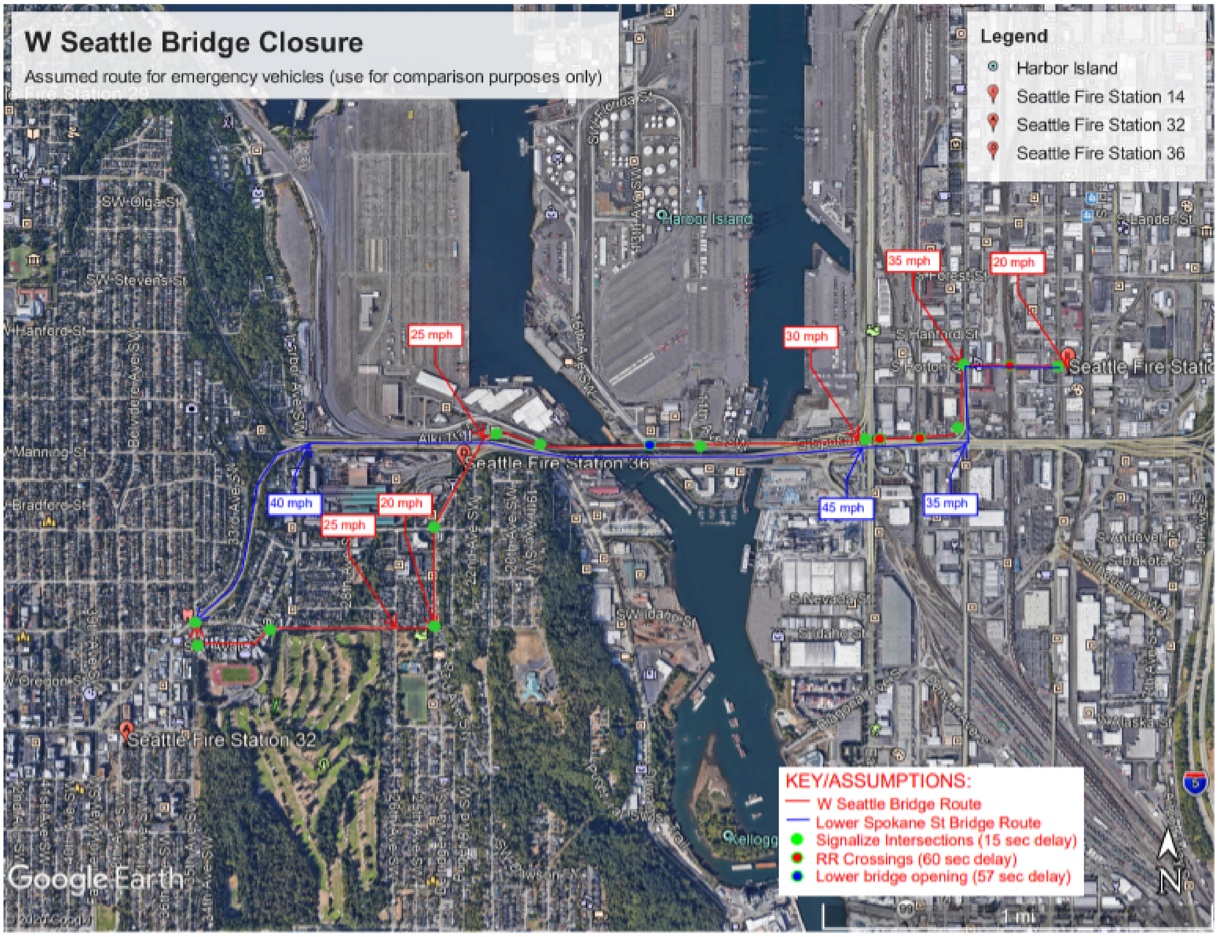

Figure 37. Assumed route for emergency vehicles prior to the West Seattle High-Rise Bridge closure

FREIGHT MOBILITY

We measured freight mobility as increases in travel time for medium and heavy trucks as a result of the bridge closure. As described in Section 3.2.8 Mobility Impacts, the increase in freight travel time is the result of PSRC-modeled results with and without the closure of the WSHB, using detours as provided by SDOT, include the Spokane Street Low Bridge.

The resulting freight adjustment factor, measured in hours, shows an increase of 422,000 hours for Alternative 1, 397,000 for Alternative 6, 360,000 hours for Alternative 2, and 295,000 hours for Alternatives 4 and 5. Replacement (except for the tunnel) is clearly the preferred option for freight mobility.

3.2.10 SEISMIC/SAFETY

This attribute evaluates anticipated post-earthquake service and damage levels relative to the design seismic event, including consideration of implementation. It seeks to ask the questions: What design seismic hazard level will the rehabilitation and replacement alternatives be analyzed for? For the design seismic hazard, what performance level (operational classification) is desired? When will the corridor meet the specified seismic design criteria? The measurements here serve to answer these questions as pertains to the assumptions made for the CBA; however, future phases of work should determine the actual seismic design criteria.

Subject matter experts from the TAP, SDOT, and WSP scored the replacement alternatives as preferred for this attribute, with Alternative 5 (full replacement) receiving an 8.78 overall score.

Measurables	Unit of Measure	Alt #1 Shoring	Alt #2 Rehabilitation	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel (ITT)
Operational Classification	Normal, Essential, Critical	Essential	Normal	Essential	Essential	Essential
Seismic Hazard Levels	100-Year Return Period		X			
	210-Year Return Period	X		X	X	X
	975-Year Return Period	X	X	X	X	X
Post design earthquake service	100-Year Return Period		Full			
	210-Year Return Period	Full		Full	Full	Full
	975-Year Return Period	Limited	No	Limited	Limited	Limited
Vertical Excitations Considered	Yes or No	Yes	No	Yes	No	Yes
Seismic Compliance Established	Year	2033	2032	2025	2026	2030
SCORE	(1,3,5,7,9)	4.56	5.00	7.89	8.78	8.67

Figure 38. Seismic/Safety attribute's measurables applied to all five alternatives

SEISMIC HAZARD LEVELS

We measured seismic hazard levels based on return period, using return periods as currently defined in the Federal Highway Administration Seismic Retrofitting Manual, the WSDOT Bridge Design Manual (BDM), and the AASHTO Guide Specifications for Load and Resistance Factor Design, Seismic Bridge Design. We assumed that all replacement alternatives would follow a multi-hazard level assessment, with the replacement alternatives being assessed at the WSDOT BDM 210-year return period and the 975-year return period, as defined in all noted design manuals.

All of the alternatives meet the 975-year return period and would be considered near equivalent from a seismic hazard level, with Alternative 2 having a slight difference since the lower level event has a 100-year return period versus the replacement alternatives having a 210-year return period.

OPERATIONAL CLASSIFICATION

Similar to the seismic hazard level, the unit of measure for the "operational classification" measurable is the return period. This is because the two measurables are directly related. We assumed the rehabilitation alternative to be classified as "normal" to allow for direct comparison to other bridges within the City's inventory. With this classification, it is assumed that the bridge would maintain life safety, but it would not be operational after the 975-year design seismic event, while the bridge would remain operational directly after a 100-year design seismic event. [19]

For the replacement alternatives, it is assumed that the City will elect to classify the bridge as "essential," which would allow for the full operation of the bridge directly after a 210-year design earthquake, and limited service (service restored within three months) after a 975-year design earthquake.

From an operational classification perspective, the replacement alternatives would be required to perform better than either shoring or rehabilitation alternatives.

VERTICAL EXCITATIONS CONSIDERED

The CBA assumed that the project-specific seismic design criteria would include vertical excitations for the design of a replacement structure. To comply with the assessment approach, and allow for direct comparison of other bridges within the City's inventory, we did not include vertical excitations in the assessment of the rehabilitation alternative.

Subject matter experts scored alternatives that considered vertical excitations higher than those that did not consider vertical excitations. As such, either shoring or replacement are preferred over rehabilitation for this alternative.[20]

SEISMIC COMPLIANCE ESTABLISHED

All the alternatives have specified design criteria. This measurable defines when the specified design criteria are assumed to be met based on when the improvements will have been incorporated into the constructed corridor. We assigned higher value to those alternatives that can meet their specified criteria sooner.

The replacement alternatives are preferred to the rehabilitation or shoring concepts for seismic compliance.

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[19] Although the rehabilitation alternative is classified as "normal," the CBA assessment of the existing bridge indicates that it would meet the essential bridge performance criteria that a replacement bridge would offer once the superstructure is rehabilitated.

[20] The CBA assessed the existing bridge for vertical excitations. Alternative 4 would address any identified superstructure deficiencies. With this consideration, all alternatives would be considered equal for this measurable.

3.3 SUMMARY OF ATTRIBUTE FINDINGS

Three schemes – shoring, rehabilitation, and replacement – encompassing five alternatives – shoring, rehabilitation, superstructure replacement, bridge replacement, and an off-alignment tunnel – were scored from a performance perspective across ten attributes and more than four dozen measurables.

Alternative 1, the shoring concept, performed poorly overall, as did Alternative 6, the immersed tube tunnel concept. Alternatives 2, 4, and 5 performed similarly, but Alternative 4 (superstructure replacement) was the overall best performer. Alternatives 1 and 2 performed particularly poorly from a Seismic/Safety perspective; however, upon completion of the CBA, WSP determined that the existing bridge performs quite well from a seismic/safety perspective (see sensitivity study in Section 6.2).

The results from the performance phase of the CBA indicate that, while rehabilitation and bridge replacement are both viable options, bridge replacement alternatives offer slightly better performance (with the exception of a tunnel replacement). Subject matters assigned a value of 1, 3, 5, 7, or 9 to each alternative for each attribute relative to the baseline (Alternative 2, with a score of 5). Scores are thus shown on a scale of 1-9, with 9 being most preferred, and 1 being least preferred (Figure 39). The fact that decimal values are reported is the result of averaging scores between the City, WSP, and the TAP.

Alternative Scores	Alternative 1: Shoring	Alternative 2: Repair (Baseline)	Alternative 4: Superstructure Replacement	Alternative 5: Bridge Replacement	Alternative 6: Tunnel (Off-alignment)
Maintenance, Inspection & Operation	3.7	5.0	7.4	7.2	3.2
Constructability	2.8	5.0	5.2	4.1	2.1
Environmental	3.7	5.0	4.8	3.9	1.3
Equity	2.8	5.0	4.1	3.2	1.0
Forward Compatibility	2.1	5.0	7.0	8.1	5.7
Funding Opportunities	5.2	5.0	4.8	4.3	3.7
Business and Workforce Impacts	3.9	5.0	3.9	2.3	1.7
Mobility Impacts	3.0	5.0	4.1	3.9	2.3
Multi-modal Impacts	4.1	5.0	6.8	5.9	4.7
Seismic/Safety	4.6	5.0	7.9	8.8	8.7

Figure 39. Attribute Performance: Subject matter experts from the TAP, SDOT, and WSP rated each alternative for each attribute. These scores were then averaged across entities to show overall attribute performance.

However, as previously mentioned, performance is just an input to the overall findings, which look at the value of the return on investment. To do this, cost and risk input is required, which is outlined in Sections 4 and 5. Section 6 presents the overall findings.

As discussed in Section 3.1, once we identified performance attributes, the next step was to weight each individual attribute against the other attributes. SDOT, the TAP, and the CTF jointly determined this weighting by ranking attributes relative to one another. Mobility Impacts, Seismic/Safety, and Constructability were the most highly rated and thus the most heavily weighted (Figure 40).

	SDOT		TAP		CTF		Combined	
	TOTAL	%	TOTAL	%	TOTAL	%	TOTAL	%
Bridge Maintenance, Inspection & Operation	4.9	8.9%	6.4	11.7%	3.1	5.7%	14.4	8.8%
Constructability	5.0	9.0%	5.9	10.6%	6.7	12.1%	17.5	10.6%
Environmental	4.8	8.7%	3.3	6.0%	5.9	10.7%	14.0	8.5%
Equity	6.6	11.9%	2.3	4.2%	5.6	10.1%	14.4	8.7%
Forward Compatibility	4.0	7.2%	5.0	9.1%	5.1	9.3%	14.1	8.5%
Funding Opportunities	5.1	9.2%	5.6	10.1%	4.7	8.5%	15.3	9.3%
Local Business Impacts	4.2	7.6%	6.3	11.4%	4.1	7.5%	14.6	8.8%
Mobility Impacts	6.7	12.2%	9.6	17.4%	6.4	11.7%	22.7	13.8%
Multi-modal Impacts	5.7	10.4%	4.7	8.6%	5.1	9.3%	15.5	9.4%
Seismic/Safety	8.2	14.9%	6.0	10.9%	8.3	15.2%	22.5	13.7%
	55.0	100%	55.0	100%	55.0	100%	165.0	100%

Figure 40. SDOT, the TAP, and the CTF's averaged rankings determined attribute weighting.

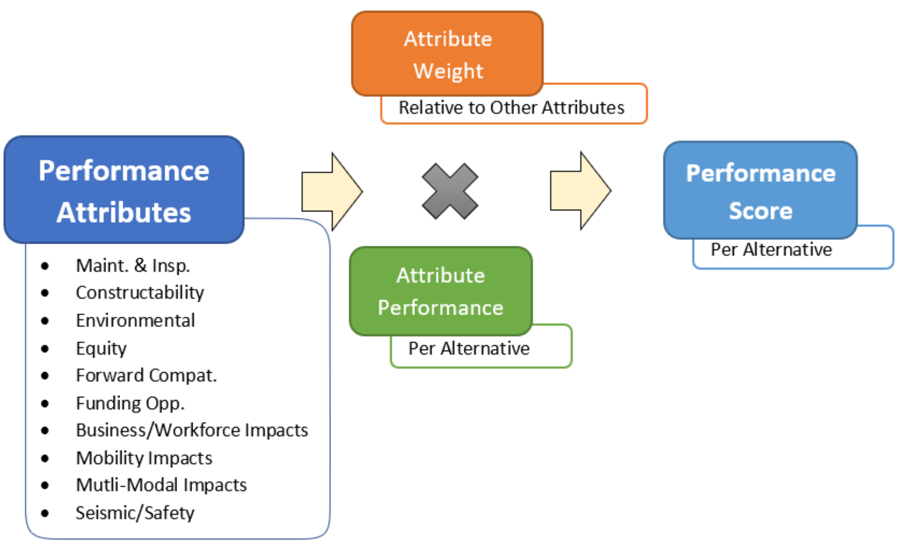

Figure 41. The CBA multiplied attribute weights by attribute performance scores to determine the overall performance score.

Once we calculated attribute weight and attribute performance averages, we were able to determine performance scores by multiplying the two (Figure 41).

Table 4 shows the overall combined performance scores, which the CBA then used to ultimately determine value indices for life cycle costs and capital costs (see Section 6).

Table 4. Average performance scores after attribute weighting is applied

Combined		
Temporary Shoring to Restore Live Load (3 to 5 years)	Alt 1	360
Direct Strengthening to Restore Live Load (40 years)	Alt 2	500
Accelerated Superstructure Replacement (50 to 75 years)	Alt 4	563
Accelerated Bridge Replacement (75 years)	Alt 5	527
Off-Alignment Immersed Tube Tunnel (75+ years)	Alt 6	362

Independent TAP Scoring Exercise

The TAP independently scored the alternatives independent of a baseline alternative using a 1 to 10 scoring system for each attribute for each alternative. Figure 42 shows the resulting absolute performance scores, as well as a scaled version of the absolute scores. Scaling set the score for Alternative 2 to 500 so that the findings could be compared to the CBA's process, which used Alternative 2 as the baseline. The TAP's independent scoring system resulted in a larger magnitude of difference in scores between the rehabilitation and replacement alternatives; however, the trend relative to their scoring stayed the same. In the CBA process, the TAP favored Alternative 2 from a performance standpoint, with Alternative 1 scoring the lowest. The TAP's independent scoring exercise favored Alternative 2, but Alternative 6 scored the lowest.

Alternative	TAP Score No Baseline	% Difference In Score	Adjusted Score
1	342	13%	399
2	500	---	500
4	383	- 17%	453
5	321	- 26%	375

Figure 42. TAP Baseline Independent Scoring[21]

[21] This table does not show results for Alternative 6 because the TAP performed their alternative scoring exercise before it had been fully developed.

4 ROUGH-ORDER-OF-MAGNITUDE CONCEPTUAL COSTS

WSP developed rough order of magnitude (ROM) cost estimates for capital project costs and life cycle costs. The costs presented within Section 4 of this report represent "base" ROM costs, which are based on a series of assumptions informed by SDOT. We show them to illustrate how costs are incorporated into the CBA evaluation process. The actual findings of the CBA evaluation process are represented by value indices, or the measure of performance over cost. Value indices measure return on investment. Capital ROM cost estimates inform short-term investments, and life cycle costs inform long-term investments. Section 6 outlines the CBA findings, explains how we developed the value indices, and presents the ranges in potential costs based on an evaluation of the sensitivity of key assumptions.

As stated, the reported capital ROM cost estimates represent project costs for the given work activities. Each alternative comprises multiple work activities occurring in time. For example, Alternative 2 initially includes the rehabilitation work in 2021-2022. It then assumes a foundation retrofit in 2032, the existing bridge's demolition in 2063, and a full replacement in 2063-2066. Capital costs account for only a given alternative's initial work activities. These activities take place in the bolded years in Figure 43.

Parameter	Alt #1 Shoring	Alt #2 Rehabilitation	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel
Life Cycle			2021 - 2100		
Shoring to Restore Live Load	**2021-2024**	--	--	--	--
Demolition	2029	2063	**2022-2023**	**2022-2023**	**2024-2026**
Rehabilitation	2083	**2021-2022**	2076	2076	--
Foundation Retrofit	--	2032	**2024**	--	--
Superstructure Replacement	--	--	**2024-2026**	--	--
"In-Kind" Bridge Replacement	2030-2033	2063-2066	--	**2024-2026**	--
Tunnel					**2024-2030**

Note: Bolded items represent initial capital investments.

Figure 43. Alternative Work Activities and Years of Occurrence

We determined actual alternative ROM costs for all work activities, reported in present value, through a life cycle cost analysis, as described in Section 4.2. Alternatives 1 and 2 assumed a bridge replacement (i.e. Alternative 5) would ultimately be required.

4.1 CAPITAL COSTS

We based ROM capital cost estimates (presented in 2021 dollars) on the alternatives and various work activities discussed in Section 2 and Appendix A of this report. Due to the preliminary nature of the CBA, not all costs were material-based estimates supported by detailed engineering analysis. We also used metrics-based methods to develop ROM cost ranges for some alternatives, or components of alternatives, in lieu of a quantity-based estimates in line with standard design approaches. Being metric based, quantity-based item specific costs do not exist, only allowances exist for various types of work based on past experience. As the project moves forward, it will be required to develop quantity-based item specific estimates in-line with the SDOT standard approach.

The ROM capital costs are intended to capture the full spectrum of potential costs for the project. These include contingency allowances appropriate for the level of design of a given work activity, a construction contingency, monetization of risk items, allowances for temporary construction easements and property acquisition, and consideration of other variable project costs. A graphical representation of the application of contingencies and cost escalation values can be seen in Figure 44 below, followed by a discussion of each.

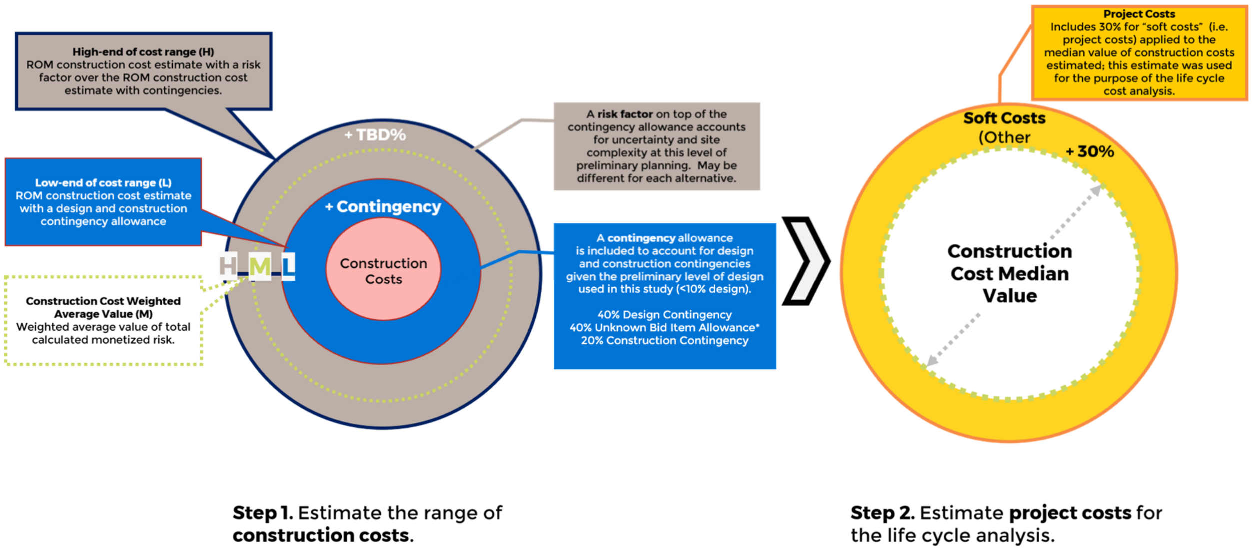

Figure 44. Capital Cost Contingency, Allowance, and Risk Superposition

Contingencies and Allowances

Different ranges in contingency values were utilized for the difference work activities per input from the City. We used a 40-percent design contingency for all work activities, except the direct rehabilitation work, which we assigned a 20-percent design contingency, due to the advanced level of design and analysis done relative to the other work activities. A similar trend was held for missing bid item allowances accounting for the preliminary nature of the design; however, we added an extra layer of allowance for undefined rehabilitation work in the future and unknowns with an off-alignment immersed tube tunnel. We also included a 20-percent lump sum construction contingency for all estimated capital cost work activities.

We included an allowance for soft costs, incorporating construction administration and inspection costs, the cost of construction support services, third-party review costs, and owner costs (internal agency costs spent on a project). Per City direction, WSP used a 20-percent lump sum value throughout. Table 5 shows an overall summary of the contingencies and allowances used in ROM cost development.

Table 5. Work Activity Contingency Assumptions

<table>
<tr><th>Work Activity</th><th>Design Contingency</th><th>Missing Bid Item Allowance</th><th>Construction Contingency</th><th>Other (Soft) Cost Allowance</th></tr>
<tr><td>Shoring</td><td>40%</td><td>20%</td><td rowspan="7">20%</td><td rowspan="7">20%</td></tr>
<tr><td>Direct Rehabilitation</td><td>20%</td><td>10%</td></tr>
<tr><td>Demolition</td><td>40%</td><td>20%</td></tr>
<tr><td>Superstructure Replacement</td><td>40%</td><td>20%</td></tr>
<tr><td>Bridge Replacement</td><td>40%</td><td>20%</td></tr>
<tr><td>Immersed Tube Tunnel</td><td>40%</td><td>40%</td></tr>
<tr><td>Future Bridge Rehabilitaiton (for replacement alts)</td><td>40%</td><td>40%</td></tr>
</table>

As previously noted, each alternative comprises multiple work activities, and so the aggregate contingency within an alternative is some combination of the work activity contingencies shown in Table 5. The effects of the aggregate contingency is illustrated in Section 6.2, which provides a discussion on the sensitivity in the reported life-cycle value index based on assumed cost contingencies.

Right-of-Way (Temporary Construction Easements and Property Acquisition)

Right-of-way costs considered potential temporary easement needs, aerial easements, and permanent acquisitions. They were based on values of the assumed affected parcels' values. The easement and acquisition needs are not yet known, but some were assumed to provide an allowance in the ROM capital cost estimates. WSP developed figures of anticipated impacted parcels and the duration of impacts and provided them to SDOT. SDOT provided an estimated value of the impacts.

Monetization of Risk

The ROM cost ranges did not use WSDOT's Cost Estimate Validation Process for formal risk modeling. Future phases of the project may consider more robust analytical tools for assessing and monetizing risk. However, we developed a risk registry and identified a series of risks to monetize and include in the ROM capital cost estimate. Section 5 provides further details related to the CBA's risk assessment.

The noted cost escalation items included are intended to recognize the preliminary nature of the CBA and capture the potential impacts associated with project complexities; this is just an allowance and not necessarily an accurate reflection of actual costs. Estimating the magnitude of the actual costs associated with the project and its complexities would be difficult to estimate without conducting the next steps identified in the CBA report and conducting a formal risk analysis. For the purpose of the CBA, Table 6 shows the resulting capital cost ROM estimates, which we then used to inform the capital cost value indices reported in Section 6.

Table 6. Base Project ROM Capital Costs

Alternative	Construction Costs	Monetized Risks	ROW Cost	Other Variable Cost	Project Capital Costs
Alt 1	$103.5M	$0	$0.9M	$20.7M	$125.1M
Alt 2	$47.0M	$175.5M*	$0.9M	$10.0M	$233.4M
Alt 4	$383.1M	$229.5M	$1.2M	$122.5M	$736.3M
Alt 5	$564.7M	$473.5M	$1.0M	$207.6M	$1,246.8M
Alt 6	$1,992.1M	$269.0M	$0	$452.2M	$2,713.3M**

*$171M of the $175.5M of Alternative 2's monetized risks is associated with the risk of a reduced service life. See Section 6.2 for details.

** Right-of-Way costs for Alternative 6 are not included

4.2 LIFE CYCLE COSTS

Life cycle cost analyses (LCCA) are important for assisting with investment decisions. The National Cooperative Highway Research Program (NCHRP) developed these analyses explicitly for bridge infrastructure investments in Report 483, entitled "Bridge Life Cycle Cost Analysis." The Federal Highway Administration recognizes this approach as a "best practice," and is the approach used within the CBA.

Constructing and managing a bridge asset covers a timeframe of many years. Following AASHTO's design life, this would be 75 years. Comparing investment costs, especially when making decisions related to rehabilitating an existing bridge which has already served a portion of its design life to a replacement bridge is complicated. It requires a conversion to a form that allows them to be compared. The value between a dollar today and a dollar in the future is different. The LCCA process distinguishes the difference between a dollar today and a dollar in the future through discounting. Discounting, or the opportunity cost of money, in the case where borrowed funds are used to fund initial construction, preservation, or maintenance activities, would include the borrowing rate (interest) of the borrowed funds.

Determining the discount rate significantly impacts the reported life cycle costs. Low discount rates favor larger current investments (such as a replacement), and high discount rates favor larger future investments (such as rehabilitate now and replace later). National standards for net discount rates on bridge structures are between 2 and 4 percent. Through consultation with SDOT, the CBA uses a net discount rate of 0 percent; in other words, the rate we used assumes that the value of a dollar in the future is the same as the value of a dollar today. Recognizing the uncertainty in the actual net discount rate, Section 6.2 of this report illustrates the effects that potential changes in the discount rate would have on the resulting value indices.

The LCCA estimated overall costs for each alternative between 2021 and 2100. The end of the life cycle cost assessment (i.e., 2100) is the same as the end of the 75-year service life for Alternative 4, which we expect to come into service around 2026. The LCCA was informed by four different types of costs: capital costs of various work activities; inspection, operating, and maintenance (O&M) costs; future repair and rehabilitation (R&R) costs, which include the cost of a future replacement for Alternatives 1 and 2; and salvage costs.

Capital Costs

Section 4.1 describes capital costs for the various work activities. We specified a duration for each capital cost work activity, as well as the actual years of work. When applied to the LCCA, the total capital cost was equally distributed over the duration of construction. Thus, with the time effect of money (i.e., discounting), the recognized capital costs may be different if other discount rates are used.

Inspection, Operating, and Maintenance Costs

Table 7 illustrates the assumed annualized inspection, operating and maintenance costs utilized in the LCCA.

Table 7. Annualized Inspection, Operating, and Maintenance Costs

	Alt #1 Shoring		Alt #2 Rehabilitation				
O&M/Inspection Costs	5 Years (Shoring)	75+ Years (Alt 5)	40 Years (Rehab)	75+ Years (Alt 5)	Alt #4 Replacement	Alt #5 Replacement	Alt #6 Tunnel
Routine Maintenance	$350k/yr	$250k/yr	$350k/yr	$250k/yr	$200k/yr	$250k/yr	
Inspection Requirements	$150k/yr	$200k/2yrs	$150k/yr	$200k/2yrs	$100k/yr	$200k/yr	
Intelligent Transportation Systems Required	$100k/yr						
Structural Health Monitoring Systems Required	$100k/yr		$100k/yr				$1,575k/yr
Painting/UV protection Required		$11.554M/25yrs	$300k/10yrs	$11,554k/25yrs		$11,554k/25yrs	
Drainage	$40k/yr	$45k/yr	$40k/yr	$45k/yr	$45k/yr	$45k/yr	

Table 7 reflects the SDOT-provided ideal (not actual) annual maintenance and inspection costs for the current WSHB, totaling approximately $500k. We divided this amount between the maintenance and inspection for each alternative, with $350k going towards routine maintenance and $150k towards inspection on an annual basis. This was applied to Alternatives 1 and 2 (before the assumed replacement with Alternative 5) and assumed that the existing structural health monitoring system would remain operational while the bridge was in service. After the replacement structure is constructed, the maintenance and inspection costs would be reduced.[22] The operating and maintenance costs are less for the replacement structures relative to the existing structure because they are new; however, the CBA assumed that an asset management system would be included in the design and would require annual operation and maintenance expenditures. In addition, Alternative 1 assumes that SDOT would install an intelligent transportation system during the shoring period.

We assumed that the new structures, in-kind replacement (Alternative 1, 2, and 5) and full-superstructure replacement (Alternative 4), would require inspections less frequently (every two years) than currently required for the existing bridge (annually). However, this is offset to some degree with more expensive inspection costs for a cable stayed bridge than a concrete box girder bridge. The drainage costs for all alternatives increased with the assumption that the current bridge's drainage requirements would increase, as there may be more drains to maintain. SDOT provided drainage values.

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[22] Based on the structures types assumed for the replacement structures within the CBA. Some replacement structures, such as fracture critical and seismically isolated structures, would require more frequent and enhanced inspection efforts.

The CBA assumed that Alternative 6 would require annual O&M costs at $250k per lane mile. This estimate was informed by databases developed for the SR 99 Alaskan Way Tunnel, I-90 Mt. Baker Tunnel, and the Mercer Island Lid. We chose these projects because they are local and provide recent knowledge of fire, life, and safety features in a representative scale. Outside of the tunnel's fire life safety systems O&M, we assumed an O&M cost of $250k per year.

Future Repair and Rehabilitation Costs

The LCCA incorporated a series of future repair and rehabilitation costs. We assumed that the cable-stayed alternatives (i.e., Alternative 5 and eventually Alternatives 1 and 2) would have to be painted every 25 years to protect the steel cables. Alternative 2 also assumed that the CFRP strips would receive a UV protection coating every 10 years until the bridge was replaced.

The bridge replacement alternatives (i.e., Alternatives 4 and 5) assumed a lump sum repair/rehabilitation value of $50 million for bridge strengthening in the year 2076 (i.e., after 50 years of service). We applied contingencies and allowances as noted in Table 5. We then inflated the costs to 2076 dollars and discounted back to present value.

For Alternative 6, the R&R costs were taken as 8.47 percent of the total construction costs annualized. This number was based on recent estimates for the SR 99 Alaskan Way Tunnel construction costs, including lid elements such as ventilation, fire suppression, and other tunnel-related items.

Salvage Costs

The salvage costs represent a fraction of the initial capital costs based on the remaining years of service at the end of the life cycle cost assessment, brought back to present value. The end of the life cycle cost assessment was taken as the end of the service life for Alternative 4 (i.e., 2100), so Alternative 4 shows zero salvage value. However, all other alternatives had remaining service life to varying levels in 2100:

- Alternative 1 – 8 years
- Alternative 2 – 41 years
- Alternative 5 – 1 year
- Alternative 6 – 5 years

Table 8 below summarizes the estimated base total ownership costs for each of the five alternatives (assuming a net discount rate of zero percent). Again, the base total ownership costs shown in

Table 8 illustrate how life-cycle cost value indices are reported (see Section 6.1), whereas the potential ranges in life-cycle costs are illustrated in Figure 46 and discussed in the summary of findings (Sections 6.2 and 6.3).

Table 8. Base Project ROM Life Cycle Costs (0% Net Discount Rate) Summary

Alternative	Initial Capital Investment	O&M	Repair & Rehabilitation	Remaining Service Life (Salvage Cost)	Estimated Total Ownership
Alt 1	$125.1M	$32.3M	$1,525.9M	($124.4M)	$1,558.9M
Alt 2	$233.4M	$40.5M	$1,279.8M	($637.8M)	$916.0M
Alt 4	$736.3M	$22.1M	$247.3M	$0M	$1,005.7M
Alt 5	$1,246.8M	$29.6M	$282.0M	($15.6M)	$1,542.7M
Alt 6	$2,713.3M	$110.3M	$214.5M	($217.1M)	$2,821.0M

NOTES:
The X's in the figure represent the base LCCA costs identified in Table 8. The blue bars illustrate the range in potential life cycle costs based on the sensitivity studies defined in Section 6.

Figure 45. Life-Cycle Cost Ranges

5 RISK ASSESSMENT

There is inherent risk in all design and construction work. Risks could result in scope, schedule, and/or budget impacts or change. It is important to try to identify the risks associated with rehabilitation and replacement alternatives to avoid surprises and ensure adequate plans are in place should a risk arise. As part of the CBA, WSP, in conjunction with SDOT, the TAP, and the CTF, created a risk registry for the WSHB project (see Appendix D).

The risk registry is a living document that should be managed throughout the life of the project. To date, the risk registry has been informed by various subject matter experts within WSP, SDOT, and the TAP. This consultation has included risk registry presentations in multiple TAP meetings and workshops, and a formal review by the TAP and SDOT. The risk registry has also been presented to the CTF for their review and input. As a result, it is based on a comprehensive contribution from experts and non-experts alike, with the objective of capturing intrinsic, technical risks, as well as extrinsic risks situated within the broader context of this project.

Risks are never removed from the registry; however, they may be closed out if a management strategy or solution has been identified. The risk registry is structured as follows:

- **Identification:** identifying the possible risks that may have significant impacts on the project.
- **Qualitative Analysis:** determining a risk factor rating based on a qualitative assessment of the probability of the identified risk occurring, and the associated impact of the identified risk. The assessment assigns ratings of very high, high, medium, low, or very low, and answers the following questions:
  - *Probability*: What is the likelihood of the identified risk occurring?
  - *Impact*: What level of impact would the identified risk have on the project if it occurred?

  The relationship between the answers to the above questions, as it relates to determining a risk factor rating, is shown in Table 9 below.

Table 9. Risk Rating Factor

PROBABILITY			IMPACT		
	VL	L	M	H	VH
VH	25%	40%	50%	65%	85%
H	20%	25%	40%	50%	65%
M	10%	20%	25%	40%	50%
L	5%	10%	20%	25%	40%
VL	5%	5%	10%	20%	25%

- **Strategy:** developing a strategy, or strategies, for managing the identified risk items. Items could involve primary and secondary plans, and could be dependent upon the level of severity. The team discusses and agrees upon strategies. Risk strategy categories include avoiding, transferring, mitigating, and accepting, as defined below:
  - *Avoid*: changes the project plan to eliminate the risk. This would be done by adjusting the scope, schedule, and/or budget.
  - *Transfer*: shifts, but does not eliminate, the risk and responsibility to a specialized third party.
  - *Mitigate*: reduces the probability and/or effect of the risk to an acceptable level.
  - *Accept*: accepts a "do nothing strategy" until/if the risk occurs, at which point it would be dealt with. Contingencies are considered within this strategy.

  The register identifies a planned response, or action, to address each risk. Planned responses may change throughout the life of the project as more details become available and the design progresses.

- **Monitor:** developing a plan to monitor and control the risk. Monitoring and controlling risk continues through the life of the project. As the design progresses, details become more evident. This allows the team to reassess and monitor the planned responses, add/re-analyze/edit the identified risks, and evaluate the registry. The registry identifies actions taken to-date, planned actions and when the actions are anticipated to occur, and who is responsible for the actions.
- **Monetization:** identifying risks as monetized or not. Monetized risks are assigned a dollar value. Non-monetized risks may be schedule-related and intended to be mitigated as the design progresses; stakeholder coordination-related intended to be mitigated through a detailed coordination plan; etc. Some risks that could be monetized may not be monetized, because they are indirect costs to the project, or covered by assumptions made in the cost estimating for the project. These are noted in the risk registry. Where risks are monetized, the approach to monetizing the risk is included in the registry. All monetized risk values include an absolute cost calculation, and then a factored value, which is the product of the risk factor rating and the absolute cost calculation.

The CBA's risk registry includes more than 40 items, eight of which have been monetized (Table 10). This list will likely grow in future project phases, once a rehabilitation or replacement decision is made and there is a clear path forward. The list of monetized risk items is tabularized below, along with the alternatives to which those risks apply – from both an initial capital investment perspective and a life cycle cost perspective.

Table 10. CBA Monetized Risk Items

Risk Item	Probability of Occurring	Applicable Alternatives…				
		1	2	4	5	6
Performance of Stabilization. *Bridge stabilization measures don't react as predicted by analytical modeling – e.g., uncertainty in expansion pier restraint, uncertainty in post-tensioning effective stress, uncertainty in locked-in forces (i.e., creep effects), etc. Could result in needing to pivot towards a replacement.*	Low		X			
Existing Bridge Foundation Retrofits/Ground Improvements. *The existing bridge is seismically in good condition and meets the essential bridge classification as defined by WSDOT. That said, the Pier 18 foundation system exhibits localized in-ground pile plastic hinging in a liquefied condition. SDOT could consider this permissible, or decide to mitigate it with localized ground improvements. This risk item captures the cost of the localized ground improvements.* *Note: Risk is monetized only for Alternative 2 to avoid double counting foundation risks.*	High		X	X		
Rehabilitation Service Life. *The rehabilitation alternative assumes the bridge will achieve a 40-year service life. This risk item addresses what would happen if the rehabilitation does not perform as expected, requiring replacement of the bridge in 15 years instead of 40.*	Very Low		X			
Geotechnical Design Seismic Hazard. *Geotechnical standards for seismic acceleration will likely change in the next few years, which may change design and sizing*	High			X	X	

of components. This relates to subduction zones, near-fault effects, basin effects, etc.						
Bridge Seismic Importance Classification. *Determines the operational importance of the bridge: "normal" - prevents collapse but has to be replaced, "essential" - operational within 3 months, "critical" - immediately operational. The CBA assumes a replacement structure is classified as essential per WSDOT design methodologies, however, ultimately project specific criteria will need to be developed by the City. Determination of this classification and performance criteria may have an impact on the material costs of the bridge.*	High			X	X	X
Federal Aviation Administration Height Restrictions. *The bridge is proximate to Boeing Field: are there any height restrictions that may prohibit certain bridge types and appurtenances from being used?*	High				X	
United States Coast Guard Navigation Clearance Requirements. *Current height limitations imposed by the existing bridge limit the size of vessels that can navigate further upstream, thus limiting Port and maritime industry business opportunities. Accordingly, the USCG might require a replacement bridge's vertical clearance be raised. Increasing the vertical clearance envelope would impact overall project scope and costs.*	Medium			X	X	
Site-Specific Casting Yard Needs. *The ITT will have minimum requirements for width, depth, and length of tunnel sections. Existing regional casting yards may not be able to accommodate those needs, and thus a site-specific casting yard would be required.*	High					X

Note: The risk registry includes other items that could have been monetized, however, those were either considered captured by allowances made in the cost estimates or considered beyond the scope of the CBA. We recommend that future phases further investigate construction- and design-specific risks. For details, see Appendix D.

The primary, and most critical, risk associated with further rehabilitation of the existing bridge (Alternative 2) is that it doesn't perform as intended, requiring another bridge closure after being put back into service (see Rehabilitated Service Life risk above). This risk could materialize because:

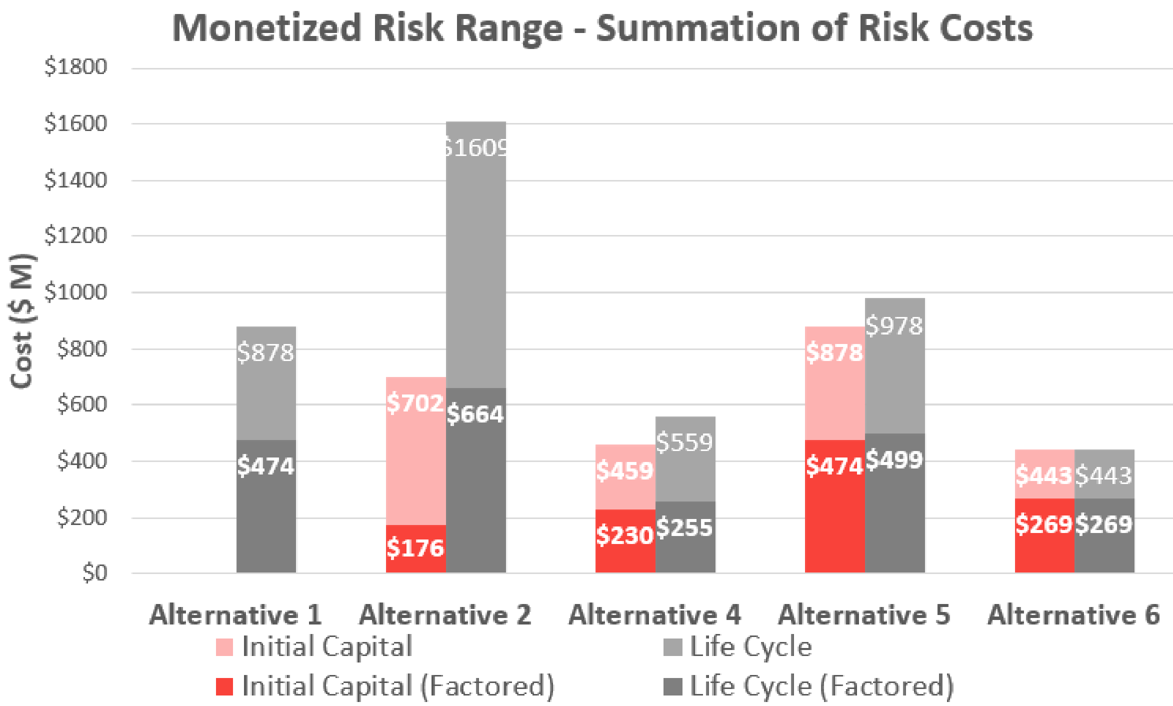
- "We got the wrong answer" – We know that soffit tensile stresses were imparted on the soffit of the bridge at the locations where bottom slab tendons terminate within the spans. We think we understand how the tensile stresses could have been generated; however, we don't know every load the bridge has seen nor the exact stress distribution within the structure. This could emerge once the repairs are constructed and the bridge put back in service.
- Incomplete Rehabilitation Design – To date, we have conducted preliminary rehabilitation concept (Alternative 2) analyses and design to support the CBA evaluation; however, there is a risk that we may find something wrong in the preliminary engineering during the final design process that could preclude the feasibility of rehabilitation.
- Remaining Stabilization Work – There remains a risk that, once stabilization measures are complete in a few months, the bridge does not behave as expected, indicating that there is a systemic issue with the bridge that neither monitoring nor non-destructive testing have identified to date.

The existing bridge service life risk was monetized, as noted in Table 10 above, through the CBA process. We used a risk factor of 25 percent; however, based on the work done to-date and the correlation of analytical modeling to measured behavior, the technical risk of the bridge not behaving as intended, thus limiting the service life of the rehabilitation, likely has a very low probability (less than 5 percent) of occurrence. This probability assumes that the bridge continues to exhibit the same trend as the stabilization measures are completed in the coming weeks.

The risk registry identifies more risk items - monetized and not monetized - associated with the replacement alternatives than with the rehabilitation alternative. The list of monetized risk items associated with the replacement are noted in Table 10 above. There are also a handful of other risk items that we could have monetized; however, we wanted to avoid double-counting costs already monetized by the selected list (i.e., formal seismic analysis identifying additional seismic deficiencies within the existing bridge foundations was not monetized for Alternative 4). Some of the biggest non-monetized risks associated with the replacement (or more heavily applicable to) alternative are related to schedule: Specific schedule risk items include:

- **Inability to get regulatory approvals** – the demolition and construction of the bridge will require construction in, and if not in, on and around the wetted perimeter of the ordinary high water. Considerations will include barge work within the river impacting fishing, containment requirements, noise, dust, in-water work (if required), relocation of avian habitat, etc. This will require close coordination with the agencies to avoid delays to the project schedule.
- **Stakeholder coordination issues** - the bridge exists within a built environment. There are many businesses and facilities that operate in and around the project site, including the Port of Seattle, Harbor Island, and BNSF, or those with plans to extend their services through the project site (i.e., Sound Transit). The Port of Seattle has plans to expand their Terminal 5 services, with a loss in revenue if not operational by 2024. It will be important that the project is coordinated with the project stakeholders to avoid delivery delays of a replacement bridge, and to maximize opportunities, such as collaboration with Sound Transit on a multimodal crossing.
- **Inability to secure adequate funding for a replacement structure** - the capital investment of a replacement structure is significantly more than that of rehabilitation. The City will likely have to borrow funds to fund a replacement structure. Problems with securing these funds could delay the design and construction of a replacement.
- **Potential public and community scrutiny and associated impacts** - as stated, the CBA does not quantify the costs of socioeconomic impacts. The closure duration has a significant impact on the community and businesses within West Seattle and the surrounding area. The CBA has shown that minimizing the duration of immediate closures is far more important than future closures based on the assumption of light rail availability after 2032. This gets exacerbated when considering opportunity costs with time. WSP recommends that this be explored in-depth in future studies.
- **Unknown design criteria** – SDOT needs to specify the bridge seismic design criteria; if they classify the bridge as “essential” or “critical,” as SDOT has stated as likely (reference the “high” probability of occurrence in the “bridge seismic importance classification” risk item in Table 7). This takes time, and careful thought should be given towards current changes within industry, both geotechnically and structurally. It is important that any investment needs to meet newly adopted, and potentially soon to be adopted, design procedures.
- **Approach structures** - a limitation of the CBA is that it does not assess the approach structures. This is needed to understand potential corridor deficiencies and would be advantageous to understand ahead of conducting the design of a high-rise replacement structure (i.e. avoid designing-in an unintended constraint). A better understanding of corridor needs will also help in making investment decisions. There is limited space, and, with Sound Transit’s future expansion plans, a need to better understand the corridor needs. This would help determine if investing a joint structure makes sense. Future studies and joint discussions between the City and SDOT should further explore these opportunities and invest in further investigations into approach structures.
- **When to demolish the existing bridge** – due to the potential schedule risks identified above, it may be advantageous to wait to demolish the existing bridge until the replacement bridge design is more fully developed, and potential schedule risks are better defined. If the replacement design does not progress as intended, the existing bridge could be rehabilitated to restore service to the corridor. However, the existing bridge would need to be monitored until this decision was made. The CBA does not capture these costs.

Figure 46 illustrates the cumulative monetized risk accounted for within the CBA for each alternative. Monetized risk values include the contingencies and allowances that we applied to the ROM capital construction cost estimates. The red bolded bars indicate the monetized risk values incorporated into the initial capital investment ROM cost estimate, and the gray bolded bars represent the cumulative monetized risk recognized in the LCCA. The bolded portion of the bars represents the factored monetized risk, whereas the lighter colored portion of the bars represent the total, or absolute, monetized risk value. The difference is the application of the risk factor rating and indicates the potential range in risk.



KEY MONETIZED RISK NOTES:

- The **Factored** values represent monetized risk values that were incorporated into the project costs. The factor is based on the product of the probability of occurrence and impact should the risk occur; reference Table 9. The lighter shaded portion of each column represents the recognized monetized risk without the risk factor (shown for reference; not applied to the project costs).
- The risk values labeled as Initial Capital (red bars) are only associated with capital investments (bolded items within Figure 43), and not future work activities within an alternative. Risks associated with future work activities (including risks not associated with future implementation of another alternative) are captured in the Life Cycle (gray bars). If Initial Capital (red bars) and Life Cycle (gray bars) show the same value, then we have not included any risks associated with future work activities as part of the currently monetized risk values.
- Alternative 1 Risks – Life cycle risks incorporate Alternative 5 risks, as Alternative 1 will be replaced in 2029, 71 years before 2100.
- Alternative 2 Risks – Initial capital investment risk is primarily associated with the limited service life of the rehabilitation. Although this has a very low (less than 5 percent) probability of occurrence, the CBA did recognize a 25 percent risk factor due to the major impacts should the risk occur. Life cycle risks incorporate Alternative 5 risks, as Alternative 2 will be replaced in 2063, 37 years before 2100.
- Alternative 4 Risks – Initial capital investment risk is primarily associated with foundation cost uncertainty and potential USCG height clearance requirements. Reported monetized risks for this alternative do not include FAA structure height limitations, potential schedule lag, or closure-related socioeconomic impacts.
- Alternative 5 Risks – Initial capital investment risk is primarily associated with foundation cost uncertainty, potential USCG height clearance requirements, and FAA structure height limitations. Potential schedule lag and socio-economic impacts have not been included in the reported monetized risks. Reported monetized risks for this alternative do not include potential schedule lag or closure-related socioeconomic impacts.
- Alternative 6 Risks – Initial capital investment risk is primarily associated with a lack of existing casting yards able to construct the tunnel segments. The base estimate uses allowances to address other risks such as contaminated soils, dredging depths, etc.

Figure 46. Monetized Risk Range

6 FINDINGS

6.1 RESULT METHODOLOGY

The CBA evaluation process entailed a phased approach. During the first phase, we selected the attributes and then weighted the attributes relative to each other. This was done in conjunction with SDOT, the TAP, and the CTF[23].

The second phase determined performance scores for each alternative, for each attribute, and added the per-attribute performance scores together to get an overall performance score for an alternative. This was done in conjunction with subject matter experts from WSP, SDOT, and the TAP. Section 3 examines the first two phases in more detail.

The third phase, addressed in this section, delivered the CBA findings, presented as value indices. We developed these value indices by dividing the performance scores by first, the capital costs of the alternatives, and then by the life cycle costs. The capital cost value index yielded the initial return on investment of a given alternative, and the life cycle cost value index yielded the long-term return on investment. This is shown pictorially in Figure 47 below.

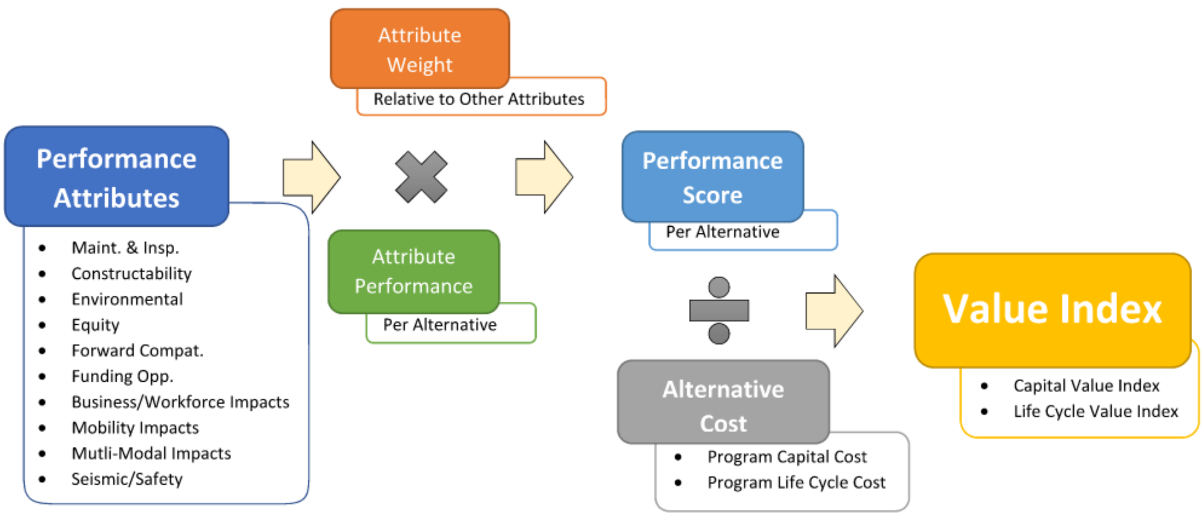


Figure 47. Pictorial View of Evaluation Process

The initial "base" value indices are based solely on the assumptions made within the CBA (Section 1.3), and are shown in Figure 49. Findings are shown as entity-specific (i.e., for the City, TAP, and WSP, individually), and then combined (an average for all entities).

[23] Reference TAP CBA Part 1 Recommendation memorandum and City/WSP response memorandum for background discussions.

	SDOT		TAP		WSP		Combined	
	Capital Value Index	Life Cycle Value Index	Capital Value Index	Life Cycle Value Index	Capital Value Index	Life Cycle Value Index	Capital Value Index	Life Cycle Value Index
Alt 1	2.66	0.21	2.42	0.19	3.55	0.28	2.88	0.23
Alt 2	2.14	0.55	2.14	0.55	2.14	0.55	2.14	0.55
Alt 4	0.79	0.58	0.63	0.46	0.88	0.64	0.76	0.56
Alt 5	0.43	0.35	0.35	0.28	0.49	0.39	0.42	0.34
Alt 6	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13

Figure 48. Resulting Value Indices (0% Net Discount Rate)

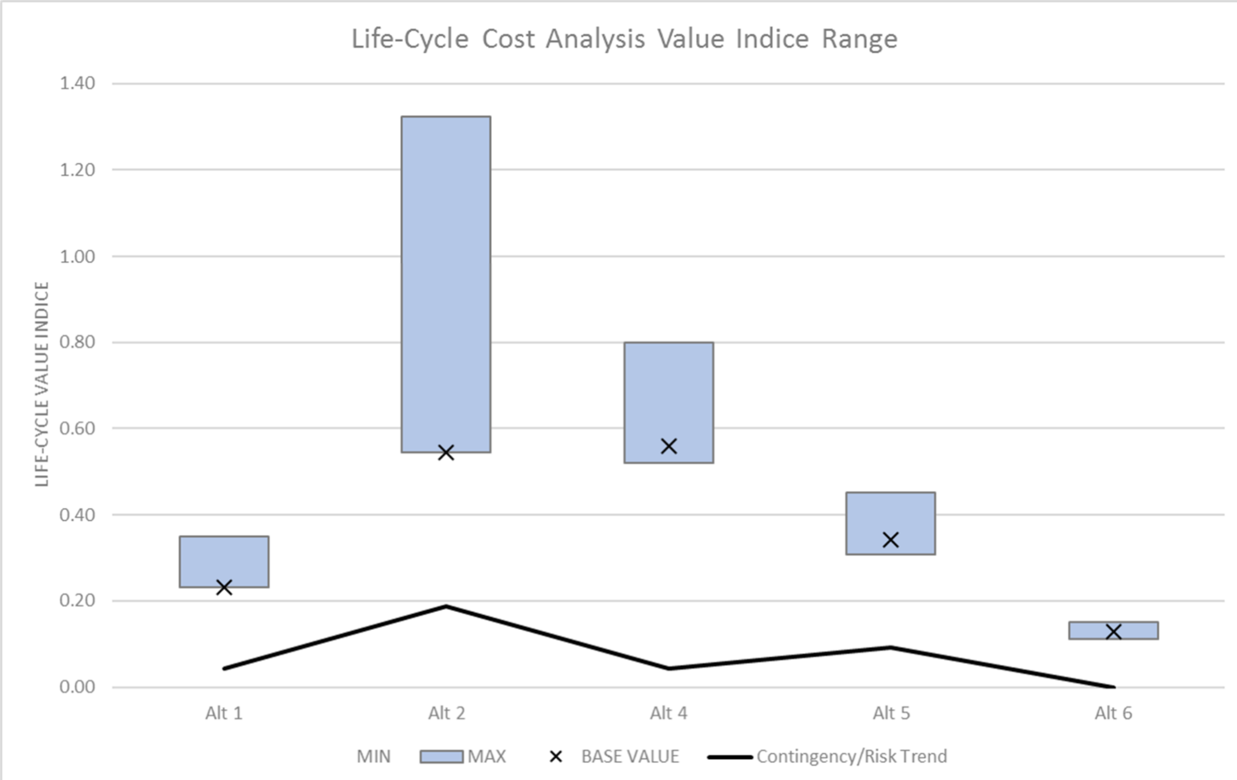
Interpretation of the base value indices requires an understanding of the sensitivity of key assumptions made within the CBA, and an understanding of the limitations of the CBA, which are discussed in Sections 6.2 and 6.3 below.

6.2 SENSITIVITY STUDIES

As a result of the conceptual nature of the work, the CBA's evaluation inherently includes assumptions about a wide variety of parameters. We have shown discrete values for performance, cost, and thus the value indices; however, it should be noted that there is variance in these findings. WSP conducted several sensitivity studies to determine the impact of specific assumptions on potential evaluation outcomes, to verify that these assumptions are not a controlling factor for the selection of the preferred alternative.

Each sensitivity study's findings are summarized individually in the below subsections. Figure 50 shows the aggregate effect of the sensitivity studies (i.e., Studies 1 through 3 – taken as the base value index for an alternative, multiplied by the product of the ratio of each study value index-to-the base value index). It also illustrates the opportunity value (or variance) in the potential value index for each alternative (i.e., the blue bar). The CBA index values based solely on the assumptions within the CBA (i.e., orange-colored dots) are located at the bottom of the ranges. The higher the value index, the better the return on investment. As shown by the height of the blue shaded bars, Alternative 2 has the highest potential for an increased value index relative to the other alternatives.

The contingency/risk trend line, determined by Sensitivity Studies 4 and 5 (below), represents the relative trends in potential increases in value index if the contingency and risk were adjusted from those used in the CBA. This is a relative trend line; actual adjustments would be a scaler multiple of the values shown. However, the trend line does show that Alternative 2 has the greatest potential for an increase in value index.



NOTES:

- Higher value indices represent better returns on investment.
- X's – "base value" indices based solely on assumptions within the CBA.
- Blue Bars – potential range in value indices based on the sensitivity study findings (Studies 1 to 3 – taken as the base value index for an alternative multiplied by the product of the ratio of each study value index-to-the base value index). Alternative 2 has the highest potential for increased value indices.
- Black Line – relative trend in potential additional value index increase if contingency and risk were removed from the assessment. Alternative 2 has the highest potential for increase.

Figure 49. Life Cycle Value Index Sensitivity (Opportunity Value)

SENSITIVITY STUDY 1: DISCOUNT RATE UNCERTAINTY

The CBA uses a net zero discount rate based on consultation with SDOT. A zero net discount rate is outside of national averages and implies that the absolute discount rate and the inflation rate are equal. National average net discount rates for bridge structures are between 2 and 4 percent. As these are future predictions, and actual net discount rates are not yet known, we conducted a sensitivity analysis using a net discount rate of 3 percent, in-line with national averages. Figure 50 illustrates the changes in life-cycle value index if the net discount rate were changed to 3 percent.

If the net discount rate were changed to 3 percent, the rehabilitation alternative (Alternative 2) provides a better long-term return on investment (by 76 percent) than the zero percent net discount rate used in the "base" reporting (Section 6.1). Other alternatives fare similarly, but the value indices show a smaller percentage change. This indicates that the opportunity cost of time and investments made today hold more value than investments in the future.

	Base CBA Values (0% Net Rate)			Adjusted Values (3% Net Discount Rate)		
	Performance	Capital Value Index	Life Cycle Value Index	Performance	Capital Value Index	Life Cycle Value Index
Alt 1	360	2.88	0.23	360	2.88	0.34
Alt 2	500	2.14	0.55	500	2.14	0.97
Alt 4	563	0.76	0.56	563	0.76	0.80
Alt 5	527	0.42	0.34	527	0.42	0.45
Alt 6	362	0.13	0.13	362	0.13	0.15

Figure 50. Life-Cycle Value Change (3 percent versus 0 percent Net Discount Rate) – Sensitivity Study

SENSITIVITY STUDY 2: ALTERNATIVE 2 SERVICE LIFE IMPACTS

Alternative 2 assumes that the existing bridge will be in service for another 40 years, thus achieving its original 75-year design life (begun in 1984). Consistent with other structures within SDOT's inventory, there is a good chance the bridge could last more than its prescribed design life if it were rehabilitated (Alternative 2). Recognizing that there are risks that could prohibit the bridge from achieving its prescribed service life (see Section 5), the Alternative 2 reported costs include a monetized risk associated with a 15-year service life rather than a 40-year service life (following rehabilitation)[24]. Our analyses to-date indicate that the probability that the bridge would not serve its remaining 40 years (out of a 75-year total service life) is low, much lower than the 25 percent risk factor recognized in the "base" value index reporting for Alternative 2. Monitoring and instrumentation have shown that the bridge is responding positively to bridge stabilization measures. We are observing that actual measurements from construction correlate well to predictions from the structural analysis model. This further supports the viability of Alternative 2.

Removing the risk monetization associated with a limited service life of 15 years reduces Alternative 2's overall life cycle costs to $745M, which would change its life cycle value index to 0.67 from 0.55 (a 22 percent change) as shown in Figure 52. The results of this sensitivity study indicate that Alternative 2 would provide the best return on investment for both a capital cost and life cycle cost perspective.

	Base CBA Values			Adjusted based on Alt 2 Service Life Impact Study		
	Performance	Capital Value Index	Life Cycle Value Index	Performance	Capital Value Index	Life Cycle Value Index
Alt 1	360	2.88	0.23	360	2.88	0.23
Alt 2	500	2.14	0.55	500	7.98	0.67
Alt 4	563	0.76	0.56	563	0.76	0.56
Alt 5	527	0.42	0.34	527	0.42	0.34
Alt 6	362	0.13	0.13	362	0.13	0.13

Figure 51. Alternative 2 Service Life Impacts – Sensitivity Study

SENSITIVITY STUDY 3: EXISTING BRIDGE SEISMIC/SAFETY PERFORMANCE

We conducted the CBA assuming that the existing bridge would be classified seismically as "normal" for Alternative 2 (see Section 3.2.10). We seismically classified the replacement alternatives as "essential." The difference in classification relates to the bridge's ability to return to service after the design earthquake. A "normal" classification ensures that the bridge does not collapse, thus maintaining life safety, but it does not require the bridge to be serviceable after the earthquake. An "essential" classification requires the bridge to undergo less inelastic

[24] WSP originally selected a lower-bound service life of 15 years for the sensitivity study based on initial unknown seismic bridge deficiencies (i.e. lowest end of anticipated service life defined by the Federal Highway Administration Seismic Retrofitting Manual). Based on findings from the CBA seismic assessment, the existing bridge behaves well seismically, and the risk the bridge does not serve its remaining service life based on inadequate seismic performance, is low, once the Phase II rehabilitation is conducted.

deformation, so that the bridge could be returned to service within a defined timeframe after the earthquake, likely two to three months. As a result of this difference in seismic performance requirements, the replacement alternatives scored higher relative to the rehabilitation alternative.

The CBA classified Alternative 2 as “normal” for consistency with standards used to evaluate all other bridges within the City’s bridge inventory. However, after a preliminary seismic evaluation of the existing WSHB structure, we have concluded that the structure appears to be very well detailed and can accommodate deformations beyond both the “normal” and “essential” classification limits. Thus, since the existing bridge technically meets the “essential” criteria, it could have been classified as “essential,” achieving the same required performance level as the replacement alternatives. As a result, the relative performance score of the rehabilitation alternative to the replacement alternatives would be less. FIGURE 52 illustrates the difference if the CBA scored the replacement alternatives as “7” versus “9” for the seismic/safety attribute, as was reported for the “base” performance scores.

	Base CBA Values			Adjusted based on Seismic Performance Study		
	Performance	Capital Value Index	Life Cycle Value Index	Performance	Capital Value Index	Life Cycle Value Index
Alt 1	360	2.88	0.23	366	2.92	0.23
Alt 2	500	2.14	0.55	500	2.14	0.55
Alt 4	563	0.76	0.56	524	0.71	0.52
Alt 5	527	0.42	0.34	475	0.38	0.31
Alt 6	362	0.13	0.13	312	0.11	0.11

Figure 52. Seismic/Safety Performance – Sensitivity Study

Since Alternative 2 represents the baseline alternative, its performance score did not change as part of the study. Instead, the other alternative scores decreased relative to Alternative 2. Looking at Alternative 4, the highest performing alternative, its performance score reduced by approximately 7 percent as compared to the values reported in the base CBA performance scores. This trend in adjustments to the performance scores and resulting value indices favors Alternative 2 when compared to those developed around the base set of assumptions.

SENSITIVITY STUDY 4: COST CONTINGENCY IMPACTS

Developing cost information during preliminary design stages is difficult. In consultation with the City, WSP applied allowances to ROM cost estimates to address incomplete designs, unknown project issues, incomplete coordination with project stakeholders, etc. Developing cost information for multiple alternatives at different stages of design adds another layer of complexity to an already complicated analysis. For example, we advanced Alternative 2’s design to a level beyond the design for the other alternatives, because of its technical similarities to current stabilization work (which WSP designed).

Figure 53 below illustrates the trend shift in LCCA value indices when we removed cost contingencies. Alternative 4 shows the best long-term return on investment, with the best life cycle cost performance. Alternative 1 shows the best short-term return investment.

	Base CBA Values			Adjusted for Zero Cost Contingencies		
	Performance	Capital Value Index	Life Cycle Value Index	Performance	Capital Value Index	Life Cycle Value Index
Alt 1	360	2.88	0.23	360	5.49	0.34
Alt 2	500	2.14	0.55	500	2.35	0.69
Alt 4	563	0.76	0.56	563	1.09	0.84
Alt 5	527	0.42	0.34	527	0.57	0.48
Alt 6	362	0.13	0.13	362	0.25	0.24

Figure 53. Life Cycle Value Indices without Contingencies

SENSITIVITY STUDY 5: RISK MONETIZATION IMPACTS

The CBA attempted to monetize risks that would directly impact project costs and that could be approximated within the CBA's accelerated timeframe. We avoided double-counting monetized risk (i.e., monetizing multiple risk items that would add cost for the same bridge component). We did not monetize risks such as socioeconomic impacts, which are associated with the project but have an indirect impact. WSP recommends that this be investigated in future studies. The magnitude of the captured monetized risk items is relatively high, and cost percentages differ for each alternative.

Figure 54 below illustrates the trend shift in the LCCA value indices, per alternative, if the monetized risk were removed from the CBA. Alternative 2 shows the best short- and long-term return on investment, scoring higher than any other alternatives for the capital value index and the LCCA value index.

	Base CBA Values			Adjusted for Zero Monetized Risks		
	Performance	Capital Value Index	Life Cycle Value Index	Performance	Capital Value Index	Life Cycle Value Index
Alt 1	360	2.88	0.23	360	2.88	0.34
Alt 2	500	2.14	0.55	500	8.73	1.06
Alt 4	563	0.76	0.56	563	1.22	0.80
Alt 5	527	0.42	0.34	527	0.78	0.55
Alt 6	362	0.13	0.13	362	0.15	0.14

Figure 54. Life Cycle Value Indices without Monetized Risk

SENSITIVITY STUDY 6: ACCELERATED CONSTRUCTION DURATION IMPACTS

As the duration of the corridor closure is a primary variable that factors into multiple attribute measurables, WSP conducted a sensitivity study to understand how performance scores could change in the event of an accelerated design and construction process. Figure 55 shows the resulting assumed potential duration reductions.

When subject matter experts considered these duration changes relative to determination of attribute performance values, they determined that there was no significant change in the alternatives' performance scores. Likewise, the change in overall life cycle cost was minimal; this shows that this crucial variable was not sensitive to direct projects impacts as defined by the CBA.

Even with a difference between replacement alternatives versus shoring or rehabilitation, the difference does not change the overall value index trend from a long- or short-term perspective. This is likely because the magnitude of differences between alternatives remains the same, even if the numbers themselves change.

	Alt 1	Alt 2	Alt 4	Alt 5	Alt 6
Standard Schedule	Duration (mo.)	Duration (mo.)	Duration (mo.)	Duration (mo.)	Duration (mo.)
Initial Design (bridge closed)	6	6	18	18	42
Initial Construction (bridge closed)	39	13	46	44	66
Later New Bridge Construction (bridge closed)	44	44	-	-	-
Total Corridor Closure (through 2100)	89	63	64	62	108

Accelerated Schedule	Duration	Diff	Duration	Diff	Duration	Diff	Duration	Diff	Duration	Diff
Initial Design (bridge closed)	6		6		6	(-12)	6	(-12)	30	(-12)
Initial Construction (bridge closed)	27	(-12)	7	(-6)	37	(-9)	35	(-9)	57	(-9)
Later New Bridge Construction (bridge closed)	35	(-9)	35	(-9)	-		-		-	
Total Corridor Closure (through 2100)	68		48		43		41		87	

Figure 55. Potential Durations Based on Accelerated Construction (Minimized Corridor Closures)

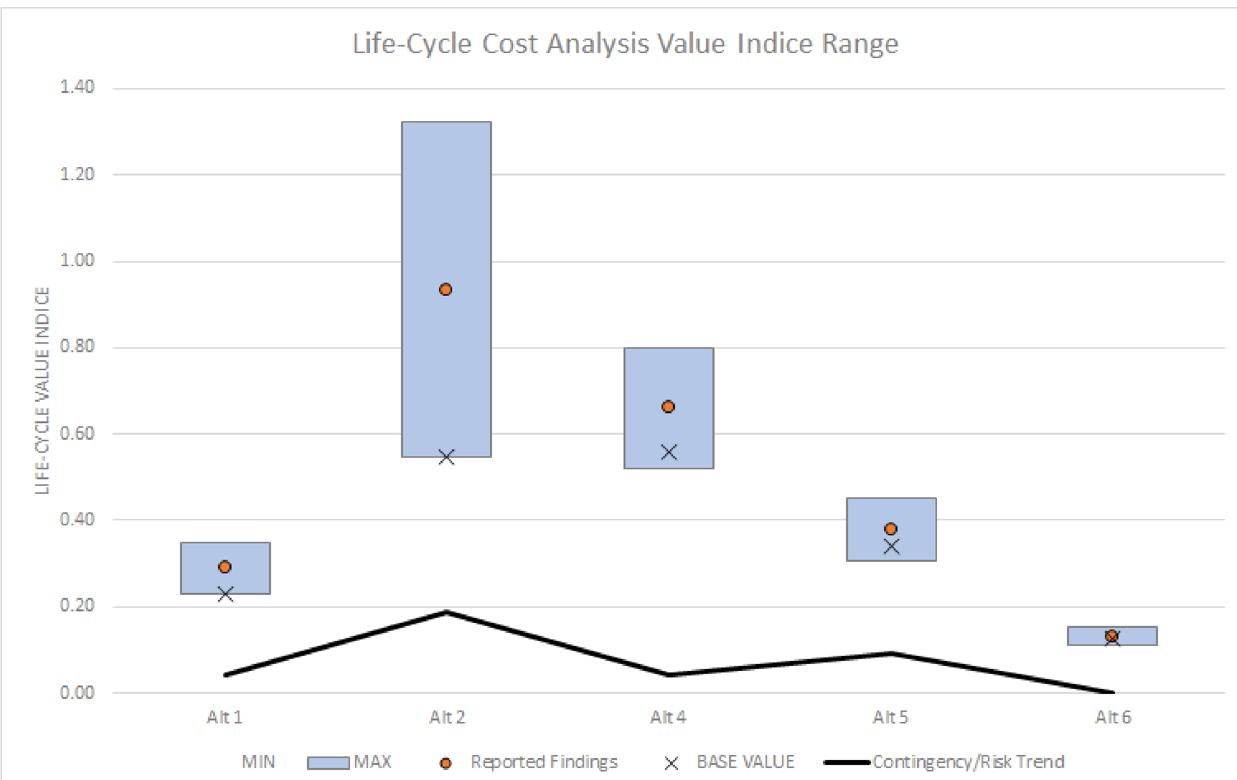
Although using an accelerated schedule resulted in no net change in the reported CBA findings, the CBA does not quantitatively address socioeconomic impacts caused by schedule. Significant socioeconomic impacts are associated with the WSHB closure – we anticipate that an accelerated schedule would decrease negative impacts. The additional duration required to design and construct a replacement structure, along with potential schedule slip risks, as compared to rehabilitating the bridge, would likely favor rehabilitating the bridge versus replacing the bridge, especially when considering the opportunity cost of time.

6.3 SUMMARY OF FINDINGS

Figure 56 and Figure 57 present a summary of the CBA's findings. Findings are reported in the form of a value index – the ratio of performance to cost – which measures return on investment: a higher value index correlates to a higher return on investment, and vice versa.

To illustrate the process, we determined a base set of values using the performance scores and costs presented in Sections 3 and 4. We developed these "base values" purely on the assumptions made within the CBA (base values are represented by the X's in Figure 56).

The "reported findings" take into account the sensitivity of key assumptions made within the CBA (Section 6.2). The "reported findings" are represented by the orange dots in Figure 56. These represent the subject matter experts' conservative best estimation of the value indices for each alternative –the averaged results of the sensitivity studies. Figure 56 and Figure 57 illustrate that Alternative 2 has the highest value index and the highest potential for an increase in value index as compared to the other alternatives.



NOTES:

- Higher value indices represent better returns on investment.
- X's – "base value" indices based solely on assumptions within the CBA.
- Orange Dots – "reported findings" conservatively taken as the average of the sensitivity studies conducted.
- Blue Bars – potential range in value indices based on the sensitivity study findings. Alternative 2 has the highest potential for increased value indices.
- Black Line – relative trend in potential additional value index increase if contingency and risk were removed from the assessment. Alternative 2 has the highest potential for increase.

Figure 56. CBA Reported Findings - Graphical

Alternatives	Performance Score Range			Capital Value Index Range			LCCA Value Index Range		
	MIN	BASE	MAX	MIN	BASE	MAX	MIN	BASE	MAX
Alt 1	360	360	366	2.88	2.88	2.92	0.23	0.23	0.35
Alt 2	500	500	500	2.14	2.14	7.98	0.55	0.55	1.32
Alt 4	524	563	563	0.71	0.76	0.71	0.52	0.56	0.80
Alt 5	475	527	527	0.38	0.42	0.38	0.31	0.34	0.45
Alt 6	312	362	362	0.11	0.13	0.13	0.11	0.13	0.15

CBA Reported Findings				
Performance	Capital Costs	Capital Value Index	LCCA Costs	LCCA Value Index
362	$124.8M	2.90	$1,248.8M	0.29
500	$98.8M	5.06	$535.1M	0.93
550	$773.3M	0.71	$833.4M	0.66
509	$1,337.1M	0.38	$1,341.4M	0.38
345	$2,780.5M	0.12	$2,630.6M	0.13

Figure 57. CBA Reported Findings - Tabularized

7 CBA LIMITATIONS & FUTURE STUDIES

The scope of this CBA was limited, as WSP has not advanced the five alternatives presented here to the level of design that would allow for an exhaustive analysis of costs, risks, or other forms of quantitative or qualitative study. particularly for attributes and performance. The CBA is, first and foremost, a tool to help illuminate some of the benefits and drawbacks of rehabilitation and replacement. While it is true that there are multiple alternatives contained herein, the output of this report is by nature binary.

WSP anticipates that, regardless of the decision to rehabilitate the existing structure or replace it with a new one, the City will pursue future studies. As future studies and phases commence, WSP, with input from the Port of Seattle, the Northwest Seaport Alliance, the CTF, the TAP, and the City, identified the following, non-exhaustive list of items we recommend be further explored:

- **Funding Opportunities** The CBA identified funding opportunities as a key attribute. Future work/studies on the project should consider not only a list of expanded funding opportunities, but also include how they relate to decisions related to rehabilitation versus replace and the timing of those decisions, as it pertains to available funding, and the necessary funding for the rest of the City's transportation infrastructure.
- **Approach Structure Assessment** The CBA did not consider modifications to the approach structures, as WSP did not do an in-depth analysis of their condition. Replacing the high-rise structure without assessing the condition of the approach structures may limit future corridor investment opportunities and understanding of funding needs ahead of coordinating with key project stakeholders.
- **Bridge Type Selection** The CBA identified an in-kind (i.e., concrete box girder) superstructure replacement for Alternative 4. Selection of alternate superstructure types and framing could have a negative impact on the existing bridge components to remain (especially the foundations). Concepts could also include increased inspection and maintenance costs (i.e. selection of a fracture critical structure and/or use of seismic isolation bearings). These costs have not been monetized in the CBA and should be investigated as part of future phases of work.
- **Duration of Service Life Assessment** The CBA service life assessment ended in 2100, which corresponded to the end of the design life for Alternative 4. The salvage value of alternatives with remaining service life were accounted for within the CBA; however, variations in the duration of the service life assessment may change the value of the life-cycle cost assessment. It may be desirable to investigate this further in future phases of work, however, it is anticipated to have minor impacts on the findings (resulting value indices) based on sensitivity studies conducted as part of the CBA.
- **Construction Uncertainties** The alternatives have differing levels of construction risk (i.e. in-water work activities, utility work, construction of foundations, etc.) that could lead to risks of claims, cost escalation, and schedule lag. These are more prevalent with the replacement alternatives than the rehabilitation alternative. For the purpose of the CBA, a constant 20-percent value was included for each alternative. This should be further investigated in future phases of work.
- **Quantification of Socioeconomic Impacts** The CBA qualitatively addressed socioeconomic impacts such as road-user costs; subject matter experts used this information in the performance scoring part of the CBA. The socioeconomic impacts were not monetized as part of the risks, capital costs, or life-cycle costs. The analysis did underscore the importance of minimizing the closure duration to reduce socioeconomic impacts, especially the duration of immediate closures.
- **Federal Aviation Administration Height Restrictions** The project site's proximity to Boeing Field may require height restrictions on the structure and its appurtenances, limiting the types of bridge replacement concepts. WSP recommends that the City and future studies coordinate with Boeing Field to eliminate this risk.
- **Equity Impacts** The CBA qualitatively assessed equity impacts, focusing primarily on the effects of the closure's detour routes *through* marginalized communities. There remains a multitude of other equity-related factors that should be considered, including the impacts on vehicle and transit users from marginalized communities, namely, the users of these detours. Other studies could also focus on the closure's impacts on small or local businesses specific to these communities.
- **Defining Marginalized Communities** The CBA focused on race in its definition of marginalized communities, as 59 percent of SDOT's diversion routes are through communities with relatively high percentages (23 to 89 percent) of people of color. Future studies could assess the closure's effects on communities based on income status, disability, immigrant population, and/or populations that do not speak English as a first language, and others.

- **Equity in Final Configuration** The CBA focused on equity impacts during the closure. Future studies should also assess equity in the crossing's final configuration.
- **Utility Service Impacts** We developed the CBA in an accelerated manner and did not do a detailed review of all utilities and their services throughout the project site. Future phases of work should develop a detailed understanding of the utility services and their potential impacts to minimize risks and potential schedule delays.
- **Environmental Impacts** The CBA was not a type, size, and location study. Alternatives were concepts developed based on apparent low cost. We identified conceptual construction schedules and potential site impacts, but future studies should develop a detailed understanding of all environmental impacts, including design and construction means and methods that could exacerbate them.
- **Environmental Impacts from Dredging** As stated above, the CBA was not a TS&L. We recommend that any future studies assessing the feasibility of the immersed tube tunnel focus on environmental impacts and potential hazardous materials from dredging the Duwamish River, which is a Superfund site.
- **Seismic Classification** All bridges within the current SDOT bridge inventory are classified as normal, and their assessment is covered by national standards augmented with City standards. A normal classification means that the bridge will maintain life safety after the design earthquake, but may not be serviceable afterwards, requiring replacement. Investment in a replacement structure on a key corridor such as the West Seattle corridor may require consideration of a higher performance criteria so the bridge could be serviceable immediately after the design earthquake, or shortly thereafter. The City and their consultants would need to develop project-specific criteria to specify higher performance criteria (i.e., "essential"). This requires time, and careful consideration of pending industry code changes, both geotechnical and structural (i.e. upcoming changes in USGS hazards, M-9 effects, NCHRP-12-106, etc.). There is also an added layer of complexity if multi-agency input is required.
- **Formal Risk Assessment** The CBA includes a risk registry, however, does not follow any formal risk modeling process, such as WSDOT's Cost Estimate Validation process. Future phases of work should consider the merit of more robust analytical tools for assessing and monetizing risks.
- **Condition Assessment of Key Corridors** Identifying the City's key corridors and how they currently compare to the West Seattle corridor in regards to importance, average daily traffic, number of bridge structures, their age, condition, and approximate cost to repair/replace the bridge structures; to determine priority for the City's infrastructure investments and to support decisions related to potential multi-agency operated structures.
- **Multi-Agency Development Plans** The project is constrained within a built environment that is key to the local and regional economy. Both the Port of Seattle (Terminal 5 Expansion) and Sound Transit (West Seattle to Ballard Link Extension) have development plans that could be affected by this project due to proximity and usage. Coordination amongst the agencies will be important to avoid placing further constraints on development plans. Future studies could provide an opportunity to optimize the potential for all agencies.
- **Forward Compatibility with Heavy Rail** The CBA did not explore opportunities for a replacement's forward compatibility with BNSF rail.
- **Future Coordination with Sound Transit** Future studies, particularly the TS&L, need to further assess the potential to accommodate light rail, structurally, geometrically, and from an asset management perspective (differing service life criteria, responsibilities, etc.). Accommodation of light rail may impact structure type decisions and the grade/profile decisions.
- **Maritime User Impacts** The CBA focused on land-based mobility impacts, specifically those on motor vehicle users and neighborhoods seeing increases in traffic. We recommend that future studies delve further into the project's impacts on the maritime community, including river mobility, industry use, and maritime recreation. It is also imperative for the local economy that the project minimize impacts on the Port of Seattle's operations, and we recommend further coordination with the Port to achieve this.
- **Railroad Impacts** The CBA focused on land-based mobility impacts, specifically those on motor vehicle users and neighborhoods seeing increases in traffic. We recommend that future studies further examine potential impacts to railroad traffic from the WSHB closure. Discussions and coordination with railroad operators such as BNSF and UPRR could be helpful.
- **Tribal Coordination** Because of its limited scope and duration, the CBA was not able to capture impacts to tribal fishing rights or examine the details of the treaties with local tribes. However, this coordination will be critical to project success. The City of Seattle recognizes all tribal treaties and so it is important that this perspective be incorporated into design and construction means and methods.

8 ACKNOWLEDGEMENTS

This report would not have been possible without the support of the Mayor of Seattle, the Seattle City Council, the Technical Advisory Panel, and the Community Task Force. In addition, we would like to recognize in particular the contributions of the indefatigable Seattle Department of Transportation team, and most of all, we would like to acknowledge the people of Seattle. The West Seattle Bridge belongs to them, and this project is dedicated to them.

9 REFERENCES

APPENDIX