Oregon Department of Transportation

US 97 Benefit-Cost Analyses Using HERS-ST

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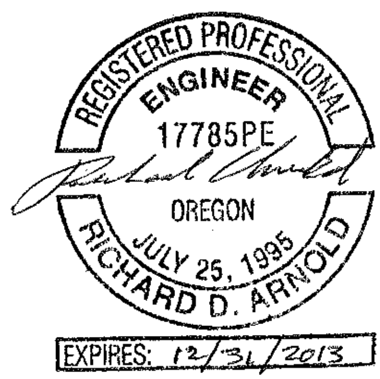

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List of Acronyms

AADT	Average Annual Daily Traffic
AES	Average effective speed
APLVM	Aggregate Probabilistic Limiting Velocity Model
BCR	Benefit-Cost Ratio
BMPO	Bend Metropolitan Planning Area
CRAC	Crash Costs
EIS	Environmental Impact Statement
FFS	Free-flow speed
FHWA	Federal Highway Administration
HCM	Highway Capacity Manual
HERS-ST	State version of the Highway Economic Requirements System
HPMS	Highway Performance Monitoring System
MPH	Miles per hour
ODOT	Oregon Department of Transportation
OPC	Operating Costs
ROW	Right-of-way
RV	Residual Value
TPAU	Transportation Planning Analysis Unit
TTC	Travel Time Costs
TUC	Total User Costs
VCR	Volume-to-capacity ratio
VMT	Vehicle miles traveled

Executive Summary

Over the past decade, the northern area of the City of Bend has undergone considerable business growth and change. The area known locally as the "Cooley Triangle" has been the location of choice for many retail organizations moving into this Central Oregon community. With growth comes traffic and increased congestion, which only adds to the current congestion issues. The location makes it extremely attractive for future retail development, which will result in greater congestion. Traffic analysis of this area is important for planning how the area develops, grows and flows.

This project analysis evaluated changes in long-range system performance measures and looked at economic benefits for improving the roadway system based on a generic benefit-cost ratio (BCR) concept. A number of system performance measures were evaluated using the state version of the Highway Economic Requirements System (HERS-ST). Based on the BCR concept, the analysis looked at economic benefits for two roadway scenarios:

- The No-Build Scenario was the existing roadway system, with no signal or widening improvements.
- The Build Scenario added a new bypass alignment, as well as some moderate widening and intersection signalization improvements, on several roadway systems within the immediate area.

The HERS-ST model evaluated each scenario as if it were operational at the beginning of the analysis period. The analysis addressed the question, "What is the long-range system user costs and performance for this condition?"

The regional significance of the US 97 bypass project and five roadway alignments were identified as key transportation facilities for analysis within the immediate area of the proposed project. Both Build and No-Build scenario datasets were developed for the five alignments and the HERS-ST model was used to evaluate and compare the system condition and performance for each alignment, as well as the total user costs. The average segment peak speed, peak delay, and volume-to-capacity ratio (VCR) analyses showed reasonable improvement for the Build scenario, as compared with the No-Build scenario.

The performance improvements are due to the added bypass alignment and the other improvements to the local infrastructure that enhance the flow in and through the project area. The bypass alignment pulls a large number of trips off the existing US 97 alignment that are considered "pass-through" trips because they do not stop within the project area. Pulling the pass-through trips out of the general flow has advantages both to the general performance of the regional system and to safety and travel cost savings as well. As a result of the improved flow, the travel time, operational costs and crash costs are reduced for the general users of the facilities, which can be directly measured with the BCR analysis.

The capital improvement cost was evaluated using two different contingency costs: 25% and 40%. The analysis showed a BCR range of 1.48 and 1.40 for a 25% and 40% contingency, respectively. These numbers are rough estimates for high level planning purposes. A detailed analysis should be conducted to develop a precise BCR.

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Introduction

Over the past decade, the northern area of the City of Bend has undergone considerable business growth and traffic change. The area known locally as the "Cooley Triangle" has been a continued location of choice for many retail organizations moving into this Central Oregon community. With growth comes increased traffic and its associated congestion. There are existing congestion issues in this area, and its attractiveness for additional retail development will only lead to greater congestion issues in the future. Traffic analysis of the area is important in planning for the area's development, growth and traffic flow.

Numerous studies have been developed for this northern Bend area over the years, resulting in the US 97/20 Refinement Plan. The plan indicated a need for a new bypass around the area rather than reliance on improvements to the existing facility to meet all the traffic needs. This plan transitioned into the US 97 Bend North Corridor Environmental Impact Statement (EIS), which looked at many different project scenarios before settling on the east corridor alternative.

The original costs for the larger-scale alternative solutions recommended to address the transportation needs were estimated at $350-$400 million, which far exceeded the region's available funding stream for the next 20 years, so the likelihood of full funding seemed unlikely. The project team sought to investigate smaller-scale solutions that would begin to address the system needs at a more reasonable cost. The HERS-ST analysis was undertaken to help inform decision-makers on the range of funding levels that could produce the highest value to the state[1].

HERS-ST Process

The HERS-ST model uses an input dataset formatted in the standard Highway Performance Monitoring System (HPMS), where each data record represents a unique roadway segment. The analyst defines the timeframe for the HERS-ST analysis period. The general analysis consists of four five-year funding periods for a total 20-year analysis period.

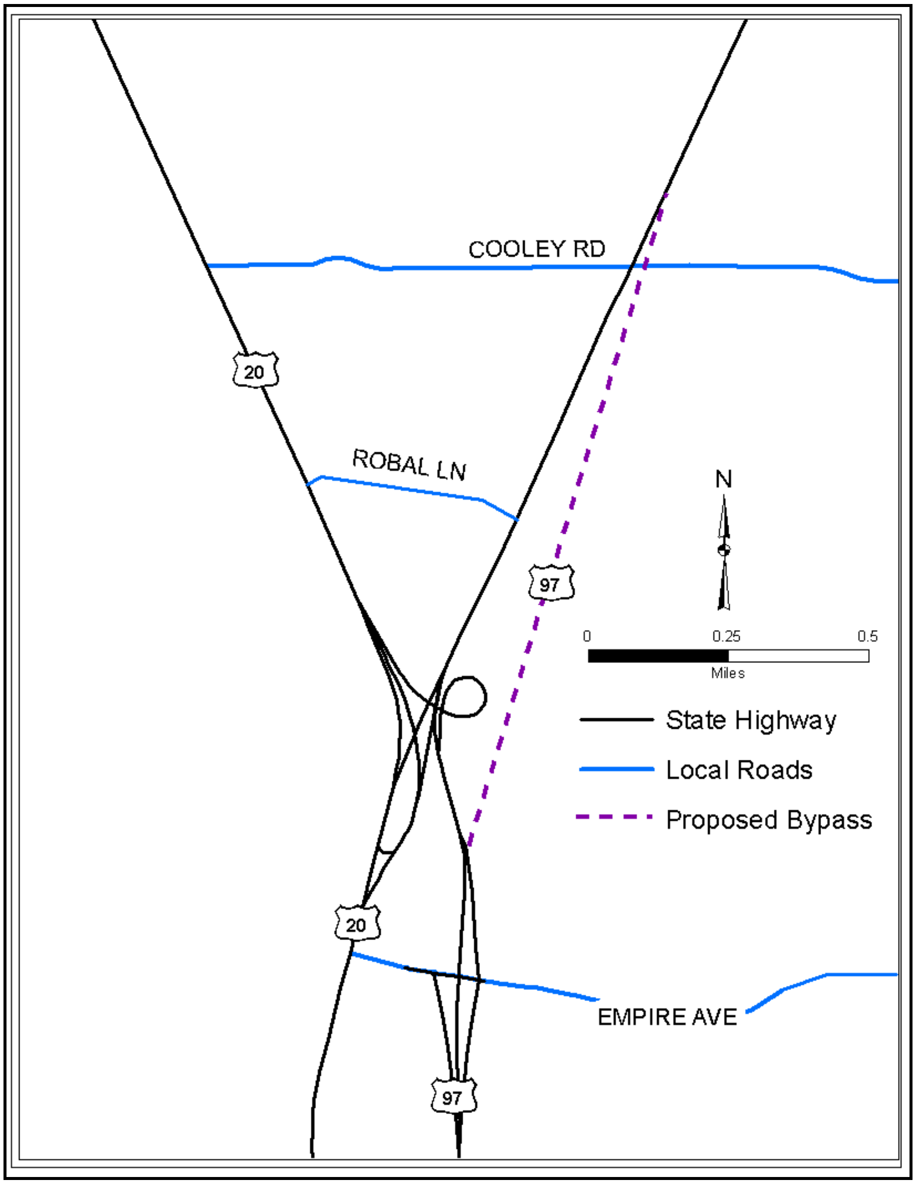
For each funding period, the HERS-ST model evaluates the individual data record one at a time, independent of all other records, to determine potential pavement or capacity deficiencies on the roadway system, as defined by the user. For each deficiency, the HERS-ST model uses a benefit-cost analysis process to evaluate a number of potential improvements to determine economically cost-effective solutions to correct the problem. The best economical improvement is then implemented and simulated in the analysis and the resulting system performance is reported.

[1] This analysis covers the roadway segments within the project footprint.

Analysis Data

The project is located in the north-central area of the Bend Metropolitan Planning Area (BMPO), known locally as the "Cooley Triangle" (see Figure 1). Though the project area currently has congestion issues, the specific location is extremely attractive for retail development, which will result in greater congestion issues in the future. Traffic analysis for this area is essential to evaluate future traffic flows in and through the project area.

Figure 1: US 97 Bend North Corridor (i.e., Cooley Triangle) Study Area



Two scenarios were analyzed for this project:

- No-Build: Reference case reflects the existing system, assuming no additional improvements beyond routine maintenance.
- Build: New bypass alignment, with various local road improvements.

The project improvements include a north-south bypass alignment (see Figure 1), which is situated to the east of the existing US 97 alignment, as well as additional intersection and alignment improvements made to US 20 and other local roadways.

In order to capture the total impacts of the proposed project analysis, the HERS-ST analysis evaluates five individual roadway alignments within the project area:

- US 97: Bowery Lane – Butler Market Road;
- US 20: Old Bend-Redmond Highway – Mervin Sampels Road;
- Cooley Road: US 20 – Boyd Acres Road;
- Empire Avenue: US 20 – Boyd Acres Road;
- Robal Road: Britta Street – Nels Anderson Road.

The base year for the project is 2016 and the horizon year is 2036, which reflects the 20-year analysis period for the project. For a direct comparison both scenarios utilize the same time periods.

The No-Build scenario is the base case that reflects the existing system layout, assuming that no improvements are made other than routine maintenance. Separate HERS-ST input datasets were built for each of the five roadway alignments. The dataset development process began with importing key traffic data elements provided by the Transportation Planning Analysis Unit (TPAU), such as base and horizon year average annual daily traffic (AADT), truck percentages for single units and combinations, peak hour traffic factors, direction factors, signal control locations and lane configurations The input data was checked using the Oregon Department of Transportation's (ODOT) video log and on-line mapping images to ensure that the data correctly reflects the existing condition.

The pavement condition was defined as "perfect" at the beginning of the analysis period in order to minimize improvement analysis within HERS-ST and to avoid introducing an additional complication factor in the BCR analysis. It was generally assumed that the pavement condition would continue to deteriorate over the 20-year analysis period and that resurfacing would be required at or near the end of the analysis period. The local costs for resurfacing, when warranted, use national improvement costs.

The Build scenario is based on the "Alternative East DS2 Modified" traffic analysis data provided by TPAU. Various data element changes were applied to the Build scenario dataset to reflect the proposed project improvements for the roadway systems. The easterly bypass alignment was coded as an urbanized expressway with full access control, and the number of lanes and speed values were coded as two lanes per direction and 45 miles per hour (mph), respectively.

The five roadway alignments were run independently for the two scenarios. There were a total of ten HERS-ST model runs for this analysis project. The purpose of the analysis was to evaluate the relative differences in several key performance measures and the total costs between the two scenarios. The No-Build scenario was the reference datum for comparison with the Build scenario.

In order to develop a reasonable BCR, the user, agency and external costs were collected and compared through a post-process analysis outside of the HERS-ST model. The post-process discussion is presented in Appendix B.

Analysis Process

The Build and No-Build scenarios were run through the Federal Highway Administration (FHWA) HERS-ST (ver. 4.5) modeling software with the primary purpose of developing performance measures and total user costs for each scenario in order to facilitate comparisons.

The HERS-ST model was only allowed to identify pavement deficiencies and simulate resurfacing improvements on the roadway system, as warranted. The global widening feasibility flag was set to “one” so that no additional widening would be allowed on the roadway segments throughout the 20-year analysis period. This ensured that no additional improvement factors were introduced into the analysis to alter evaluations of the performance measures and total user costs.

To simplify the analysis, individual roadway alignments for each scenario were run independently. The post-processing compared performance measures and cost for the Build scenario against the No-Build scenario to evaluate the potential benefits associated with the project. Keeping the timeframe identical for two scenarios reduced the need to discount the improvement benefits back to different time periods and facilitated the post-process analysis of the results.

General Discussion

As a general assumption, the No-Build scenario for all alignments assumes no changes to alignment geometry over the 20-year analysis period. Traffic volumes will increase resulting in greater congestion, reduced travel speeds and increased delay.

The HERS-ST analysis identifies three broad classes of costs: user costs, agency costs and external costs. In all cases for this project analysis, HERS-ST incorporates national values for the various costs and rates. A detailed description of the various costs is presented in Appendix A.

The Total User Cost (TUC) is a sum of three subcategories: Travel Time Costs (TTC), Operating Costs (OPC) and Crash Costs (CRAC). The TTC is simply the cost of travel. The OPC is a function of numerous variables that can be adjusted by the analyst and includes the cost to the user of fuel and oil consumption, tire wear, vehicle maintenance and repair, and depreciation. The benefit associated with an increase in the speed is likely to be balanced with a disbenefit associated with an increase in vehicle operating costs. CRAC and crash rates are a function of safety issues on the roadway system. By removing conflict points, both crash rates and costs are generally reduced.

Agency costs are closely associated with the reduction in the cost of routine maintenance. External costs are a reflection of pollution damages associated with vehicle emissions. HERS-ST employs a set of tables to specify the national average cost of air pollutant emissions on each functional class generated per vehicle-mile, by vehicle class, and operating at various speeds. HERS-ST uses the projected mix of vehicle classes and the average speed of travel on each section to determine the average cost of emissions per vehicle-mile. This value is then multiplied by the total vehicle-mile forecasts to calculate the total cost of air pollutant emissions generated by travel on the section.

The benefits for this project are defined as a reduction in costs as a result of the implementation of an improvement, which is measured as the difference in total 20-year costs between the No-Build scenario and the Build scenario. The summation of the three cost elements for the No-Build scenario is subtracted from the summation of the same three elements for the Build scenario. The result is defined as a benefit (if positive) or disbenefit (if negative). Of the three cost categories (i.e., user costs, agency costs and external costs) the user costs control the benefits calculations, making up 99% of the total costs. Though the agency and external costs are important for other considerations, changes to user costs are essential for defining BCR.

US 97 User Costs

The No-Build scenario evaluated the existing US 97 alignment, whereas the Build scenario included both the “new” US 97 bypass alignment in addition to the “old” original alignment. The old highway segment was included in the Build scenario for the solo purpose of being able to capture the complete performance differences between the two scenarios that is associated with shifting of trips from the “old” to the “new” alignment. As an example, using a point just south of the Cooley Road intersection on the existing roadway, the 2036 AADT is 50,800 for the No-Build scenario and 23,000 for the Build scenario. This would suggest that 27,800 trips (55%) shift to the “new” bypass alignment defined in the Build scenario. However, the Build scenario analysis shows 42,000 trips on the “new” bypass, immediately adjacent to the point on the existing alignment. When the traffic on the “new” bypass is summed with the traffic on the “old” alignment, the Build scenario shows a 30% increase in total north-south flow through the area just south of Cooley Road.

In reality, a phenomenon called induced demand factors into the analysis such that as the roadway capacity on a system improves and traffic movement is freed, additional trips will be attracted to and through the area.

There are two components for the US 97 Build scenario. The first component compares the flows exclusively on US 97 between the two scenarios, i.e., the traffic flow that shifts from one alignment to the other. With the inclusion of the bypass alignment, the overall flow will be good, the speeds will be higher and the congestion and delay will be reduced, significantly improving the performance conditions on the rerouted US 97. The second, and more important component, is an analysis of how the performance on the existing alignment changes once the bypass is introduced into the analysis.

It is important to keep in mind that the 42,000 trips on the "new" bypass are predominately pass-through trips that do not stop within the study area, whereas the remaining 23,000 trips on the "old" alignment are coming from, or going to, places within the study area. It is important to track both alignments.

Analysis on the US 97 alignment reflects a 25% increase in system capacity to the current roadway system with the addition of the "new" US 97 bypass alignment in the Build scenario. The Build scenario shows a 9% increase in total peak VMT at the end of the 20-year analysis period. The VMT increase is due to the significant shift in travel from the "old" 3rd Street alignment to the "new" bypass alignment.

Using national safety statistics, HERS-ST evaluates the safety element of the roadway improvement by projecting changes in three crash rates: property damage only, injuries and fatalities. The three crash rates are defined within HERS-ST as the rate of which crashes, injuries and fatalities occur per 100 million VMT. Because the bypass alignment is expected to include controlled access to the system, the alignment analysis anticipates a significant reduction in conflict points, resulting in a reduction to the projected crash rates for the roadway system. The reduction crash rate ranges from 13% for fatalities (per 100 million VMT), to 20% for other injuries. This equates to an overall 15% net reduction in crash costs over the 20-year analysis period.

The reduction in the crash rates also contributes to a 41% reduction in average hours of incident delay. The inclusion of the access control element for the bypass alignment also results in a 10% reduction of zero-volume delay associated with intersections and stop/start cycles. The other-delay, which is generally associated with congestion, is reduced by 45% because of the shifting of trips to the bypass alignment. The bypass pulls the through trips from the 3rd Street alignment that fronts the shopping area and improves the travel flow for both alignments.

Over 99% of the total 20-year costs are associated with the TUC, which accounts for the travel time, operating and crash costs for the roadway alignment. The total 20-year TUC for the Build and No-Build scenarios are $1,457 million and $1,515 million, respectively, resulting in a 4% net saving (or benefit) in user costs between the two scenarios. Even though the VMT and the lane miles are increased for the Build scenario, the total user costs declines. This is directly associated with the improved overall flow on the system through the area, such as the access control element that reduces the conflict points and the stop/start cycles, and the shifting of through trips from the congested areas to a higher speed system.

US 20 User Costs

The Build scenario improvements include widening on US 20 and the addition of a signal at Cooley Road.

The Build scenario shows a net benefit of 7% ($53,600,000) when the total costs are compared with the No-Build scenario on US 20. The induced demand factor associated with the Build scenario increases the overall traffic flow by 8% on the US 20 roadway system, which equates to a reduction of 1% and 44% for the TTC and CRAC, respectively. The system improvements also demonstrate a 62% and 40% reduction in average hours of both incident and congestion delay, respectively.

Cooley Road User Costs

The Build scenario improvements include a new signal at US 20 and a four lane widening of the sections from US 97 west to Hunnell Road and from US 97 east to Boyd Acres Road.

The difference in total cost between the Build and No-Build scenarios show a net benefit of 8% ($14,300,000), which indicates the improvements to the Cooley Road produce a positive impact to the traffic flow in the area. The 20-year peak VMT for the Build scenario is reduced by 4%, which equates to a reduction of 9% for the TTC, 7% for the OPC and 2% for the CRAC. The system improvements also demonstrate a 36% reduction in average hours of both incident and congestion delay.

Empire Avenue User Costs

The Build scenario improvements include a new signal at the US 97 south bound on-ramp.

The Build scenario shows a net benefit of 6% ($13,300,000) when the total costs are compared with the No-Build scenario on Empire Avenue. The 20-year VMT for the Build scenario is reduced by 6%, which equated to a reduction of 11% and 4% for the TTC and OPC, respectively. Though there appears to be a slight increase in CRAC of 2%, which seems to be associated with the additional signalization improvements, the zero-delay only increased by 4%, while the average hours of incident delay are reduced by 55% and congestion delay are reduced by 32%.

Robal Road User Costs

For Robal Road, the Build scenario shows a net benefit of 9% when the total costs are compared with the No-Build scenario, which is a savings of -$4,700,000. The 20-year peak VMT for the Build scenario is reduced by 1%, which results in a 10% reduction for TTC, a 7% reduction for OPC and a 6% reduction for CRAC. The zero-delay decreased by 6%, while the average hours of incident delay are reduced by 51% and congestion delay is reduced by 34%.

Benefit-Cost Summary

All five roadway alignments demonstrate a cost savings benefit by virtue of the reduction of total costs (see Table 1).

Table 1: Percent Difference in Total Costs – 20-Year Summary[2]

Percent Reduction in Total Costs (%) Between Build and No Build Scenarios					
Costs Categories	**US 97**	**US 20**	**Cooley Rd**	**Empire Ave**	**Robal Rd**
Total User **(x $1,000)**	-4% (-$60,150)	-7% (-$53,740)	-7% (-$14,270)	-5% (-$13,280)	-9% (-$4,710)
Agency* **(x $1,000)**	38% ($2,000)	21% ($10)	37% ($10)	20% ($2)	0% ($0)
External **(x $1,000)**	1% (-$80)	3% (-$110)	-7% (-$50)	-4% (-$30)	-6% (-$10)
Total Costs **(x $1,000)**	-3% (-$58,100)	-7% (-$53,600)	-8% (-$14,300)	-6% (-$13,300)	-9% (-$4,700)

* Maintenance costs increase due to the new and improved

Because the TUC accounts for 99% of the total costs, changes within the agency and external costs contribute very little to the overall benefit analysis. Ignoring the latter two for the moment, the TUC can be primarily broken into three areas: TTC, OPC, and CRAC. The general ranges are 50-60% for TTC, 20-35% for OPC and 15-25% for CRAC. Of these three groupings, the contribution of the TTC is approximately twice the contribution of OPC and about three times that of CRAC. This suggests that though the TTC costs are the controlling factor, they are not overwhelmingly so, as compared with the TUC's overwhelming influence on the total cost calculations. This makes for an interesting dilemma because the general expectation is that as travel flow improves on a

[2] A negative number represents a reduction in costs and a positive number is an increase in costs.

system; the TTC would inversely decrease, resulting in travel time savings. However, as the travel flows increase (i.e., higher speeds), so does the OPC (i.e., higher operating costs) for a given scenario. Using the US 97 values in Table 2 as an example, the TTC decreases by 4% as a result of building the bypass alignment; the traffic flow throughout the area improves, while at the same time the OPC increases by 2%.

Table 2: Percent Difference in Total User Costs – 20-Year Summary[3]

Percent Reduction in Total User Costs Between Build and No Build Scenarios					
Costs Categories	**US 97**	**US 20**	**Cooley Rd**	**Empire Ave**	**Robal Rd**
Travel Time (TTC)	-4	-1	-9	-11	-10
Operating (OPC)	2	7	-7	-4	-7
Crash (CRAC)	-15	-44	-2	2	-6
Total User Costs **(x $1,000)**	-4% (-$60,100)	-7% (-$53,700)	-7% (-$14,300)	-5% (-$13,300)	-9% (-$4,700)

Residual Value

The final factor in the BCR equation is the residual value (RV), which addresses the capital value of the project that remains at the end of the analysis period and covers continued future value of improvement beyond the analysis period. This is an important asset management measure that attempts to capture a pseudo-salvage value of an improvement discounted back to the beginning of the analysis timeframe (similar to getting credit for the unused portion of an investment).

For the purpose of this analysis, the RV is a function of the capital improvement cost. The estimated construction costs were provided with two construction cost contingencies, 25% and 40%. It will be assumed that the total project costs cover the $76.6 million purchase price for procuring right-of-way (ROW) for the Build scenario; $9.4 million of the construction costs are dedicated to structural construction (i.e., overpasses and ramps); and the remaining $46.8 million accounts for standard earthwork, pavement construction and overlay costs, signalized intersections and general additional construction costs. Construction and preliminary engineering is expected to cost between 20-25% of the total construction costs; these costs are not included in RV.

Right-of-Way

The Asset Management Unit acknowledges that the value of land has an indefinite life. However, they prefer to treat it from an accounting perspective as a land asset rather than as a residual value. Because the ultimate purpose of this analysis is to look specifically at the project's costs and benefits, the ROW is assumed 100% RV. The land that is acquired as part of the project costs will not lose its value and can be sold for

[3] A negative number represents a reduction in costs and a positive number is an increase in costs.

development at a later time if the roadway were to be removed. Any loss in value is assumed to be negligible and is ignored.

Utilities costs are also included in this category, such that the total estimated ROW costs are $80.45 million, of which 100% is RV.

Bridge/Structures

ODOT has changed how they account for infrastructure assets. A residual value is no longer used for bridges. A useful life of 75 years is assigned for new structures. Because this project analysis period only covers 20 years, all structures, at a minimum, will still have 55 years of service value. A web review found an 80% RV is used, so this analysis applies the 80% RV for all bridges/structures.

Retaining and sound walls are also included in this category, such that the total estimated Bridge/Structure costs are $7.55 million, of which 80% is RV.

Roadway

The overall analysis assumes that the pavement condition is perfect for all roadway surfaces at the beginning of the 20-year analysis period. It is anticipated that each alignment will need to be resurfaced at the end of the 20-year analysis period, but that assumption is beyond the scope of this analysis. This assumes the value of the roadway surface will be low at the end of the analysis period. The Asset Management Unit places a 50% RV on the roadway surface layers, but excludes the subsurface foundation layer from RV consideration. The subsurface foundation layers are treated in a similar manner as other structures and are assigned a useful life of 75 years. For the new bypass alignment, the foundation layer will still have 55 years of service value remaining at the end of the 20-year analysis period.

The above reasoning does not seem to consider an RV for the existing roadway alignment. The pavement material can be ground up and recycled. Clearly the road cannot be moved to another location, but its existence will reduce the cost for future generations to (re)build a road at the current location because the land has been acquired, graded, and an aggregate base has been laid.

For high-level planning, this category is considered a “catch-all” for other construction elements, such as signals and other safety features, so a 50% RV is assumed.

Frontage roads and other street improvements are included in this category, such that the total estimated Roadway costs are $46.8 million, of which 50% is RV.

Benefit-Cost Ratio

The capital improvement costs include construction and preliminary costs and unknown contingencies, none of which are included in the RV analysis. The contingencies are provided as bookend, with a 25% and a 40% range; the two ranges are evaluated separately in Tables 3 & 4, respectively.

The benefit-cost ratio (BCR) is the total net benefit of an improvement (defined as a reduction in total costs) plus residual value, divided by the capital cost of the improvement. The summary of costs and benefits are provided in Tables 3 & 4.

Table 3: Summary of BCR – 25% Contingency Costs

Roadway	No-Build ($)	Build ($)	Diff ($)
US 97	1,514,900,000	1,456,800,000	58,100,000
US 20	825,100,000	771,500,000	53,600,000
Cooley Rd.	203,000,000	188,700,000	14,300,000
Empire Ave.	244,000,000	230,700,000	13,300,000
Robal Rd.	54,500,000	49,800,000	4,700,000
Total	**2,841,500,000**	**2,697,500,000**	**144,000,000**
Total Net Benefit			$ 144,000,000
Residual Value			$ 111,400,000
Total Capital Improvement Cost (25% Contingency)			$ 172,600,000
Benefit-to-Cost-Ratio (BCR)			1.48

The BCR for the 25% contingency is 1.48, which is greater than 1.00, so the project has a positive BCR for building.

Table 4: Summary of BCR – 40% Contingency Costs

Roadway	No-Build ($)	Build ($)	Diff ($)
US 97	1,514,900,000	1,456,800,000	58,100,000
US 20	825,100,000	771,500,000	53,600,000
Cooley Rd.	203,000,000	188,700,000	14,300,000
Empire Ave.	244,000,000	230,700,000	13,300,000
Robal Rd.	54,500,000	49,800,000	4,700,000
Total	**2,841,500,000**	**2,697,500,000**	**144,000,000**
Total Net Benefit			$ 144,000,000
Residual Value			$ 111,400,000
Total Capital Improvement Cost (40% Contingency)			$ 182,500,000
Benefit-to-Cost-Ratio (BCR)			1.40

The resulting BCR for the improvement scenario is over one, meaning that the improvement scenario has an acceptable value.

Conclusion

The regional significance of the US 97 bypass project was reviewed and the HERS-ST model was used to evaluate the performance and user costs on five roadway alignments within the immediate area of the proposed project, including the actual bypass alignment.

Two scenarios were developed, reflecting the No-Build and Build conditions, and the results were compared. The average segment speed, delay, and VCR analyses showed reasonable improvement for the Build scenario, as compared with the No-Build scenario. The performance improvements are due to the added bypass alignment and the other improvements to the local infrastructure that improve the flow in and through the project area.

The bypass alignment pulls a large number of trips off the existing US 97 alignment because these trips do not stop within the project area. These are considered "pass-through" trips because they are using the facility to travel from one end of the project area to the other with minimal interruptions. Pulling the pass-through trips out of the general flow has advantages to the general performance of the regional system as a whole, and also to safety and travel cost savings. As a result of the improved flow, the travel time and operational and crash costs are reduced for the general users of the facilities, which can be directly measured with the BCR analysis.

Two capital improvement costs were evaluated, where the difference was in the projected contingency costs. The analysis found a BCR range of 1.40 and 1.48 for a 40% & 25% contingency, respectively. These numbers are rough estimates for high level planning purposes. A detailed analysis should be conducted to develop a precise BCR.

References

U.S. Department of Transportation: Federal Highway Administration. 2005. "Highway Economic Requirements System – State Version: Technical Report," August 2005

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APPENDIX A – General HERS-ST Analysis Concepts

Average Speed

The HERS-ST model consists of a number of individual complex sub-models, including Pavement Deterioration, Safety, and Speed Models[4]. The primary focus for this report is the speed model procedures, as the majority of the US 97 analysis is centered on speed and delay calculations.

The speed procedure within HERS-ST is based on the Aggregate Probabilistic Limiting Velocity Model (APLVM) and covers two distinct processes, free-flow speed (FFS) and average effective speed (AES). The FFS estimation is developed to reflect the average unconstrained speed that exists on the highway system in the absence of any other traffic or geometric influences. The FFS estimates are then adjusted to account for the effects of congestion delay and traffic control devices to produce the AES for each roadway segment.

Several key data elements affect speed, including vehicle type, curves, grades, pavement surface quality, speed limits, congestion and traffic control devices. There are three controlling factors in the APLVM that potentially limit the free speed on a roadway section: curves, pavement roughness and posted speed limit. All of these factors have the potential of lowering the sectional speed estimate.

A vehicle traveling through a curved roadway section is subject to a centrifugal force that acts against the vehicle, forcing it to leave the curved path of the roadway. The higher the vehicular speed entering the curve, the heavier the vehicle, and the sharper the curvature of the road, the greater the external force acting upon the vehicle. This results in a reduced FFS for the roadway section.

When the pavement is smooth and the curvature is low (below two degrees) the average speed is governed by the posted speed limits. This model does not explicitly consider enforcement.

Average Delay

There are three kinds of delays estimated in HERS-ST:

- Zero-volume delay is the delay associated with traffic control devices. This is the expected delay that a single vehicle would encounter even if it were the only vehicle on the road. Zero-volume delay only exists for sections controlled with stop signs or traffic signals and is not calculated for uncontrolled sections.
- Incident delay is the delay associated with crashes. HERS-ST estimates delay due to crashes through a secondary (or inferred) process where the HERS-ST model

[4] HERS-ST model uses six internal models: Fleet Composite Model, Widen Feasibility Model, Capacity Model, Pavement Deterioration Model, Speed Model and Travel Forecast Model

estimates the delay cost of crashes and then back-calculates the delay estimates due to crash incidents from the cost calculations.
- Other congestion (or recurring) delay is the average delay due to non-incident congestion.

Total daily traffic is broken into three phases, or demand periods, for all delay and speed analysis:
- Peak period analysis in the peak direction.
- Peak period analysis in the counter-peak direction.
- Off peak analysis in both directions.

Volume-to-Capacity Ratio (VCR)

HERS-ST incorporates revised Highway Capacity Manual (HCM) equations to calculate peak-hour capacity for each roadway segment, for each travel direction. The model then estimates a VCR for the peak and counter-peak directions separately, for signalized arterials or for free-flow sections with two or more lanes per direction.

Total peak traffic is broken into two phases for all VCR calculations:
- Peak period analysis in the peak direction.
- Peak period analysis in the counter-peak direction.

Total User Costs

For travel time costs, HERS-ST incorporates national U.S. Department of Transportation values of time per person for personal and business travel. The operating costs evaluate vehicle operating costs as a function of cost for fuel and oil consumption, tire wear, vehicle maintenance and repair and mileage-related depreciation. The safety costs use national crash rates to estimate the number of crashes and severity for improved and unimproved roadway segments.

The benefits for each variable are defined as a reduction in costs as a result of the implementation of an improvement. Some improvements might show a savings in one variable, such as travel time, while showing an increased cost (disbenefit) in another variable, such as increased fuel consumption. A reduction in the summation of all three costs is defined as the total benefit for the selected improvement.

Agency Costs

Agency costs include the cost of routine maintenance. A selected improvement may or may not be associated with a reduction in roadway maintenance costs. HERS-ST evaluates this measure for the current funding period and evaluates the potential reduction of improvement costs in future years resulting from the improvement.

External Costs

The HERS-ST model uses national values to estimate the costs to society, such as the costs associated to vehicular emissions (air pollutants) resulting from the implementation of a selected improvement. The air pollution costs are measured as the difference between total pollution costs generated by the forecast volumes of travel on the section under unimproved and improved conditions. Because the cost of air pollutant emissions per vehicle-mile varies by both travel speed and vehicle class, this effect can be negative or positive depending on how a proposed improvement influences forecast travel volumes, the mix of vehicle types and travel speeds.

Capital Improvement Costs

HERS-ST identifies segment deficiencies, evaluates a series of improvements that will correct the condition, and estimates the cost of the highway improvement. The capital improvement costs are simply the construction costs for the selected improvements. When analyzing the economic attractiveness of a potential improvement, the improvement cost is used as the denominator in the benefit-cost equation.

Residual Value (RV)

The little known part of the BCR equation is in the residual value of an improvement. The residual value is the capital value of the improvement that still remains at the end of the final analysis period, and is credited back as the unused portion of the investment. The residual value for an improvement is discounted back to the initial year of the analysis period and treated as a benefit.

Benefit-Cost Ratio (BCR)

HERS-ST defines the benefit-cost ratio of a highway improvement as the discounted sum of the present value benefits for the user, agency and environment divided by the implementation costs of the improvement. For BCR analysis, HERS-ST recognizes four broad classes of costs:

- User costs are the costs incurred by the highway user and include travel time costs, operating costs, and safety costs (i.e., crash costs).
- Agency costs are the on-going roadway maintenance costs borne by the administrative agency responsible for the highway section.
- External costs (emissions costs) are the social costs passed to the non-users of the highway system.
- Residual value is the capital value of the improvement that still remains at the end of the final analysis period.
- Capital improvement costs are the estimated construction costs of the improvement.

The analyst can change many variables and factors[5] within the HERS-ST model that influence user, agency and external costs. The HERS-ST procedure estimates the incremental costs and benefits of each potential improvement for each period of the benefit-cost analysis period, as well as the residual value of the improvement at the end of the analysis period. For BCR, the benefits of an improvement are defined as a reduction in user, agency and external costs as the result of implementing an improvement, and are measured as the difference in costs between the no-improved case and the improved case. The cost variable is the estimated capital improvement cost.

In theory, any project with BCR greater than one is considered a worthy project. However, for this report the HERS-ST BCR is used to reveal the value of a set of alternative projects related to each other.

[5] User parameters affect deficiency levels, design standards, improvement costs, auto and truck growth factors, funding and performance constrains, and weights for highway performance goals.

APPENDIX B – The Process for Evaluating Benefit-Cost Ratio

The overall HERS-ST dataset represented the opening year of the project (2016), which is the condition of the roadway system after the improvements were made. The horizon year is the end of the 20-year analysis period (2036). In order to capture the flow of the traffic through the area, the roadway segments of the project were split out by the following five designated roadway corridors and analyzed separately:

1. US 97: Bowery Lane – Butler Market Road
2. US 20: Old Bend-Redmond Highway – Mervin Sampels Road
3. Cooley Road: US 20 – Boyd Acres Road
4. Empire Avenue: US 20 – Boyd Acres Road
5. Robal Road: Britta Street – Nels Anderson Road

There were two approaches used for calculating BCR.

First Approach

During the initial analysis setup, the analyst determines the number of years and funding periods needed for the HERS-ST model runs. The HERS-ST outputs the condition of the system at the end of each of the defined funding periods. The standard HERS-ST analysis usually evaluates four 5-year funding periods (FP) over a 20-year project analysis period, so with a 2016 base year the standard HERS-ST model evaluates the roadway system conditions over the following four FP:

- FP1: 2017 – 2021
- FP2: 2022 – 2026
- FP3: 2027 – 2031
- FP4: 2032 - 2036

The HERS-ST model evaluates each funding period separately and then outputs data elements representing key system conditions and performance measures at the end of the funding period. In this analysis, the HERS-ST output covers the years 2021, 2026, 2031 and 2036. Because the data for each funding period represents a single year, the results need to be expanded to reflect the total value over the 5-year period.

The first approach simply multiplies the individual cost values at the end of each funding period by a factor of five to simulate a total 5-year cost for that funding period. This approach is subsequently applied for each funding period and all values are summed to achieve a 20-year cost.

Step 1 – Gather the System Output

The HERS-ST model run automatically saves the System Level analysis data (SS1) in the HERS.SS1; which is a standard comma delimited (CSV) text file. The SS1 data was pulled into an Excel spreadsheet and the system summary data was aggregated and analyzed (see Table 5).

Table 5: Summary of Roadway Conditions & Costs for US 97, Build Scenario

	Base Year	At End of Five Year Funding Periods			
	2016	**2021**	**2026**	**2031**	**2036**
Segment Miles	12.7	12.7	12.7	12.7	12.7
VMT (1000)	57,597	63,288	68,733	74014	79,360
Average Speed (mph)	47.1	46.9	46.7	46.5	46.2
Average Delay (Hours per 1000 VMT)					
Zero-Volume Delay	0.310	0.329	0.346	0.359	0.369
Incident Delay	0.202	0.245	0.298	0.366	0.454
Other Delay	0.300	0.325	0.348	0.375	0.410
Total Delay	0.812	0.899	0.991	1.100	1.234
Total Costs ($ per 1000 VMT), except Agency*					
Total User Costs	1016	1028	1042	1059	1067
– Travel Time Costs	522	527	532	539	548
– Operating Costs	358	363	371	380	378
– Crash (Safety) Costs	135	137	138	139	140
Agency Costs*	0	281	667	993	885
External (Emissions) Costs	5.36	5.36	5.36	5.35	5.34
Rate of which crashes/injuries/fatalities occur (per 100 million VMT)					
Property Damage Only	207.2	209.8	211.7	213.6	215.4
All Injuries	82.9	84.0	84.8	85.6	86.3
Fatalities	1.04	1.05	1.05	1.06	1.06

* Exception: Agency Costs are $ per mile

Step 2 – Highlighting Vehicles Miles Traveled and Miles Data

The System Level analysis provides the various costs that are used within the BCR calculations. Both the Total User Costs and External Costs values are provided as “Dollar per 1,000 VMT” and the Agency Costs values are provided as “Dollar per Mile”. The Vehicle Miles Traveled (VMT) and Miles data is needed to convert all costs to the same units.

Step 3 – Calculate Total User Costs

The Total User Costs (TUC) is the total cost to the user of the system and is a summation of the Travel Time Costs (TTC), the Operating Costs (OPC) and the Crash (or Safety) Costs (CRAC). The units are “Dollar per 1,000 VMT”. The TUC for each FP reflects the total user costs at the end of each FP. The TUC is converted to dollars and then multiplied by five to develop an assumed total average for the entire five year period. The final TUC for the 20-year analysis period is the summation of all TUC for all four FP. The example data in Table 5 is from the model run for the Build scenario on US 97.

- FP1 ➔ $1,028 ($/1000VMT) * 63,288 (1000VMT) * 5 Years ➔ $325,300,000
- FP2 ➔ $1,042 * 68,733 * 5 ➔ $358,100,000
- FP3 ➔ $1,059 * 74,014 * 5 ➔ $391,900,000
- FP4 ➔ $1,067 * 79,360* 5 ➔ $423,400,000

- $\text{TUC}_{\text{Build}}$ ➔ FP1 + FP2 + FP3 + FP4 ➔ $1,498,700,000 (for this scenario)

This step is calculated separately for the No-Build and Build scenarios. Following the same steps for the No-Build scenario, the $\text{TUC}_{\text{No-Build}}$ is $1,549,000,000. The total TUC for the Build scenario is 3% less than for the No-Build scenario.

Step 4 – Calculate Total Agency Maintenance Costs

The Agency Maintenance Costs (MNT) is the average annual maintenance costs to the local jurisdiction that owns the roadway system. This cost is generally associated with on-going maintenance costs other than resurfacing. The units are "Dollar per Mile" (i.e., centerline miles). The TUC for each FP reflects the total user costs at the end of the each FP. The MNT is converted to dollars and then multiplied by five to develop an assumed total average for the entire five year period. The final MNT for the 20-year analysis period is the summation of all MNT for all four FP.

- FP1 ➔ $281 ($/Mile) * 12.7 (Mile) * 5 Years ➔ $17,850
- FP2 ➔ $667 * 12.7 * 5 ➔ $42,350
- FP3 ➔ $993 * 12.7 * 5 ➔ $63,050
- FP4 ➔ $885 * 12.7 * 5 ➔ $56,200

- $\text{MNT}_{\text{Build}}$ ➔ FP1 + FP2 + FP3 + FP4 ➔ $179,450 (for this scenario)

The initial input data calls for a perfect roadway system at the beginning of the 20-year analysis, so the early maintenance costs are lower based on the assumption of an excellent pavement condition. As the traffic flows grow, and the pavement conditions deteriorate, the MNT increases. Note the HERS-ST model simulated a pavement improvement for the fourth FP, which is why MNT for FP4 is less than for FP3. The HERS-ST improvement will be discussed in Step 6.

Step 4 is calculated separately for the No-Build and Build scenarios. Following the same steps for the No-Build scenario, the $\text{MNT}_{\text{No-Build}}$ is $129,950. The total MIN for the Build scenario is 38% greater than for the No-Build scenario.

Step 5 – Calculate Total External Emissions Costs

The External Emissions Costs (EMIC) is the average pollution damage costs.

- FP1 ➔ $5.36 ($/1000VMT) * 63,288 (1000VMT) * 5 Years ➔ $1,700,000

- FP2 ➔ $5.36 * 68,733 * 5 ➔ $1,800,000
- FP3 ➔ $5.35 * 74,014 * 5 ➔ $2,000,000
- FP4 ➔ $5.35 * 79,360 * 5 ➔ $2,100,000

- $\text{EMIC}_{\text{Build}}$ ➔ FP1 + FP2 + FP3 + FP4 ➔ $7,600,000 (for this scenario)

Step 5 is calculated separately for the No-Build and Build scenarios. Following the same steps for the No-Build scenario, the $\text{EMIC}_{\text{No-Build}}$ is $7,500,000. The total EMIC for the Build scenario is 2% greater than for the No-Build scenario.

Step 6 – Add HERS-ST Improvement Costs

One of the primary assumptions at the beginning of the 20-year analysis period is that the pavement surface is brand new for the entire roadway system, equating to a perfect pavement condition. As traffic on the system increases throughout the analysis period, the wear and tear on the roadway system intensifies and the pavement condition deterioration rate escalates.

HERS-ST model was allowed to perform additional resurfacing improvements, if the analysis deemed the action to be required. For larger volume roadways, with higher pavement deterioration, the HERS-ST model simulates pavement resurfacing in the FP4; this is never an issue for lower volume roads. The units are $1,000. Note that this is a one time improvement cost and should not be multiplied by five.

- FP1 ➔ $0 ➔ $0
- FP2 ➔ $0 ➔ $0
- FP3 ➔ $0 ➔ $0
- FP4 ➔ $3,178.1 * 1,000 ➔ $2,900,000

- $\text{HERS-ST}_{\text{Build}}$ ➔ FP1 + FP2 + FP3 + FP4 ➔ $2,900,000 (for this scenario)

Step 6 is calculated separately for the No-Build and Build scenarios. Following the same steps for the No-Build scenario, the $\text{HERS-ST}_{\text{No-Build}}$ is $ 900,000.

Step 7 – Calculate Total Costs for Scenario

For each scenario the total costs are simply a summation of Steps 3 - 6.

- $\text{TUC}_{\text{Build}}$ ➔ $1,498,700,000 (Step 3)
- $\text{MNT}_{\text{Build}}$ ➔ $179,450 (Step 4)
- $\text{EMIC}_{\text{Build}}$ ➔ $7,600,000 (Step 5)
- $\text{HERS-ST}_{\text{Build}}$ ➔ $2,900,000 (Step 6)

- Total 20-year Costs ➔ $1,509,000,000 (for this scenario)

Following the same steps for the No-Build scenario, the total No-Build scenario costs are $1,558,000,000, which is 3% greater than for the Build scenario.

Second Approach

The First Approach assumes that the funding period costs are constant across each 5-year FP. However, the VMT will increase over time, across each funding period, as the economical activities grow throughout the area. Though this first approach serves as a quick response process, it also introduces a small level of error into the overall total costs.

The Second Approach assumes a linear growth between the known data points. In this case the known points are the costs at the beginning of the 20-year analysis period (i.e., 2016, which is also considered the base year), and the costs at the end of each of the five FP. The costs for each interim year (i.e., one, two, three, four, etc.) are calculated using a linear regression approach. Then all yearly costs are summed to develop the total 20-year costs. This approach more closely matches the analysis process within the HERS-ST model, which generally utilizes a linear growth process to determine yearly traffic volumes throughout the 20-year analysis period. Note that the traffic growth process within the HERS-ST model can be adjusted by the analyst; any changes made to the HERS-ST process should also be applied to this approach.

Step 8 – Calculate Linear Costs

The FP data elements are defined as the control years; a linear regression process is then used to develop the costs for the interim years. The control years are 2016, 2021, 2026, 2031 and 2036.

Using TUC as a quick example, the 2016 column represents the condition of the system at the beginning of the 20-year analysis period. The VMT_{2016} is 57,597 (x1000), and the TUC_{2016} calculates to be $58,500,000. The 2021 column represents the condition of the system at the end of the first funding period. Using a VMT_{2021} of 63,288 (x1000), the TUC_{2021} calculates to be $65,100,000. The unknown TUC_{2017} through TUC_{2020} values are developed from a linear trend between the known data points TUC_{2016} and TUC_{2021}.

Example:

- TUC_{2016} ➔ $58,500,000 (Control Point)
- TUC_{2017} ➔ $59,800,000
- TUC_{2018} ➔ $61,100,000
- TUC_{2019} ➔ $62,400,000
- TUC_{2020} ➔ $63,800,000
- TUC_{2021} ➔ $65,100,000 (Control Point)

The same process is repeated to develop the other interim year costs for the TUC, as well as for all interim year costs for MNT and EMIC. The different costs for the interim year for the US 97 Build scenario are shown in Table 6. The same process is applied for all scenarios.

Table 6: Summary of Interim Year Costs for US 97, Build Scenario

YEAR	TUC	MNT	EMIC
*2016**	*58,500,000*	*0*	*309,000*
2017	59,800,000	1,100	315,000
2018	61,100,000	1,700	321,000
2019	62,400,000	2,400	327,000
2020	63,800,000	3,000	333,000
*2021**	*65,100,000*	*3,600*	*339,000*
2022	66,400,000	4,500	345,000
2023	67,700,000	5,500	351,000
2024	69,000,000	6,500	356,000
2025	70,300,000	7,500	362,000
*2026**	*71,600,000*	*8,500*	*368,000*
2027	73,000,000	9,300	374,000
2028	74,300,000	10,100	379,000
2029	75,700,000	11,000	385,000
2030	77,000,000	11,800	390,000
*2031**	*78,400,000*	*12,600*	*396,000*
2032	79,600,000	12,300	402,000
2033	80,900,000	12,100	407,000
2034	82,200,000	11,800	413,000
2035	83,400,000	11,500	418,000
*2036**	*84,700,000*	*11,200*	*424,000*
SUM	**1,446,400,000**	**158,000**	**7,400,000**

* Control Years

For each scenario the total costs are simply a summation of columns and rows.

- Total User Costs➔ $1,446,400,000
- Total Agency Costs ➔ $158,000
- Total External Costs➔ $7,400,000
- Total HERS-ST Improvement Costs➔ $2,900,000 (from Step 6)

- Total Scenario Costs ➔ $1,456,800,000

Following the same steps for the No-Build scenario, the total No-Build scenario costs are $1,514,900,000, which is 4% greater than for the Build scenario.

Step 9 – Total Cost Difference between Approaches

Using the US 97 analysis, the difference between the two approaches varies from 2.8% for the No-Build scenario to 3.6% for the Build scenario. In both cases, the total costs for the second approach are 3-4% lower than those developed through the first approach. This difference is the error that is introduced through the first approach by assuming the costs are constant across the 5-year FP.

It is not clear how significant this error might be. On one hand the first approach is simple to develop and apply, but on the other hand, the growth assumptions in the second approach more closely match the data analysis within the HERS-ST model. The 3-4% error does not seem much on its own, but it appears more significant when compared with the fact that there is only a 4% difference in total costs between the Build and No-Build scenarios. However, this will only be an issue when the final BCR is close to "unity", because a BCR less than one is not an acceptable project. The overall analysis process defined here is for planning analysis, and a more detailed approach is required for project level analysis.

For this project, the second approach was used to develop the BCR.

Step 10 – Net Benefit

The net benefit is the difference between the total scenario costs associated with the Build scenario, minus the total costs associated with the No-Build scenario. A negative difference means that the total costs for the build scenario are less than the total costs for the no-build scenario, and that the improvements saves money. A negative difference represents a benefit in the benefit-cost calculations; a positive difference between the two represents a disbenefit. The roadway section costs data for US 97 is shown in Table 7.

Table 7: Net Benefits for US 97 – Example (using second approach)

COSTS	NO-BUILD ($)	BUILD ($)
Total User Costs	1,506,500,000	1,446,400,000
Agency Costs	114,000	158,000
External Emission Costs	7,300,000	7,400,000
HERS-ST Improvement Costs	900,000	2,900,000
Total Costs	1,514,900,000	1,456,800,000
	Total Costs for Build Scenario	1,456,800,000
	Total Costs for No-Build Scenario	1,514,900,000
	Net Benefit	**-58,100,000**

As shown in Table 7, the improvements to US 97 demonstrate a 3% decrease in total costs on the roadway system, resulting in a positive net benefit for US 97.

But this is not the entire story. Improvements were made to other roadway alignments as part of this project, including roadway extensions, additional travel lanes, left & right turn refuges and upgrades to intersection controls. All five roadway sections, as shown in Table 8, demonstrated a net benefit. The greater benefits associated with US 97 and US 20 can be directly attributed to the significantly larger VMT found on the two roadways.

Table 8: Net Benefit Summary – All Roadways

ROADWAY	NO-BUILD ($)	BUILD ($)	BENEFIT ($)
US 97	1,514,900,000	1,456,800,000	58,100,000
US 20	825,100,000	771,500,000	53,600,000
Cooley Road	203,000,000	188,700,000	14,300,000
Empire Avenue	244,000,000	230,700,000	13,300,000
Robal Road	54,500,000	49,800,000	4,700,000
Total	**2,841,500,000**	**2,697,500,000**	**144,000,000**

Step 11 – Residual Value

Residual Value is an Asset Management element that attempts to capture the value of a project at the end of the analysis period. For this analysis, it is assumed that the project will have reasonable levels of future value for ROW, structures and roadway beyond the analysis period. The future value is evaluated and defined as a benefit.

Right-of-Way:
For this analysis, we will assume that ROW has 100% RV value. The land that is acquired for the project can be resold at a later time for development if the roadway were to be removed. Loss in value is assumed to be negligible, if at all.

Bridge/Structures:
The design life of the structures is generally about 75 years. At a minimum, the structure will still have 55 years of service value available at the end of the analysis period. Because the basic structure exists, with proper maintenance it will have significantly more value, as compared to starting over and building a new structure. This analysis will assume an RV of 80%.

Roadway:
The overall analysis is starting with perfect pavement. It is assumed that the various roadways will need to be resurfaced at the end of the 20-year analysis period. The HERS-ST model is allowed to make pavement improvements during the analysis period as needed, but modernization improvements are not allowed.

Without some level of on-going pavement improvements, the value of the roadway surface will be reduced at the end of the 20-year analysis period. However, aside from grinding and recycling the pavement surface, the roadway cannot be physically picked up and moved to another location; so its existence makes it easier to (re)build in the future. The land has been acquired, cleared and graded and an aggregate base has been laid, which reduces the cost for future generations to build upon. This section is also a great catch-all for other construction elements, and is assumed to include signals and other safety elements.

Step 12 – Benefit- Cost Ratio

The Benefit Cost Ratio is simply an accumulation of all the data elements discussed above. Keeping in mind that there are a number of assumptions associated with this analysis, the general BCR development is as follows:

$$BCR = (\text{Net Benefit} + \text{Residual Value}) / (\text{Total Project Costs})$$

where the Total Net Benefit comes from Step 10 (see Table 8) and the Residual Value comes from Step 11.

Table 9