BILLINGS AREA I-90 CORRIDOR PLANNING STUDY

APPENDIX D
IMPROVEMENT OPTIONS REPORT

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1.0 INTRODUCTION

This report presents improvement options recommended within the study area for the Billings Area I-90 Corridor Planning Study. The study area includes approximately 22 miles of Interstate 90 (I-90) beginning at the Laurel Interchange (Reference Post [RP] 433.8) and ending immediately west of the Pinehills Interchange (RP 455.85). This study supplements information and findings contained in the 2006 Billings I-90 Interchanges Project report (Short Elliott Hendrickson Inc [SEH] 2006). The 2006 SEH report provided a detailed study of various interchanges within the same corridor limits. Figure 1-1 shows the study area termini, mainline Interstate segments, and interchanges within the corridor.

The study focuses on mainline I-90 elements, including Interstate segments and ramp gore areas, or merge/diverge locations. The study also includes an analysis of the Laurel and Mossmain Interchanges which were not included in the 2006 SEH report. The West Billings Interchange was not included in the 2006 SEH report or this study due to Montana Department of Transportation (MDT) improvements completed in 2007.

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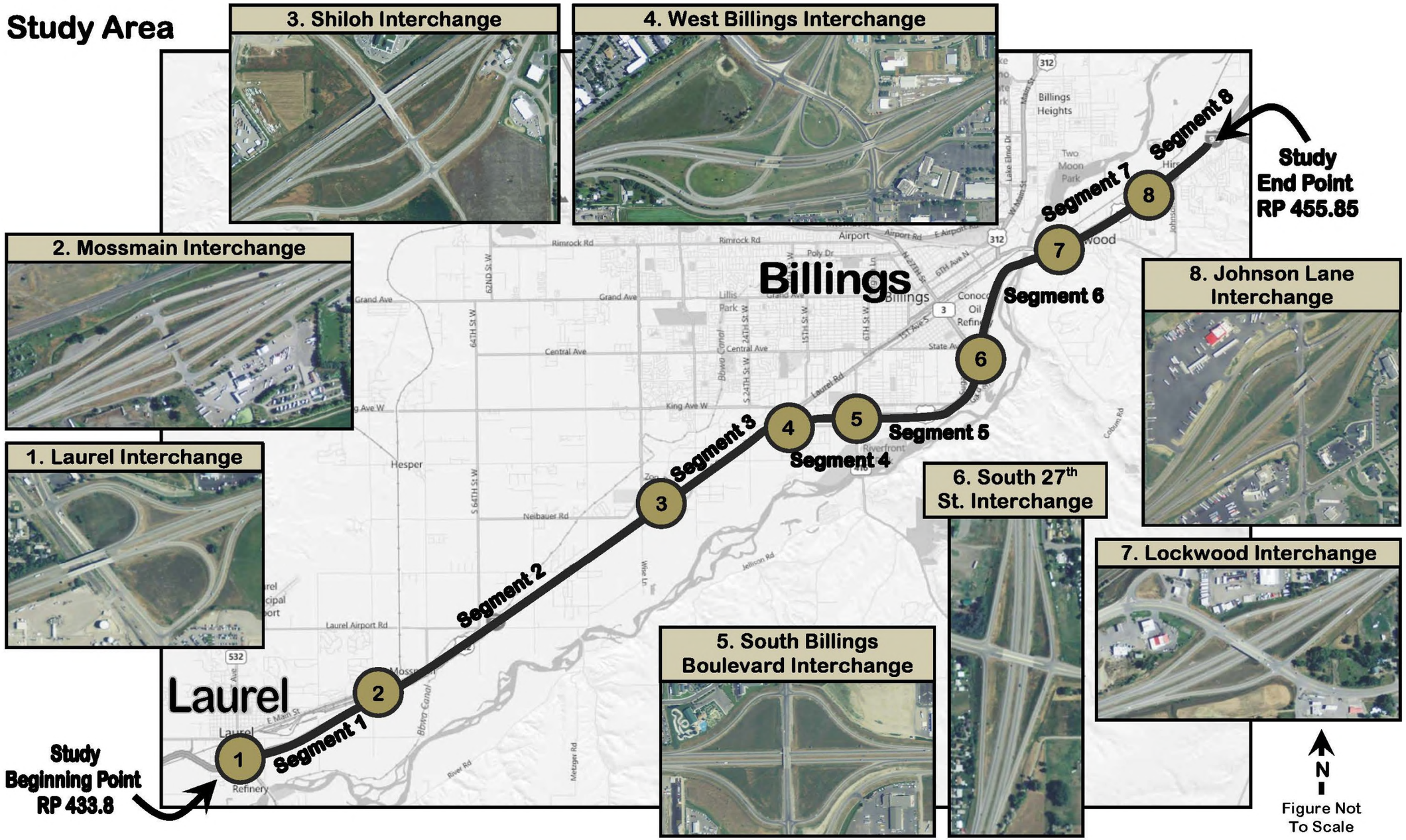
Figure 1-1 Study Area



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2.0 DEVELOPMENT OF IMPROVEMENT OPTIONS

2.1 Corridor Needs

Improvement options were developed to address the operational, geometric, and safety needs within the study area between Laurel and Billings. Operational improvements were identified to decrease congestion and improve traffic operations at locations where Level of Service (LOS) is anticipated to drop below desirable levels by 2035. Traffic operations and lane balance improvements were identified to provide lane continuity and to reduce weaving and merging maneuvers throughout the corridor. Safety improvements were developed to reduce conflicts at interchange ramps. Geometric improvements were identified where modifications are needed to bring facilities up to current MDT design standards. Current and anticipated future operational, geometric, and safety conditions within the I-90 corridor are described in detail in the Existing and Projected Conditions Report prepared for this study.

2.2 Community and Stakeholder Input

Stakeholders and members of the public requested that improvement options avoid or minimize impacts to natural and community resources, minimize right-of-way acquisition and impacts to adjacent land uses, and maintain consistency with local plans. There were also requests for context sensitive design; aesthetic improvements; and safe passage across the Interstate facility for non-motorized users at overpasses, bridges, and interchanges in the corridor. These concepts relate to specific design elements and are would be considered at the project level.

2.3 Mainline Capacity Considerations

Improvement options for mainline segments of the Interstate were developed to address the capacity needs of the Interstate segments and to maintain desirable LOS through the 2035 planning horizon. Segments are defined as the portions of the Interstate mainline located between adjacent interchanges. The MDT Traffic Engineering Manual and the MDT Road Design Manual define desirable LOS for rural and urban Interstate facilities as LOS B or better. The term freeway is used interchangeably with the term Interstate in this study.

Several mainline Interstate segments between the Shiloh Interchange and the Johnson Lane Interchange are projected to operate at LOS C by 2035. A third lane in each direction would improve these segments to a desirable LOS B.

A third mainline Interstate lane can be developed in one of two ways:

- Construct an auxiliary lane on one or more mainline segments between interchanges. An auxiliary lane is a lane that occurs between interchanges, but does not proceed through adjacent interchanges. Auxiliary lanes can occur on consecutive or alternating mainline segments.
- Increase the basic number of lanes on the Interstate by constructing an additional travel lane on two or more consecutive mainline segments traveling through consecutive interchanges.

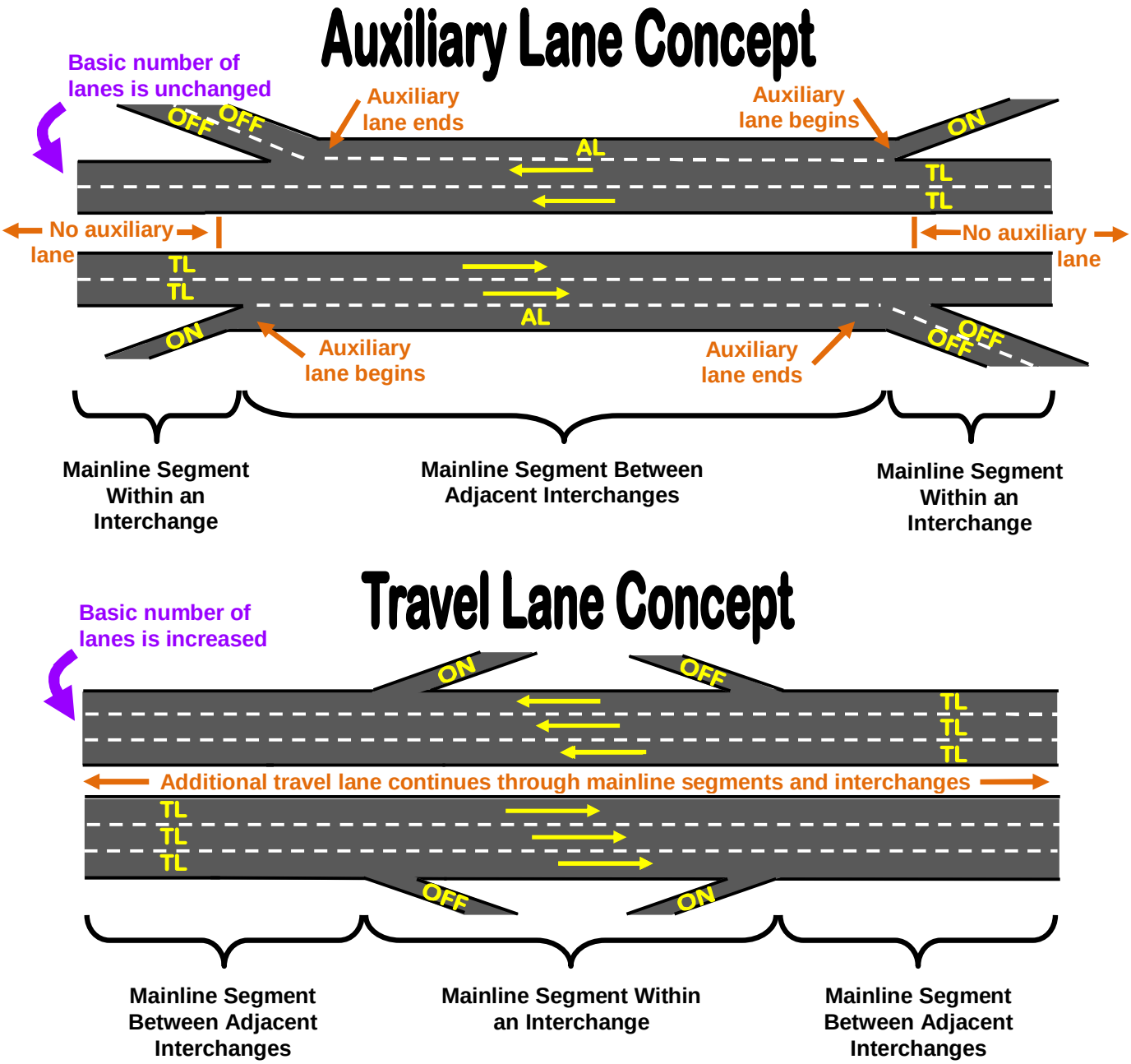
Auxiliary lanes are typically developed where additional capacity is needed between adjacent interchanges, due to traffic volumes entering the Interstate at one interchange and exiting the Interstate at the following interchange.

Continuous travel lanes constructed through interchanges are typically used where additional capacity is needed due to traffic volumes continuing through one or more downstream interchanges.

In order to achieve efficient traffic operation through and beyond interchanges, MDT and American Association of State Highway and Transportation Official (AASHTO) guidelines recommend maintaining consistency in the basic number of lanes. The term "basic number of lanes" is defined as the minimum number of through lanes designated and maintained over a significant length of a route based on the overall operational needs of that highway segment.

The auxiliary lane and travel lane concepts are illustrated in Figure 2-1.

Figure 2-1 Auxiliary Lane and Travel Lane Concepts



Key

TL:	Travel Lane	AL:	Auxiliary Lane
ON:	On-Ramp	OFF:	Off-Ramp

Note: This figure is intended for illustrative purposes only and does not represent any portion of the I-90 study corridor.

Further analysis would be required to determine if auxiliary lanes or additional through travel lanes are warranted. For example, an origin-destination study could be conducted at the project level to identify traffic usage patterns, including trip length and termini.

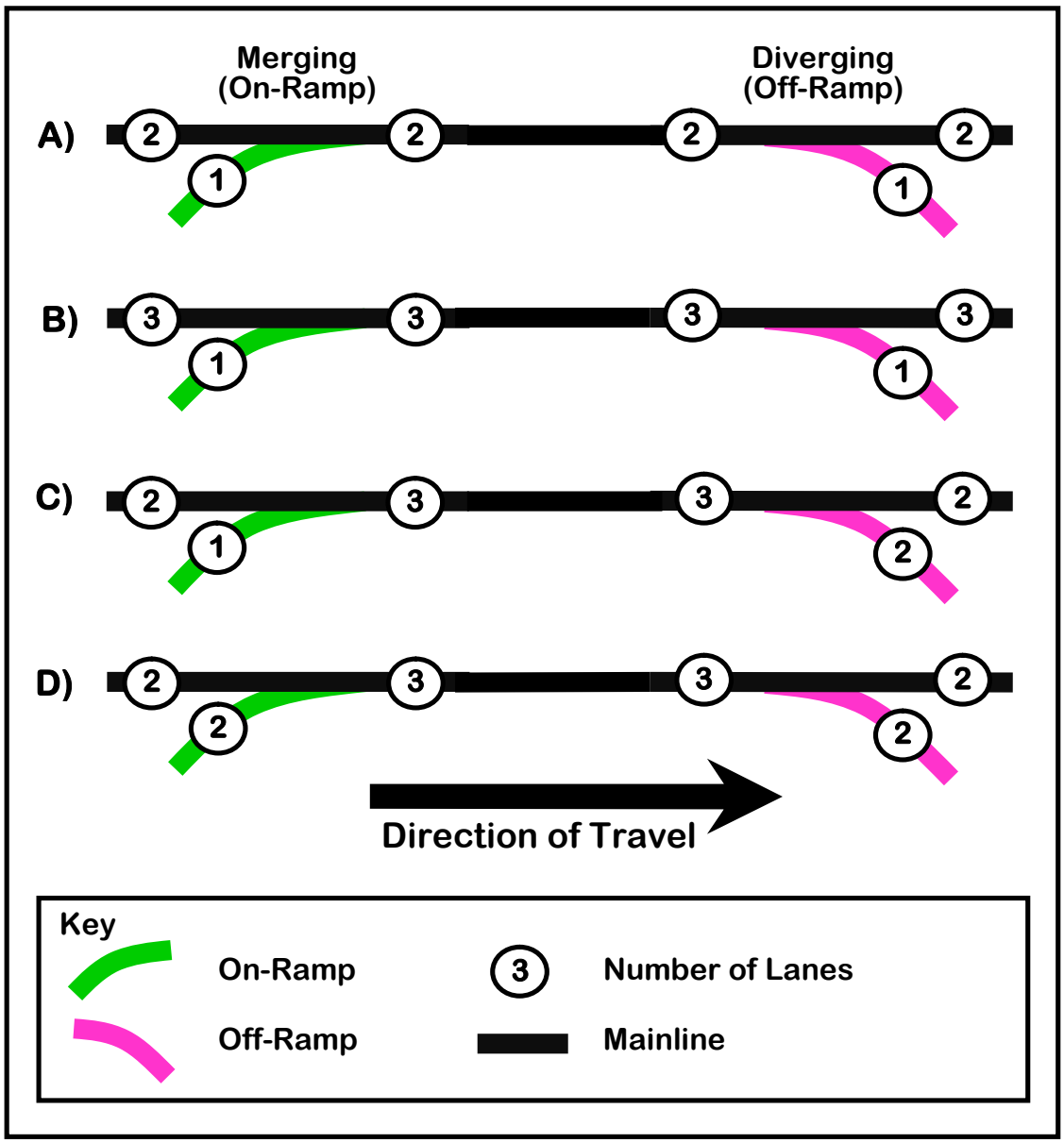
2.4 Lane Balance Considerations

The concept of lane balance should be considered when proposing changes to Interstate lane configuration. MDT's lane balance guidelines provided in (Section 29.3.2 of the Traffic Engineering Manual) state:

- At entrances, the number of lanes beyond the merging of the two traffic streams should not be less than the sum of the approaching lanes minus one.
- At exits, the number of approach lanes on the highway should equal the sum of the number of mainline lanes beyond the exit plus the number of exiting lanes minus one.

Figure 2-2 illustrates acceptable lane configurations that follow lane balance guidelines.

Figure 2-2 Lane Balance Concept



As noted in Figure 2-2, Examples A and B illustrate a continuous basic number of lanes, while examples C and D illustrate an auxiliary lane condition where an additional third lane does not continue upstream or downstream beyond the interchanges. The appropriate number of off-ramp lanes varies based on the number of mainline lanes. If a mainline lane is dropped downstream of an off-ramp as in Example C and D, a second off-ramp lane is needed to satisfy lane balance guidelines.

3.0 DESCRIPTION OF IMPROVEMENT OPTIONS

Improvement options are described in the following sections according to their Option ID. The Option ID is a letter and number combination used to identify options, and is defined as follows:

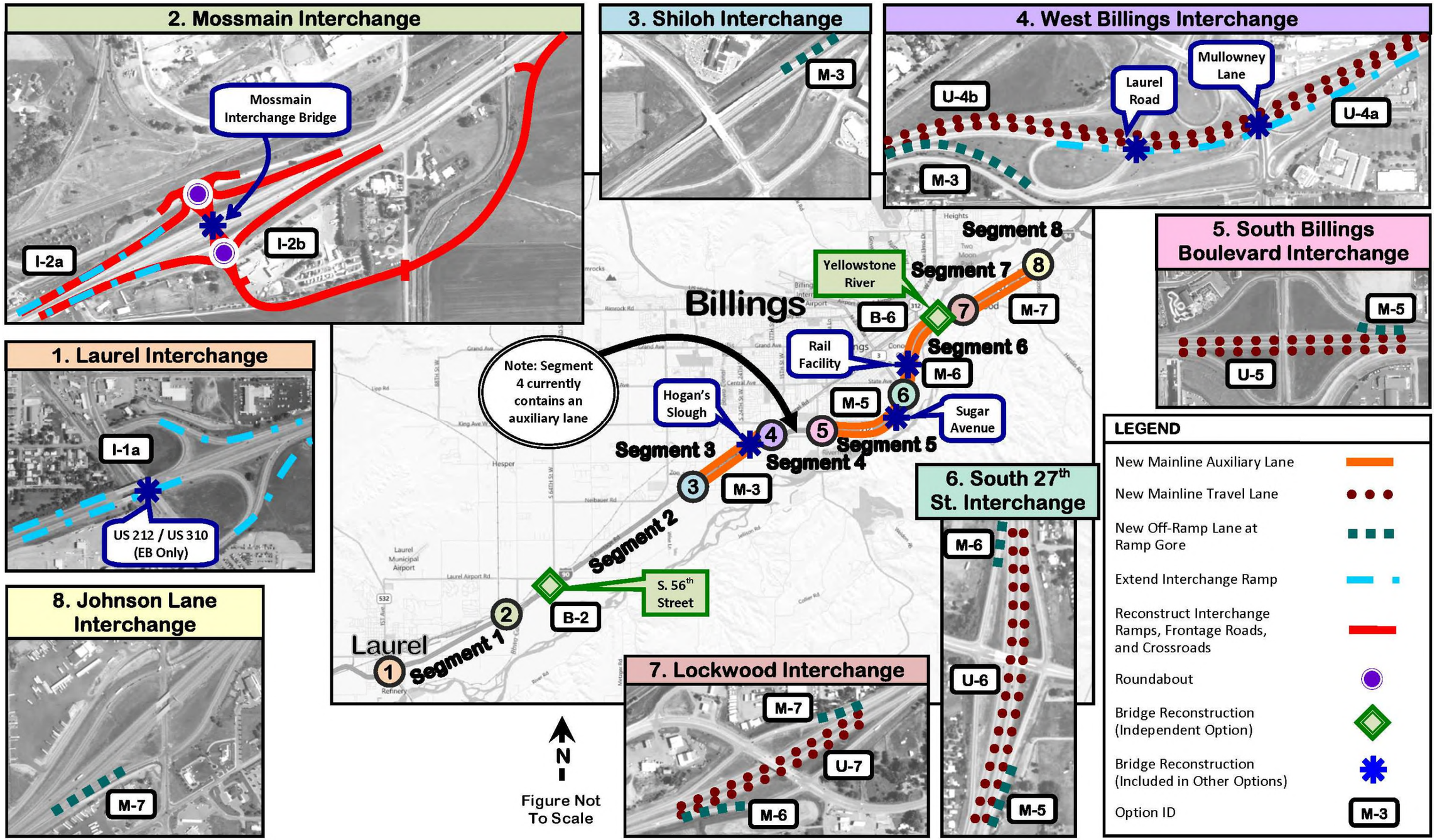
- Letter:
  - M - an improvement to a mainline Interstate segment occurring between the gore areas of two interchanges
  - U - a mainline Interstate improvement occurring underneath or through an interchange (i.e., between the gore areas of an interchange)
  - B - a bridge or structure improvement that is independent from other options
  - I - an interchange improvement

- Number: Improvement option numbering reflects the segment or interchange number within the study corridor and is typically consecutive from west to east

Improvement options are also categorized according to option type. The type of improvement option corresponds to the need identified in a specific location, such as capacity, geometric, traffic operations, and safety needs.

Figure 3-1 illustrates recommended improvement options. Detailed plan view and typical section illustrations are provided in Appendices 1, 2, and 3.

Figure 3-1 Recommended Improvement Options



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3.1 Mainline Segments Between Adjacent Interchanges (M Options)

Mainline segments in the I-90 corridor are generally configured with two lanes in each direction. Improvement Options M-3, M-5, M-6, and M-7 would address LOS issues by constructing an auxiliary lane on mainline segments 3, 5, 6, and 7, for a total of three lanes in each direction. The auxiliary lanes would not extend through the upstream and downstream interchanges, but would be limited to the mainline segment between adjacent interchanges. The location of the third lane would be determined during project design and development. Constructing a third lane toward the median could reduce right-of-way needs, and was assumed for this study.

Project level analysis would be required to determine if auxiliary lanes or additional through travel lanes are warranted based on observed traffic usage patterns in the I-90 corridor. For example, it may be appropriate to conduct an origin-destination study during project development to identify traffic usage patterns in the corridor, including trip length and termini. Vehicles entering the Interstate at an interchange and exiting at the following interchange would indicate a need for auxiliary lanes.

Mainline Segment 4 between the West Billings Interchange and the South Billings Boulevard Interchange is configured with two through lanes and an auxiliary lane in both directions. This segment is projected to operate at a desirable LOS B through the 2035 planning horizon year. No improvements are recommended for this segment to address LOS.

Bridge structures impacted as a result of mainline widening improvements are identified in Table 3.1. Bridges are discussed in more detail in Section 3.3.M Options would require a second off-ramp lane at each of the ramp gore points where an auxiliary lane is recommended.

Additional off-ramp lanes would address lane balance requirements, and are not a requirement for LOS purposes. Lane configurations recommended in the 2006 SEH report are considered valid. If improvement options are forwarded from this study, lane transitions between ramp gore points and ramp intersections would need to be considered.

Option M-3 would involve adding an additional WB off-ramp lane at the Shiloh Interchange to maintain lane balance. This effort would include complete reconstruction of the mechanically stabilized earth (MSE) wall currently supporting the single lane off-ramp from the gore area to the ramp bridge structure. Installation of the current MSE wall involved a year-long soil

stabilization process and required coordination with BNSF Railway regarding the existing railroad easement and its daily railway operations. A similar process could be expected for ramp reconstruction. The westbound off-ramp would need to be closed during reconstruction, requiring westbound off-ramp traffic to use either the Mossmain Interchange or the West Billings Interchange.

Plan view and typical section illustrations for Improvement Options M-3, M-5, M-6, and M-7 are provided in Appendices 1 and 3.

Table 3.1 Mainline Segments Between Adjacent Interchanges (M Options)

Location	Option ID	Option Type	Improvement Option Description
Mainline Segment 3	**M-3**	Capacity	Construct EB and WB auxiliary lanes on the mainline segment between the Shiloh and West Billings Interchanges Other elements include: • Construct additional WB off-ramp lane at Shiloh Interchange ramp gore • Construct additional EB off-ramp lane at West Billings Interchange ramp gore • Reconstruct EB and WB I-90 bridge crossing of Hogan's Slough
Mainline Segment 5	**M-5**		Construct EB and WB auxiliary lanes on the mainline segment between the South Billings Boulevard and South 27th Street Interchanges Other elements include: • Construct additional WB off-ramp lane at South Billings Boulevard Interchange ramp gore • Construct additional EB off-ramp lane at South 27th Street Interchange ramp gore • Reconstruct EB and WB I-90 bridge crossing of Sugar Avenue
Mainline Segment 6	**M-6**		Construct EB and WB auxiliary lanes on the mainline segment between the South 27th Street and Lockwood Interchanges Other elements include: • Construct additional WB off-ramp lane at South 27th Street Interchange ramp gore • Construct additional EB off-ramp lane at Lockwood Interchange ramp gore • Reconstruct EB and WB I-90 bridge crossing of rail facility
Mainline Segment 7	**M-7**		Construct EB and WB auxiliary lanes on the mainline segment between the Lockwood and Johnson Lane interchanges Other elements include: • Construct additional WB off-ramp lane at Lockwood Interchange ramp gore • Construct additional EB off-ramp lane at Johnson Lane Interchange ramp gore

3.2 Mainline Segments Under or Through an Interchange (U Options)

Mainline segments under or through an interchange (termed "under" segments) currently have two travel lanes in both the eastbound and westbound directions. Improvement Options U-4b, U-5, U-6, and U-7 would involve constructing a third travel lane within these "under" segments. U options would connect with M options to provide continuity in the basic number of lanes throughout the corridor and reduce weaving maneuvers as a result of ramp and auxiliary lane merging. The location of the third lane would be determined during project design and development. Constructing the third lane toward the median could reduce right-of-way needs and was assumed for this study. Recommended improvement options for under segments and impacted bridge structures are identified in Table 3.2. Bridges are discussed in more detail in Section 3.3.

Table 3.2 Mainline Segments Under or Through an Interchange (U Options)

Location	Option ID	Option Type	Improvement Option Description
Interchange 4: West Billings	**U-4a**	Safety	Lengthen EB on-ramp at Laurel Road Other elements include: • Modify vertical curve • Reconstruct EB I-90 bridge crossing of Laurel Road • Reconstruct EB I-90 bridge crossing of Mullowney Lane
	U-4b	Traffic Operations & Lane Balance	Construct additional EB and WB mainline lanes through the West Billings Interchange Other elements include: • Modify vertical curve • Reconstruct EB and WB I-90 bridge crossing of Laurel Road ramps • Reconstruct EB and WB I-90 bridge crossing of Mullowney Lane • Restripe WB off-ramp at West Billings Interchange
Interchange 5: South Billings Boulevard	**U-5**	Traffic Operations & Lane Balance	Construct additional EB and WB mainline lanes under and through the South Billings Boulevard Interchange
Interchange 6: South 27th Street	**U-6**	Traffic Operations & Lane Balance	Construct additional EB and WB mainline lanes under and through the South 27th Street Interchange Other elements include: • Restripe EB off-ramp at South Billings Boulevard Interchange
Interchange 7: Lockwood	**U-7**	Traffic Operations & Lane Balance	Construct additional EB and WB mainline lanes under and through the Lockwood Interchange

A third lane is not needed to improve LOS within the "under" segments during the 2035 planning horizon. Additional capacity is needed at mainline segments 3, 5, 6, and 7, which are located between the interchanges. Project level analysis would be required to determine if auxiliary lanes or additional through travel lanes are warranted based on observed traffic usage patterns in the I-90 corridor. Vehicles entering the Interstate at an interchange and continuing through multiple downstream interchanges would indicate a need for three continuous travel lanes in each direction.

Constructing a third through travel lane within the study corridor would have different lane balance implications as compared to constructing auxiliary lanes with M Options. For example, if a continuous third travel lane were to be constructed through either the West Billings Interchange (Option U-4b) or the South Billings Boulevard Interchange (Option U-5), the downstream off-ramp would need to be reconstructed or restriped as a single lane diverging off-ramp to maintain lane balance. If improvement options are forwarded from this study, the issue of lane balance would need to be investigated relating to the proper number of off-ramp lanes for each project. Due to multiple variations in off-ramp configurations, under improvements are not illustrated.

Project level analysis would also be needed to assess traffic patterns within segment 4 located between the West Billings Interchange and the South Billings Boulevard Interchange. This mainline segment is currently configured with two travel lanes and an auxiliary lane in each direction. Auxiliary lanes allow vehicles to enter and exit the Interstate with less conflict than mainline configurations with on-ramps and off-ramps that directly merge onto and diverge from the Interstate. If improvement options are forwarded from this study, project level analysis should be conducted to determine if traffic patterns, capacity needs, or safety issues continue to warrant an auxiliary lane configuration between the West Billings Interchange and the South Billings Boulevard Interchange mainline segment.

If three through travel lanes are not warranted and Option U-4b is not implemented, Option U-4a is would address a documented safety concern at the West Billings Interchange. This option would lengthen the EB Laurel Road on-ramp at the West Billings Interchange. The high number of rear-end crashes involving multiple vehicles in this location may indicate either merging or acceleration issues. This option would allow vehicles to gradually attain speed within a lengthened parallel ramp, reducing merging conflicts with mainline volumes.

3.3 Bridges (B Options)

Independent bridge options involve reconstructing bridge structures classified as functionally obsolete and/or fracture critical and eligible for rehabilitation by MDT. The term "functionally obsolete" indicates the bridge was built to standards that are no longer used today. This term does not imply that the bridge is unsafe, rather that the bridge does not meet current MDT design standards for lane widths, shoulder widths, or vertical clearances to serve current traffic demand. The term "fracture critical" indicates the bridge does not include redundant supporting elements, meaning if key supporting elements were to fail, the bridge would be in danger of collapse. This term does not mean the bridge is inherently unsafe, only that there is a lack of redundancy in its design.

Independent bridge options are listed in Table 3.3.

Table 3.3 Independent Bridge Options (B Options)

Location	Option ID	Option Type	Improvement Option Description
Mainline Segment 2	**B-2**	Geometric	Reconstruct EB and WB I-90 bridges crossing S. 56th Street; modify vertical curve
Mainline Segment 6	**B-6**	Capacity Geometric	Reconstruct EB and WB I-90 bridges crossing the Yellowstone River

Option B-2 would reconstruct the EB and WB I-90 bridges crossing S. 56th Street. The current structures are functionally obsolete and reconstruction would bring the structures up to current MDT design standards. The bridges are anticipated to retain their current lane configuration throughout the planning horizon of 2035 because mainline Interstate widening options are not recommended adjacent to Option B-2. If Option B-2 is forwarded from this study, additional analysis should be conducted during project development to verify future traffic demands and mainline capacity needs at this location as the bridge design life is longer than the planning horizon.

Option B-6 would reconstruct the EB and WB Yellowstone River Bridges. The current structures are designated as functionally obsolete and fracture critical. Reconstruction would bring the structures up to current MDT design standards and address the fracture critical designation. The Yellowstone River Bridges are located within mainline segment 6, identified as a segment requiring widening to address capacity needs within the planning horizon. To match improvement options identified for Segment 6, the Yellowstone River Bridges should be

reconstructed with three travel lanes in each direction. For this study, it was assumed that the Yellowstone River Bridge would be constructed with three 12-foot travel lanes, a two-foot inside shoulder, and a ten-foot outside shoulder (see typical sections provided in Appendix 3). If Option B-6 is forwarded from this study, it may be appropriate to consider widening the bridge further to accommodate an emergency travel lane. Modifications to the width could be considered during the design phase of an individual project. Additional analysis should be conducted during project development to verify future traffic demands and mainline capacity needs at this location.

A number of other bridges in the corridor will need to be reconstructed due to mainline widening and interchange reconstruction projects, as discussed in Sections 3.1, 3.2, and 3.4. These bridges are otherwise functionally and structurally sound, but will require reconstruction due to widening associated with a mainline or interchange improvement and are included in mainline improvements.

For all options involving bridge reconstruction (including independent bridge options, mainline widening, and interchange options), this study assumes that the new bridge structures will be designed and built to accommodate anticipated traffic demands within the 2035 planning horizon only. Although the design life identified by MDT for new bridge structures (roughly 75 years) extends beyond the planning horizon of this study, a reporting of possible traffic demands beyond this study's timeframe were not projected beyond 2035 to a 75-year period due to the high number of unknown variables and the unreliability of extended forecasts. It is anticipated that specific design requirements will be addressed during the design phase for any forwarded improvements.

If improvement options involving bridge reconstruction are forwarded from this study, bridges could be designed and constructed to allow expansion of additional travel lanes to accommodate future capacity needs throughout the design life of the bridge. Mainline bridge structures, ramps and on-system overpass structures may be constructed using methods and structure types commonly used on the Interstate system in Montana. Substructures typically consist of pile or drilled shaft foundations supporting cast-in-place concrete pile caps, pier walls, or hammerhead caps. Superstructures range from steel plate girders to pre-stressed concrete I-girders supporting cast-in-place concrete deck slabs. Miscellaneous elements supported by and attached to the bridge deck include sidewalks, vehicle barriers, pedestrian barriers and steel bridge railing, as appropriate. These types of systems have been used successfully since the inception of the

Interstate system and can generally be widened to accommodate additional traffic lanes without adversely affecting traffic flow.

At a major river crossing such as the Yellowstone River, efforts should be undertaken to minimize the substructure's impact on the established floodplain. Longer span superstructures may be designed to minimize the number of piers within the floodplain. The recent development of supergirders within the pre-cast, pre-stressed concrete industry have resulted in single span lengths in excess of 300 feet, although the feasibility of shipping or transporting such lengths to the project site may affect consideration of these systems. Steel box girders and pre-cast segmented concrete bridges may also be viable options, although these systems may require more intense planning to determine the feasibility of widening the bridge deck to accommodate additional traffic lanes in the future.

Depictions of Options B-2 and B-6 are provided in Appendices 1 and 3.

3.4 Interchanges (I Options)

This study includes an analysis of the Laurel and Mossmain Interchanges to supplement analysis conducted for 2006 SEH report. Improvement options identified in the 2006 SEH report are valid and are provided in Appendix 4 of this document. Table 3.4 lists recommended interchange improvement options.

Table 3.4 Interchanges (I Options)

Location	Option ID	Option Type	Improvement Option Description
Interchange 1: Laurel	**I-1a**	Geometric	Extend EB and WB on-ramps and off-ramps; flatten horizontal curves at WB off-ramp and EB on-ramp; modify vertical curves Other elements include: • Reconstruct EB I-90 bridge crossing of US 212 / US 310
	I-1b	Safety	Upgrade lighting at Laurel Interchange to CIL standards
Interchange 2: Mossmain	**I-2a**	Geometric	Extend EB and WB on-ramps and off-ramps
	I-2b	Capacity	Reconstruct Mossmain Interchange Variations include: • Braided Ramps • Roundabouts • Single Point Urban Interchange (SPUI) • Reconstruction of Frontage Roads
	I-2c	Safety	Upgrade lighting at Mossmain Interchange to CIL standards

Options I-1a and I-2a would extend the EB and WB on- and off-ramps at the Laurel Interchange and the Mossmain Interchange to bring each interchange up to current MDT design standards for ramp lengths. As part of Option I-1a, the EB I-90 bridge crossing US 212 / US 310 would need to be reconstructed to accommodate the additional width needed to support the ramp improvement. Option I-1a and I-2a are illustrated in Appendix 2.

Option I-1b and I-2c would install additional lighting at the Laurel and Mossmain Interchanges to meet CIL standards. If improvement options are forwarded from this study, an appropriate level of lighting could be considered during project development. CIL is warranted at these interchanges, although Chapter 13 of the MDT Traffic Engineering Manual (November 2007) notes PIL is generally MDT's preferred method for interchange lighting.

The Laurel Interchange intersections are anticipated to operate at LOS C or better through the study horizon year. The Mossmain Interchange is expected to experience a degradation of its LOS and continue to exhibit capacity issues at the ramp and frontage road intersections. While traffic volumes at these intersections are not overwhelming, geometric deficiencies resulting from the interchange's closely spaced intersections may result in operational failure during peak demand periods. Option I-2b would involve a complete reconstruction of the Mossmain Interchange to address these issues. Multiple variations on this option were considered, including braided ramps, roundabout configurations, a single-point urban interchange (SPUI), and reconstruction of the frontage roads. These variations would require modifications to adjacent transportation systems, structure improvements, drainage and irrigation features, and right-of-way acquisition to accommodate a final design. A traffic analysis and geometric design would be developed if a project is initiated. Illustrations of possible concepts are included in Appendix 2.

FHWA has developed an 8-Point Policy Analysis that is required in order to approve new or revised access points to the Interstate System. This 8-Point Policy Analysis must be supported by substantiated information justifying and documenting the decision to modify the existing access points along the Interstate. FHWA's decision to approve a request is dependent on the proposal satisfying and documenting the eight requirements pursuant to 23 U.S.C. 111. This policy would apply only to Improvement Option I-2b and would be addressed at the projected level.

4.0 IMPROVEMENT OPTION ANALYSIS

Improvement options altering the number or configuration of mainline lanes or interchange ramp lanes were analyzed to determine how the options would affect LOS within the 2035 planning horizon. Mainline and ramp intersection locations were analyzed using procedures outlined in the Highway Capacity Manual (HCM) 2010. Freeway components, HCM concepts, LOS criteria, operational analysis methods, and software applications used for this study are described in detail in the Existing and Projected Conditions Report and are summarized in the following sections.

4.1 Mainline Segments Between Adjacent Interchanges (M Options)

Methodology

Mainline Interstate

Traffic conditions on transportation facilities are commonly defined using the Level of Service (LOS) concept. The HCM 2010 defines LOS based on a variety of factors to provide a qualitative assessment of the driver's experience. For mainline Interstate operations, the HCM defines LOS on the basis of vehicle density. Factors affecting mainline LOS include free flow travel speed, percentage of trucks and buses within the travel stream, driver population factor, peak hour factor, the number of travel lanes, and terrain. LOS for freeway segments is generally a measure of the degree of congestion on a roadway and applies to a specific time period, usually 15 minutes. For a mainline, six LOS categories ranging from A to F are used to describe traffic operations, with A representing the best conditions and F representing the worst.

Basic freeway segments are the portions of a freeway outside the influence area of any on-ramp or off-ramp. Table 4.1 presents LOS density criteria for basic mainline freeway segments.

Table 4.1 LOS Criteria for Basic Freeway Segments

Level of Service	Density (pc/mi/ln)[1]
A	≤11.0
B	>11.0 to 18.0
C	>18.0 to 26.0
D	>26.0 to 35.0
E	>35.0 to 45.0
F	>45.0 or any component with a vd/c[2] ratio >1.00

Source: HCM 2010, Exhibit 10-7 LOS Criteria for Freeway Facilities.
[1] pc/mi/ln: passenger cars per mile per lane
[2] A Demand Flow Rate (vd/c) > 1.00 indicates vehicle demand exceeds available capacity.

Freeway weaving segments are the portions of a freeway where an on-ramp is closely followed by an off-ramp and entering or exiting traffic must make at least one lane change to enter or exit the freeway. Table 4.2 presents LOS density criteria for mainline weaving segments.

Table 4.2 LOS Criteria for Weaving Segments

Level of Service	Density (pc/mi/ln)[1]
A	0 to 10.0
B	>10.0 to 20.0
C	>20.0 to 28.0
D	>28.0 to 35.0
E	>35.0
F	Demand exceeds capacity[2]

Source: HCM 2010, Exhibit 12-10 LOS Criteria for Weaving Segments.
[1] pc/mi/ln: passenger cars per mile per lane
[2] Level of service for weaving segments is generally based on density, although in this case LOS is defined as F when the demand volume exceeds available capacity.

Highway Capacity Software (HCS) 2010 was used to analyze LOS for basic and weaving Interstate links throughout the corridor. Appendix 5 contains operational analysis worksheets for each analysis location.

Ramp Gore Areas

Ramp gore areas (also called freeway merge and diverge segments) are the portions of a freeway where traffic enters or exits without having to change lanes to enter or leave a through traffic lane. As with mainline operations, six LOS categories ranging from A to F are used to describe

traffic operations for ramps, with A representing the best conditions and F representing the worst. To reflect driver perceptions regarding the operations of ramps and transitional facilities between freeways and intersecting arterials, the density ranges for corresponding levels of service for ramps is broader than that for freeway segments. Table 4.3 presents LOS criteria for ramp gore areas. HCS was used to analyze LOS for ramp gore areas throughout the corridor. Appendix 5 contains operational analysis worksheets for each analysis location.

Table 4.3 LOS Criteria for Ramp Gore Areas

Level of Service	Density (pc/mi/ln) [1]	Comments
A	≤10.0	Unrestricted operations
B	>10.0 to 20.0	Merging and diverging maneuvers noticeable to drivers
C	>20.0 to 28.0	Influence area speeds begin to decline
D	>28.0 to 35.0	Influence area turbulence becomes intrusive
E	>35.0	Turbulence felt by virtually all drivers
F	Demand exceeds capacity	Ramp and freeway queues form

Source: HCM 2010, Exhibit 13-2 LOS Criteria for Freeway Merge and Diverge Segments
[1] pc/mi/ln: passenger cars per mile per lane

Analysis Results

The MDT Traffic Engineering Manual and MDT Road Design Manual define desirable operations for urban and rural freeway facilities as LOS B. Mainline segments and gore areas are expected to operate at LOS B or better with implementation of the recommended auxiliary lane improvements.

Tables 4.4 through 4.7 present the results of the LOS analysis for mainline improvement options between adjacent interchanges. Each table lists only the mainline segments and ramp gore areas that would be affected by the particular option. Detailed analysis worksheets are contained in Appendix 5.

Option M-3

Option M-3 is located within the mainline Interstate segment between the Shiloh Interchange and the West Billings Interchange. As noted in Table 4.4, this mainline segment is expected to operate at LOS C in its current configuration by the study horizon year of 2035. Additionally, the Shiloh eastbound on-ramp and the West Billings westbound on-ramp are expected to reach LOS C by 2035 if no improvements are made. The eastbound off-ramp at the West Billings Interchange is projected to operate at LOS F in the horizon year. This poor LOS is a result of a

high 15-minute peak traffic demand that was observed in the field during the collection of traffic data. The right-hand columns in Table 4.4 illustrate that Segment 3 and adjacent ramps are expected to operate at LOS B with implementation of Option M-3.

Table 4.4 LOS Analysis for Option M-3

Location		2035 Without Improvement				2035 With Improvement Option M-3			
		EB		WB		EB		WB	
		Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS
Shiloh	On-Ramp	25.4	C	-	-	19.6	B	-	-
	Off-Ramp	-	-	17.5	B	-	-	12.6	B
Shiloh to West Billings	Mainline	21.6	C	20.4	C	13.8	B	13.5	B
West Billings	On-Ramp	-	-	23.4	C	-	-	18.3	B
	Off-Ramp[2]	13.4	B	-	-	15.2	B	-	-

Source: DOWL HKM, 2011.
[1] pc/mi/ln: passenger cars per mile per lane
[2] The West Billings off-ramp generally operates at LOS B during the peak hour, as indicated by the reported density. Due to a high 15-minute traffic volume observed within the peak hour, calculations indicate that the capacity of the ramp gore is briefly exceeded and operates at LOS F. If Option M-3 is forwarded from this study, updated traffic data should be collected and the need for an additional off-ramp lane should be considered.
Dashes (-) indicate option does not address location.

The eastbound Shiloh on-ramp and the westbound West Billings on-ramp are projected to operate with densities very near the threshold between LOS B and LOS C of 20.0 passenger cars per mile per lane with implementation of Option M-3 in 2035. These on-ramps are projected to operate at a desirable LOS B through the planning horizon of 2035, and an additional on-ramp lane is not recommended as part of this study. If improvement options are forwarded from this study, additional analysis should be conducted during project development to determine if traffic volumes warrant additional ramp lanes.

Option M-5

Option M-5 is located within the mainline segment between the South Billings Boulevard Interchange and the South 27th Street Interchange. In its current configuration, the eastbound lanes of this mainline segment are expected to operate at LOS C by the study horizon year. Additionally, the eastbound on-ramp and westbound off-ramp at the South Billings Boulevard Interchange and the eastbound off-ramp at the South 27th Street Interchange are expected to

reach LOS C by 2035. Segment 5 and adjacent ramps are expected to operate at LOS B with implementation of Option M-5, as noted in Table 4.5.

Table 4.5 LOS Analysis for Option M-5

Location		2035 Without Improvement				2035 With Improvement Option M-5			
		EB		WB		EB		WB	
		Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS
South Billings Boulevard	On-Ramp	21.5	C	-	-	15.7	B	-	-
	Off-Ramp	-	-	23.2	C	-	-	12.4	B
South Billings Boulevard to South 27th Street	Mainline	19.7	C	17.7	B	13.1	B	11.8	B
South 27th Street	On-Ramp	-	-	19.1	B	-	-	13.3	B
	Off-Ramp	22.4	C	-	-	11.2	B	-	-

Source: DOWL HKM, 2011.
[1] pc/mi/ln: passenger cars per mile per lane
Dashes (-) indicate option does not address location.

Option M-6

Option M-6 is located within the mainline segment between the South 27th Street Interchange and the Lockwood Interchange. In its current configuration the eastbound lanes of this mainline segment, the eastbound on-ramp at the South 27th Street Interchange, and the westbound on-ramp and eastbound off-ramp at the Lockwood Interchange are expected to operate at LOS C by the study horizon year of 2035. The westbound lanes of this mainline segment are predicted to experience a density of 18 passenger cars per mile per lane (pc/mi/ln) in 2035, which is just at the demarcation between LOS B and LOS C. As noted in Table 4.6, Segment 6 and adjacent ramps are expected to operate at LOS B with implementation of Option M-6.

Table 4.6 LOS Analysis for Option M-6

Analysis Location		2035 Without Improvement				2035 With Improvement Option M-6			
		EB		WB		EB		WB	
		Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS
South 27th Street	On-Ramp	23.7	C	-	-	16.6	B	-	-
	Off-Ramp	-	-	17.8	B	-	-	11.7	B
South 27th Street to Lockwood	Mainline	25.4	C	18.0	B	15.6	B	11.8	B
Lockwood	On-Ramp	-	-	21.8	C	-	-	15.2	B
	Off-Ramp	23.4	C	-	-	16.5	B	-	-

Source: DOWL HKM, 2011.
[1] pc/mi/ln: passenger cars per mile per lane
Dashes (-) indicate option does not address location.

Option M-7

Option M-7 is located within the mainline segment between the Lockwood Interchange and Johnson Lane Interchange. In its current configuration the westbound lanes of this mainline segment are expected to operate at LOS C by the study horizon year of 2035. The westbound on-ramp at the Johnson Lane Interchange the eastbound on-ramp and westbound off-ramp at the Lockwood Interchange are expected to operate at LOS C by 2035. Segment 7 and adjacent ramps are expected to operate at LOS B with implementation of Option M-7, as noted in Table 4.7.

Table 4.7 LOS Analysis for Option M-7

Analysis Location		2035 Without Improvement				2035 With Improvement Option M-7			
		EB		WB		EB		WB	
		Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS
Lockwood	On-Ramp	21.7	C	-	-	14.2	B	-	-
	Off-Ramp	-	-	20.7	C	-	-	13.4	B
Lockwood to Johnson Lane	Mainline	17.1	B	20.3	C	11.4	B	13.1	B
Johnson Lane	On-Ramp	-	-	23.8	C	-	-	19.9	B
	Off-Ramp	19.7	B	-	-	11.0	B	-	-

Source: DOWL HKM, 2011.
[1] pc/mi/ln: passenger cars per mile per lane
Dashes (-) indicate option does not address location.

In 2035, the westbound Johnson Lane on-ramp is projected to operate with a density very near the threshold between LOS B and LOS C of 20.0 passenger cars per mile per lane with implementation of Option M-7 (see Table 4.7). This on-ramp is projected to operate at a desirable LOS B through the planning horizon of 2035, and an additional on-ramp lane is not recommended as part of this study. If improvement options are forwarded from this study, additional analysis should be conducted in this location to determine if an additional on-ramp lane is warranted during project development.

4.2 Mainline Segments Under or Through an Interchange (U Options)

Methodology

Please refer to Section 4.1 for a description of applicable methodology.

Analysis Results

Improvement Options U-4b, U-5, U-6, and U-7 would involve constructing a third travel lane under or through interchanges and linking Improvement Options M-3, M-5, M-6, and M-7 in order to provide continuity in the basic number of lanes throughout the corridor, as well as to eliminate weaving maneuvers as a result of ramp and auxiliary lane merging. Under segments are not anticipated to reach LOS C by 2035 and a third lane is not needed for LOS reasons.

Although under options are not recommended in order to improve LOS, they are expected to affect LOS within the corridor due to the addition of a third lane and the resulting impact on lane configuration. Tables 4.8 through 4.11 present the results of the LOS analysis for mainline improvement options under or through an interchange. Each table lists only the mainline segments and ramp gore areas that would be affected by the particular option. Detailed analysis worksheets are contained in Appendix 5.

Option U-4b

Option U-4b is located within the West Billings Interchange between the on-ramps and off-ramps on the eastern and western ends of the interchange. As noted previously in the discussion for Option M-3, the westbound on-ramp at the West Billings Interchange is expected to operate at LOS C if no improvements are made. Additionally, the eastbound off-ramp at the West Billings Interchange is projected to operate at LOS F in the horizon year. This poor LOS is a result of a high 15-minute peak traffic demand that was observed in the field during the collection of traffic data, as well as a higher volume of vehicles exiting the freeway than

continuing on the mainline Interstate as projected by the current MDT TransCAD model. The combination of a high 15-minute peak traffic demand and higher volumes exiting the freeway than continuing on the mainline over-saturates the eastbound off-ramp, leading to a projected LOS F. With implementation of Option U-4b, this issue is compounded further due to additional weaving at the eastbound off-ramp resulting from the construction of a third travel lane. The high 15-minute peak traffic demand observed in the field may not be representative of normal peak demand at the off-ramp and may be considered within a margin of error for this planning study. If the 15-minute peak is discounted, the eastbound off-ramp is projected to operate at LOS B with or without implementation of Option U-4b. If improvement options are forwarded from this study, additional analysis should be conducted at the eastbound off-ramp for the West Billings Interchange to determine if an additional off-ramp lane is warranted.

Table 4.8 LOS Analysis for Option U-4b

Location		2035 Without Improvement				2035 With Improvement Option U-4b			
		EB		WB		EB		WB	
		Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS
West Billings	On-Ramp	12.6	B	23.4	C	8.8	A	18.3	B
	Off-Ramp[2]	13.4	B	[3]	[3]	17.4	B	18.4	B
	On-Ramp at Mullowney	[3]	[3]	-	-	14.9	B	-	-
West Billings Over	Mainline	7.9	A	10.9	A	5.3	A	7.2	A
West Billings Over Part 2	Mainline	8.8	A	-	-	5.8	A	-	-

Source: DOWL HKM, 2011.
[1] pc/mi/ln: passenger cars per mile per lane
[2] The West Billings off-ramp generally operates at LOS B during the peak hour, as indicated by the reported density. Due to a high 15-minute traffic volume observed within the peak hour, calculations indicate that the capacity of the ramp gore is briefly exceeded and operates at LOS F. If Option U-4b is forwarded from this study, updated traffic data should be collected and the need for an additional off-ramp lane should be considered.
[3] The eastbound on-ramp at Mullowney and the westbound off-ramp are analyzed together as a weaving segment. Individual density and LOS values are not reported.
Dashes (-) indicate option does not address location.

In 2035, the West Billings WB off-ramp and WB on-ramp are projected to operate with densities very near the threshold between LOS B and LOS C of 20.0 passenger cars per mile per lane with implementation of Option U-4b (see Table 4.8). These on-ramps are projected to operate at a desirable LOS B through the planning horizon of 2035, and additional ramp lanes are not recommended as part of this study. If improvement options are forwarded from this study,

additional analysis should be conducted in these locations to determine if additional ramp lanes are warranted during project development.

Option U-5

Option U-5 is located within the South Billings Boulevard Interchange between the on-ramps and off-ramps on the eastern and western ends of the interchange. The eastbound on-ramp and westbound off-ramp at the South Billings Boulevard Interchange are expected to reach LOS C by 2035 if no improvements are made. The eastbound on-ramp and the westbound off-ramp are projected to operate at LOS B with implementation of Option U-5, as identified in Table 4.9.

Table 4.9 LOS Analysis for Option U-5

Analysis Location		2035 Without Improvement				2035 With Improvement Option U-5			
		EB		WB		EB		WB	
		Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS
South Billings Boulevard	On-Ramp	21.5	C	[2]	[2]	15.7	B	13.2	B
	Off-Ramp	[2]	[2]	23.2	C	16.4	B	17.6	B
South Billings Boulevard Under	Mainline	12.7	B	16.2	B	8.5	A	10.7	A

Source: DOWL HKM, 2011.

[1] pc/mi/ln: passenger cars per mile per lane

[2] The eastbound off-ramp and the westbound on-ramp are analyzed together as a weaving segment. Individual density and LOS values are not reported.

Option U-6

Option U-6 is located within the South 27th Street Interchange between the on-ramp and off-ramps on the eastern and western ends of the interchange. The eastbound on-ramp and the eastbound off-ramp are expected to operate below the desirable LOS B by the study horizon year of 2035 if no improvements are made. The eastbound on-ramp and the eastbound off-ramp are projected to operate at LOS B with implementation of Option U-6, as noted in Table 4.10.

Table 4.10 LOS Analysis for Option U-6

Analysis Location		2035 Without Improvement				2035 With Improvement Option U-6			
		EB		WB		EB		WB	
		Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS
South 27th Street	On-Ramp	23.7	C	19.1	B	16.6	B	13.3	B
	Off-Ramp	22.4	C	17.8	B	17.2	B	14.4	B
South 27th Street Under	Mainline	16.2	B	12.2	B	10.8	A	8.2	A

Source: DOWL HKM, 2011.
[1] pc/mi/ln: passenger cars per mile per lane

Option U-7

Option U-7 is located within the Lockwood Interchange between the on-ramps and off-ramps on the eastern and western ends of the interchange. All ramps at the Lockwood Interchange are expected to operate at LOS C by 2035 if no improvements are made. The interchange on-ramp and off-ramps are projected to operate at LOS B with implementation of Option U-7, as noted in Table 4.11.

Table 4.11 LOS Analysis for Option U-7

Analysis Location		2035 Without Improvement				2035 With Improvement Option U-7			
		EB		WB		EB		WB	
		Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS	Density (pc/mi/ln)[1]	LOS
Lockwood	On-Ramp	21.7	C	21.8	C	14.2	B	15.2	B
	Off-Ramp	23.4	C	20.7	C	19.8	B	17.2	B
Lockwood Under	Mainline	17.2	B	14.0	B	11.5	B	9.3	A

Source: DOWL HKM, 2011.
[1] pc/mi/ln: passenger cars per mile per lane

In 2035, the eastbound Lockwood off-ramp is projected to operate with a density very near the threshold between LOS B and LOS C of 20.0 passenger cars per mile per lane with implementation of Option U-7 (see Table 4.11). This off-ramp is projected to operate at a desirable LOS B through the planning horizon of 2035, and an additional ramp lane is not recommended in this study. If improvement options are forwarded from this study, additional analysis should be conducted in this location to determine if an additional ramp lane is warranted during project development.

4.3 Interchanges (I Options)

Methodology

Intersection capacity and LOS analyses were completed using Synchro 8.0 plus SimTraffic software, which employs the methodology from the 2000 and 2010 Highway Capacity Manual (HCM). Synchro 8.0 is a network-based interactive computer program that enables calculation of LOS at signalized and unsignalized intersections and roadway networks, while SimTraffic simulation software allows visual observation of overall network operation.

Analysis was based on HCM calculations, which evaluate capacity in terms of demand volume-to-capacity (v/c) ratio and LOS based on controlled delay in seconds per vehicle (sec/veh). Controlled delay is defined as the portion of the total delay attributed to the traffic control operation including deceleration delay, queue move-up time, stopped delay, and the final acceleration delay. For intersections, six LOS categories ranging from A to F are used to qualitatively describe traffic operations, with LOS A representing free-flow conditions (i.e., no delay) and LOS F representing severe congestion with stop-and-go conditions (i.e., substantial delay).

Delay times for each of these categories differ depending on the type of intersection control. LOS delay criteria for signalized intersections are higher than those reported for unsignalized intersections. This difference, as explained in the HCM, accounts for the greater variability in delay associated with each intersection control type as well as different driver expectations associated with each intersection control type. Drivers expect greater delays to be associated with signalized intersections as compared to unsignalized intersections because the perception is that signalized intersections are designed to carry higher traffic volumes and create more delay than would otherwise be expected at an unsignalized intersection. Table 4.12 presents delay times for each category, as defined by the HCM. Factors affecting mainline LOS include average travel speed, percent time delay, intersection delay, capacity utilization, and maximum density.

Table 4.12 Intersection LOS Criteria

LOS	Average Control Delay (seconds per vehicle)	
	Two-Way Stop-Controlled Intersections	Signalized Intersections
A	0 to 10.0	≤10.0
B	>10.0 to 15.0	>10.0 to 20.0
C	>15.0 to 25.0	>20.0 to 35.0
D	>25.0 to 35.0	>35.0 to 55.0
E	>35.0 to 50.0	>55.0 to 80.0
F	>50.0	>80.0

Source: HCM 2010, Exhibit 18-4 Level of Service Criteria for Signalized Intersections and 19-1 Level of Service Criteria for Two-Way Stop-Controlled (TWSC) Intersections.

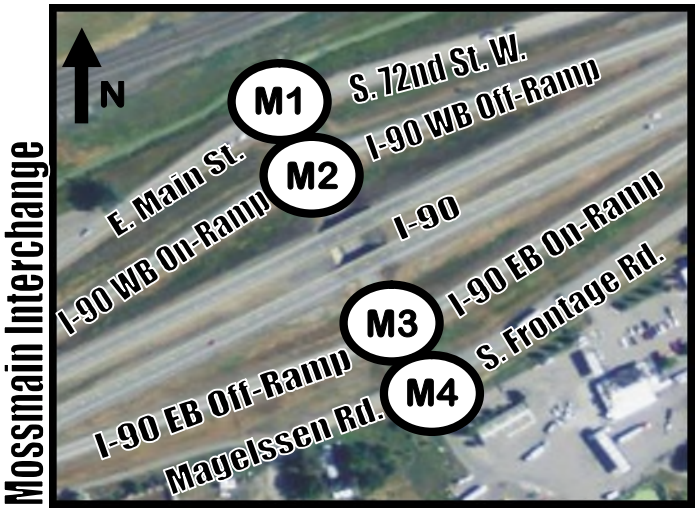
Analysis Results

The MDT Road Design Manual notes that individual interchange elements should not operate at more than one LOS below that of the mainline Interstate. Desirable operations for the mainline Interstate and ramp intersections are defined as LOS B and LOS C, respectively.

The Laurel Interchange intersections are anticipated to operate at desirable LOS C or better through the study horizon year. The Laurel ramp intersections were not assessed for this report.

All intersections at the Mossmain Interchange are expected to reach failing LOS by 2035. For reference, Figure 4-1 illustrates the locations of Mossmain Intersections.

Figure 4-1 Mossmain Ramp Intersections



With no improvements at the Mossmain Interchange, Intersection M1 is projected to experience a higher demand than can be served during the peak hour (noted as an "overflow" condition in Tables 4.13 through 4.16) in 2035. Furthermore, delays reported for Intersection M2 could experience queues beyond the ability of the ramp to store the vehicles.

Option I-2b proposes to reconstruct the Mossmain Interchange to address operational issues. Four (4) conceptual reconstruction scenarios were assessed to determine if they would operate at a desirable LOS C through the planning horizon of 2035. Tables 4.13 through 4.16 present the results of the LOS analysis for these improvements at the Mossmain Interchange. Analysis worksheets are contained in Appendix 5.

Roundabouts

The Roundabouts scenario would involve constructing two roundabouts, with the northern roundabout replacing Intersections M1 and M2, and the southern roundabout replacing Intersections M3 and M4. This scenario would also reconstruct the South Frontage Road. The consolidation of the current intersections and re-routing South Frontage Road traffic to the south is expected to reduce delay and queuing that is projected to occur if no improvements are made to the interchange. As noted in Table 4.13, the Mossmain Interchange ramp intersections are expected to operate at a desirable LOS A and B with implementation of the roundabouts scenario. This scenario would provide sufficient separation between the two roundabouts, thus allowing additional storage length. SimTraffic simulation did not indicate any traffic accumulation resulting from this scenario. From a feasibility standpoint, this scenario may require modification to the overpass span length, as it will require construction of an additional northbound lane (see Interchange Detail Sheets in Appendix 2).

Braided Ramps

The Braided Ramps scenario would also involve constructing two roundabouts, although a braided ramp configuration would be utilized to accommodate traffic volumes using eastbound and westbound on-ramps, the westbound off-ramp, South Frontage Road, and East Main Street / South 72nd Street West. As noted in Table 4.14, the Mossmain Interchange ramp intersections are expected to operate at LOS C. However, this scenario would require westbound traffic on 72nd Street and the off-ramp to merge upstream of the northern roundabout intersection. This is not a major issue if traffic volumes are low, but as traffic volumes rise this becomes critical. SimTraffic simulation indicated severe westbound traffic accumulation at the merge point and

South Frontage Road approach. This scenario will more likely require an additional northbound lane between the two roundabouts.

Single-Point Urban Interchange (SPUI)

The SPUI scenario would involve constructing two roundabouts and a signalized Single-Point Urban Interchange (SPUI). The term "single-point" indicates that the configuration would allow traffic volumes on the interchange crossroad as well as the interchange ramps to be controlled by a single signalized intersection in the center of the interchange. As noted in Table 4.15, the northern roundabout intersection and the central signalized intersection are projected to operate at an undesirable LOS D and E under this scenario. Furthermore, this scenario would operate with less than 300 feet of separation between the SPUI and the roundabouts on each side. SimTraffic simulation analysis shows that the two roundabouts are anticipated to experience severe queuing accumulation with this limited separation distance.

Frontage Road

The Frontage Road scenario would reconstruct East Main Street and South 72nd Street West, construct a new above grade structure crossing over the I-90 mainline, and eliminate Intersections M1 and M4. Using HCM 2000 procedures for Two-Way Stop-Controlled (TWSC) intersections, LOS is determined for a particular movement rather than the intersection as a whole. Table 4.16 shows that the westbound approach of the northern intersection and eastbound off-ramp approach will be operating at LOS F and D, respectively. SimTraffic simulation analysis indicated traffic accumulation at the westbound approach of the northern intersection.

Table 4.13 LOS Analysis for Option I-2b (Roundabouts)

Intersection		Control Type	Intersection Approach	Turning Movement	Without Improvement 2035				With Improvement Option I-2b (Roundabouts) 2035				
					Approach		Overall Intersection		Control Type	Approach		Overall Intersection	
					Delay (s/veh)[1]	LOS	Delay (s/veh)[1]	LOS		Delay (s/veh)[1]	LOS	Delay (s/veh)[1]	LOS
M1	E. Main Street / S. 72nd Street West / Interchange Crossroad	Stop	EB Approach (E. Main Street)	EB Through / Right	528.7	F	Overflow	F	Roundabout	13.4	B	12.1	B
		Stop	WB Approach (S. 72nd Street West)	WB Left / Through	Overflow	F			Roundabout	15.3	C		
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Left / Right	9.2	A			Roundabout	7.9	A		
M2	I-90 WB Ramps / Interchange Crossroad	Stop	WB Approach (WB I-90 Off-Ramp)	WB Left / Through / Right	241.1	F	241.1	F	Roundabout	16.4	C		
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Left / Through	5.3	A			-	-	-		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Through / Right	-	-			-	-	-		
M3	I-90 EB Ramps / Interchange Crossroad	Stop	EB Approach (EB I-90 Off-Ramp)	EB Left / Through / Right	42.0	E	42.0	E	Roundabout	8.8	A	9.0	A
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Through / Right	-	-			Roundabout	10.6	B		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Left / Through	5.3	A			Roundabout	5.9	A		
M4	Magelssen Road / S. Frontage Road / Interchange Crossroad	Stop	EB Approach (Magelssen Road)	EB Left / Through / Right	-	-	25.5	D	-	-	-	-	-
		Uncontrolled	WB Approach (S. Frontage Road)	WB Left / Through / Right	6.3	A			-	-	-		
		Stop	NB Approach (Driveway)	NB Left / Through / Right	25.5	D			-	-	-		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Left / Through / Right	-	-			-	-	-		

Source: DOWL HKM, 2011.
[1] s/veh: seconds per vehicle
Dashes (-) indicate no conflicting movements (i.e., no delay). Overflow indicates volume exceeds capacity.

Table 4.14 LOS Analysis for Option I-2b (Braided Ramps)

Intersection		Control Type	Intersection Approach	Turning Movement	Without Improvement 2035				With Improvement Option I-2b (Braided Ramps) 2035				
					Approach		Overall Intersection		Control Type	Approach		Overall Intersection	
					Delay (s/veh)[1]	LOS	Delay (s/veh)[1]	LOS		Delay (s/veh)[1]	LOS	Delay (s/veh)[1]	LOS
M1	E. Main Street / S. 72nd Street West / Interchange Crossroad	Stop	EB Approach (E. Main Street)	EB Through / Right	528.7	F	Overflow	F	Roundabout	9.4	A	97.5	F
		Stop	WB Approach (S. 72nd Street West)	WB Left / Through	Overflow	F			Roundabout	231.0	F		
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Left / Right	9.2	A			Roundabout	24.0	C		
M2	I-90 WB Ramps / Interchange Crossroad	Stop	WB Approach (WB I-90 Off-Ramp)	WB Left / Through / Right	241.1	F	241.1	F	-	-	-	-	-
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Left / Through	5.3	A			-	-	-		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Through / Right	-	-			-	-	-		
M3	I-90 EB Ramps / Interchange Crossroad	Stop	EB Approach (EB I-90 Off-Ramp)	EB Left / Through / Right	42.0	E	42.0	E	Roundabout	10.0	B	17.0	C
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Through / Right	-	-			-	-	-		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Left / Through	5.3	A			-	-	-		
M4	Magelssen Road / S. Frontage Road / Interchange Crossroad	Stop	EB Approach (Magelssen Road)	EB Left / Through / Right	-	-	25.5	D	-	-	-		
		Uncontrolled	WB Approach (S. Frontage Road)	WB Left / Through / Right	6.3	A			Roundabout	24.3	C		
		Stop	NB Approach (Driveway)	NB Left / Through / Right	25.5	D			Roundabout	6.7	A		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Left / Through / Right	-	-			Roundabout	6.1	A		

Source: DOWL HKM, 2011.
[1] s/veh: seconds per vehicle
Dashes (-) indicate no conflicting movements (i.e., no delay). Overflow indicates volume exceeds capacity.

Table 4.15 LOS Analysis for Option I-2b (Single Point Urban Interchange [SPUI])

Intersection		Control Type	Intersection Approach	Turning Movement	Without Improvement 2035				With Improvement Option I-2b (SPUI) 2035				
					Approach		Overall Intersection		Control Type	Approach		Overall Intersection	
					Delay (s/veh)[1]	LOS	Delay (s/veh)[1]	LOS		Delay (s/veh)[1]	LOS	Delay (s/veh)[1]	LOS
M1	E. Main Street / S. 72nd Street West / Interchange Crossroad	Stop	EB Approach (E. Main Street)	EB Through / Right	528.7	F	Overflow	F	Roundabout	8.3	A	27.0	D
		Stop	WB Approach (S. 72nd Street West)	WB Left / Through	Overflow	F			Roundabout	13.8	B		
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Left / Right	9.2	A			Roundabout	37.1	E		
M2	I-90 WB Ramps / Interchange Crossroad	Stop	WB Approach (WB I-90 Off-Ramp)	WB Left / Through / Right	241.1	F	241.1	F	Signalized	61.5	E	-	-
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Left / Through	5.3	A			Signalized	32.6	C		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Through / Right	-	-			Uncontrolled	-	-		
M3	I-90 EB Ramps / Interchange Crossroad	Stop	EB Approach (EB I-90 Off-Ramp)	EB Left / Through / Right	42.0	E	42.0	E	Signalized	50.0	D	-	-
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Through / Right	-	-			Uncontrolled	-	-		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Left / Through	5.3	A			Signalized	17.3	A		
M4	Magelssen Road / S. Frontage Road / Interchange Crossroad	Stop	EB Approach (Magelssen Road)	EB Left / Through / Right	-	-	25.5	D	Roundabout	5.2	A	15.8	C
		Uncontrolled	WB Approach (S. Frontage Road)	WB Left / Through / Right	6.3	A			Roundabout	21.2	C		
		Stop	NB Approach (Driveway)	NB Left / Through / Right	25.5	D			Roundabout	5.4	A		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Left / Through / Right	-	-			Roundabout	7.4	A		

Source: DOWL HKM, 2011.
[1] s/veh: seconds per vehicle
Dashes (-) indicate no conflicting movements (i.e., no delay). Overflow indicates volume exceeds capacity

Table 4.16 LOS Analysis for Option I-2b (Frontage Road Reconstruction)

Intersection		Control Type	Intersection Approach	Turning Movement	Without Improvement 2035				With Improvement Option I-2b (Frontage Road Reconstruction) 2035				
					Approach		Overall Intersection		Control Type	Approach		Worst Approach	
					Delay (s/veh)[1]	LOS	Delay (s/veh)[1]	LOS		Delay (s/veh)[1]	LOS	Delay (s/veh)[1]	LOS
M1	E. Main Street / S. 72nd Street West / Interchange Crossroad	Stop	EB Approach (E. Main Street)	EB Through / Right	528.7	F	Overflow	F	-	-	-	-	-
		Stop	WB Approach (S. 72nd Street West)	WB Left / Through	Overflow	F			-	-	-		
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Left / Right	9.2	A			-	-	-		
M2	I-90 WB Ramps / Interchange Crossroad	Stop	WB Approach (WB I-90 Off-Ramp)	WB Left / Through / Right	241.1	F	241.1	F	Stop	314.2	F	314.2	F
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Left / Through	5.3	A			Uncontrolled	5.3	A		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Through / Right	-	-			Uncontrolled	-	-		
M3	I-90 EB Ramps / Interchange Crossroad	Stop	EB Approach (EB I-90 Off-Ramp)	EB Left / Through / Right	42.0	E	42.0	E	Stop	32.9	D	32.9	D
		Uncontrolled	NB Approach (Interchange Crossroad)	NB Through / Right	-	-			Uncontrolled	-	-		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Left / Through	5.3	A			Uncontrolled	4.3	A		
M4	Magelssen Road / S. Frontage Road / Interchange Crossroad	Stop	EB Approach (Magelssen Road)	EB Left / Through / Right	-	-	25.5	D	-	-	-	-	-
		Uncontrolled	WB Approach (S. Frontage Road)	WB Left / Through / Right	6.3	A			-	-	-		
		Stop	NB Approach (Driveway)	NB Left / Through / Right	25.5	D			-	-	-		
		Uncontrolled	SB Approach (Interchange Crossroad)	SB Left / Through / Right	-	-			-	-	-		

Source: DOWL HKM, 2011.
[1] s/veh: seconds per vehicle
Dashes (-) indicate no conflicting movements (i.e., no delay). Overflow indicates volume exceeds capacity.

4.4 Summary of Improvement Option Analysis

All mainline improvement options between adjacent interchanges (M Options) are anticipated to address the capacity needs in the corridor and provide desirable LOS through the planning horizon. Accordingly, all M Options are forwarded for further consideration.

Options U-4b, U-5, U-6, and U-7 are also forwarded for further consideration pending project level analysis to determine if continuous travel lanes are warranted. Project level analysis should also be conducted to determine if additional ramp lanes are warranted at such time that a project design phase is initiated.

The roundabout variation of Option I-2b at the Mossmain Interchange is anticipated to address the operational needs of the interchange. All other variations of this option (including the braided ramps, SPUI, and frontage road reconstruction variations) are not anticipated to achieve desirable LOS C within the 2035 planning horizon and were eliminated from further consideration.

A detailed traffic analysis and geometric design would be developed during project development.

5.0 ANTICIPATED IMPACTS AND POTENTIAL MITIGATION MEASURES

Improvement options were developed to minimize impacts to important resources and adjacent land areas to the extent practicable. Mainline widening options are recommended to occur toward the median in order to minimize right-of-way acquisition, reduce impacts to natural resources, and avoid bridge reconstruction where possible. Interchange improvements were identified and considered in an effort to identify workable solutions with the smallest footprint.

Despite these efforts, improvement options are anticipated to result in some unavoidable impacts. Impacts to some resources may be considered negligible and are expected to be addressed as part of standard project development procedures. Please refer to the Environmental Scan Report for a more detailed description of MDT practices and procedures relative to the project development and environmental review process.

Coordination with regulatory agencies will likely be necessary for some improvements. Table 5.1 lists anticipated impacts that may require permitting and/or coordination with regulatory agencies. Construction phase permitting is not identified.

If improvement options are forwarded from this study, additional analysis will be needed to identify and quantify anticipated impacts, identify appropriate mitigation strategies, and define the appropriate level of environmental documentation commensurate with the scope and scale of the improvement.

Table 5.1 Potential Permitting and Regulatory Agency Coordination

Option ID	Potentially Impacted Resource	Potential Permitting and Agency Coordination*
I-1a	Farmlands	Coordination with the Natural Resources Conservation Service (NRCS) may be required to address any impacts to soils classified as prime or important farmland.
	Italian Ditch	Coordination with the U.S. Army Corps of Engineers (USACE) may be required to determine jurisdictional status of the irrigation ditch and any associated wetlands. A Section 404 permit may be required.
		Coordination with the State Historic Preservation Office (SHPO) may be required to address any impacts to this historic ditch.
I-2b	Farmlands	Coordination with NRCS may be required to address any impacts to soils classified as prime or important farmland.
	Canyon Creek Ditch and BBWA Canal and laterals	Coordination with USACE may be required to determine jurisdictional status of irrigation ditches and any associated wetlands. A Section 404 permit may be required.
	Mossmain Overpass	Coordination with SHPO may be required to address any impacts to historic ditches and/or overpass structures.
M-3	Hogan's Slough	Coordination with the Montana Department of Environmental Quality (DEQ) may be required to address impacts to water quality. A 318 authorization may be required.
		Coordination with USACE may be required to address impacts to Waters of the U.S. and any associated wetlands. A Section 404 permit may be required.
		Coordination with Montana Fish, Wildlife & Parks (FWP) and the U.S. Fish and Wildlife Service (UWFWS) may be required to address any impacts to fish and wildlife species. A SPA 124 authorization may be required.
M-5	Suburban Ditch, Eagle Ditch, Grey Eagle Ditch	Coordination with the Montana Department of Environmental Quality (DEQ) may be required to address impacts to water quality. A 318 authorization may be required.
		Coordination with USACE may be required to determine jurisdictional status of irrigation ditches and any associated wetlands. A Section 404 permit may be required.
		Coordination with Montana Fish, Wildlife & Parks (FWP) and the U.S. Fish and Wildlife Service (UWFWS) may be required to address any impacts to fish and wildlife species. A SPA 124 authorization may be required.
		Coordination with SHPO may be required to address any impacts to historic ditches.

M-6 **B-6**	Yellowstone River	Coordination with DEQ would likely be required to address impacts to water quality. A 318 authorization would likely be required.
		Coordination with USACE would be needed to address impacts to Waters of the U.S. and any associated wetlands. Section 10 and Section 404 permits would likely be required.
		Coordination with Yellowstone County would be needed to address any impacts to floodplains. A floodplain development permit would likely be required.
		Coordination with the Montana Department of Natural Resources and Conservation (DNRC) would be needed to address any anticipated work within the high water mark of a navigable river. A Land Use License (LUL) or easement on navigable waters may be required.
		Coordination with FWP and UWFWS would be needed to address any impacts to fish and wildlife species. A SPA 124 authorization would likely be required.
U-7	Lockwood Ditch	Coordination with DEQ would likely be required to address impacts to water quality. A 318 authorization would likely be required.
		Coordination with USACE may be required to determine jurisdictional status of irrigation ditch and any associated wetlands. A Section 404 permit may be required.
		Coordination with Montana Fish, Wildlife & Parks (FWP) and the U.S. Fish and Wildlife Service (UWFWS) may be required to address any impacts to fish and wildlife species. A SPA 124 authorization may be required.

6.0 OTHER PLANNING EFFORTS AND PROJECTS

This study and the 2006 SEH report recommend improvement options assuming the configurations of Interstate mainline and interchange facilities remain unchanged throughout the respective study horizon years. Corridor recommendations from the 2008 Lockwood Transportation Study and the Billings Bypass EIS are listed below. If constructed, these improvement options would alter conditions at the Johnson and Lockwood Interchanges under which improvement options were recommended for the subject study and the 2006 SEH report.

Billings Bypass EIS

MDT, in cooperation with FHWA, is preparing an EIS for a project to improve access and connectivity between I-90 and Old Hwy 312 in the northeast portion of the Billings urban area. The area assessed in the EIS is mainly outside the corridor study area. The area of overlap is described below.

Johnson Lane Interchange

- Alternatives include a No Build Alternative and several Build Alternatives requiring reconstruction of the interchange and a new crossing of the Yellowstone River. Build Alternatives generally begin at the Johnson Lane Interchange and head northwesterly towards Old Highway 312. The final EIS and Record of Decision (ROD) for this project are expected to be completed and approved by 2013.

Lockwood Transportation Study

The 2008 Lockwood Transportation Study identified transportation improvement options in the Lockwood area northwest of Billings. Recommended corridor improvements are described below.

Lockwood Interchange

- A recommended improvement option would construct an additional right-turn lane at the EB off-ramp. This improvement would modify traffic flow at the interchange intersection.
- A recommended improvement option would construct a Single Point Urban Interchange (SPUI). This improvement would modify the design of the interchange ramps and traffic flow at the interchange intersections.

Johnson Lane Interchange

- A recommended improvement option would construct dual right-turn lanes at the EB off-ramp interchange intersection. This improvement would modify traffic flow at the interchange intersection.
- A recommended improvement option would:
    - remove the EB off-ramp connection from Johnson Lane and connect it with Old Hardin Road just west of the Flying J Truck Stop located at Old Hardin Road and Johnson Lane;
    - alter the deceleration distance of the off-ramp; and
    - remove the connection with Johnson Lane.

  These changes would redirect traffic at the interchange intersection.

This corridor study was conducted assuming no changes would occur within the I-90 study corridor through the planning horizon of 2035. Reconstruction of the Lockwood and Johnson Lane Interchanges and resulting effects on traffic volumes were not considered. Construction of the Billings Bypass project or other improvements in the corridor could alter trip distribution patterns in the region, affecting traffic volumes and LOS within the Interstate corridor.

7.0 SUMMARY OF FORWARDED IMPROVEMENT OPTIONS

Table 7.1 summarizes improvement options recommended within the corridor. Improvement options are listed from west to east. Table elements not previously defined are described below.

The deficiency year for capacity improvements is defined as year when operations are anticipated to reach LOS C for Interstate facilities and LOS D for ramp intersections. The deficiency year for traffic operation improvements located under and through interchanges is based on the identified deficiency year for adjacent mainline Interstate segments. The deficiency year for geometric and safety improvements is 2012, reflecting the condition occurs currently. The deficiency year does not indicate the anticipated timeframe for implementation of any recommended improvements, which is dependent on available funding and other system priorities.

The planning priority categories are defined as follows:

- Near Term: Implementation is recommended in the near term (5-10 years) to address a documented need.
- Long Term: Implementation is recommended in the long term (10-20 years) to address a documented need.
- As Needed: Option can be implemented to meet current MDT design standards as funding allows. Option is not associated with a documented crash trend or capacity need.

Impacts to environmental resources and right-of-way acquisition are identified as follows.

- "No" indicates an option is anticipated to result in negligible impacts to environmental resources and is anticipated to remain within the existing MDT right-of-way.
- "Yes" indicates an option is anticipated to require coordination and permitting with regulatory agencies and is anticipated to require new right-of-way.

Planning level cost estimates are listed in 2012 dollars for each improvement option. Cost estimates reflect construction costs; costs associated with right-of-way acquisition are not included. Cost estimates are rounded for planning purposes. Cost estimates assume the use of asphalt paving materials as opposed to concrete. Detailed cost estimates, including construction material assumptions, are provided in Appendix 6.

Reconstructing the entire Interstate facility within the study corridor as a single project may be difficult to fund and may pose constructability challenges. This corridor study identifies multiple

improvement options to address discrete mainline segments, bridges, and interchanges within the study corridor. If multiple improvement options are implemented together, there may be cost savings associated with engineering design, mobilization, construction administration, and material costs. However, implementation decisions will be based on available funding.

Project level analysis would be required to determine if auxiliary lanes or additional through travel lanes are warranted based on observed traffic usage patterns in the I-90 corridor. Mainline (M) options would involve construction of auxiliary lanes between adjacent interchanges, providing additional capacity in these discrete segments. The combination of all M options and Under (U) options would result in three continuous travel lanes, providing additional capacity throughout the entire corridor. Appropriate combinations of these options may be selected in the future following project level analysis for specific improvement projects.

Table 7.1 Improvement Options Forwarded for Further Consideration

Location	Option ID[1]	Option Type[2]	Improvement Option Description	Deficiency Year[3]	Planning Priority[4]	Impacts to Environmental Resources[5]	Right-of-Way Acquisition[6]	Low Cost Estimate[7]	High Cost Estimate[7]
Interchange 1: Laurel	**I-1a**	Geometric	Extend EB and WB on-ramps and off-ramps; flatten horizontal curves at WB off-ramp and EB on-ramp; modify vertical curves Other elements include: • Reconstruct EB I-90 bridge crossing of US 212 / US 310	2012	As Needed	Yes	Yes	$6,700,000	$7,300,000
	I-1b	Safety	Upgrade lighting at Laurel Interchange to CIL standards	2012	As Needed	No	No	$380,000	$410,000
Interchange 2: Mossmain	**I-2a**	Geometric	Extend EB and WB on-ramps and off-ramps	2012	Near Term	No	No	$730,000	$780,000
	I-2b	Capacity	Reconstruct Mossmain Interchange with two roundabouts	2012	Near Term	Yes	Yes	$10,800,000	$11,600,000
	I-2c	Safety	Upgrade lighting at Mossmain Interchange to CIL standards	2012	As Needed	No	No	$390,000	$420,000
Mainline Segment 2	**B-2**	Geometric	Reconstruct EB and WB I-90 bridges crossing S. 56th Street; modify vertical curve	2012	Long Term	No	No	$2,300,000	$2,500,000
Mainline Segment 3	**M-3**	Capacity	Construct EB and WB auxiliary lanes on the mainline segment between the Shiloh and West Billings Interchanges Other elements include: • Construct additional WB off-ramp lane at Shiloh Interchange ramp gore • Construct additional EB off-ramp lane at West Billings Interchange ramp gore • Reconstruct EB and WB I-90 bridge crossing of Hogan's Slough	2027	Long Term	Yes	No	$9,600,000	$10,300,000
Interchange 4: West Billings	**U-4a**	Safety	Lengthen EB on-ramp at Laurel Road Other elements include: • Modify vertical curve • Reconstruct EB I-90 bridge crossing of Laurel Road • Reconstruct EB I-90 bridge crossing of Mullowney Lane	2012	Near Term	No	No	$6,700,000	$7,300,000
	U-4b	Traffic Operations & Lane Balance	Construct additional EB and WB mainline lanes through the West Billings Interchange Other elements include: • Modify vertical curve • Reconstruct EB and WB I-90 bridge crossing of Laurel Road ramps • Reconstruct EB and WB I-90 bridge crossing of Mullowney Lane • Restripe WB off-ramp at West Billings Interchange	2028	Long Term	No	No	$12,200,000	$13,100,000
Interchange 5: South Billings Boulevard	**U-5**	Traffic Operations & Lane Balance	Construct additional EB and WB mainline lanes under and through the South Billings Boulevard Interchange	2028	Long Term	No	No	$1,500,000	$1,700,000
Mainline Segment 5	**M-5**	Capacity	Construct EB and WB auxiliary lanes on the mainline segment between the South Billings Boulevard and South 27th Street Interchanges Other elements include: • Construct additional WB off-ramp lane at South Billings Boulevard Interchange ramp gore • Construct additional EB off-ramp lane at South 27th Street Interchange ramp gore • Reconstruct EB and WB I-90 bridge crossing of Sugar Avenue	2028	Long Term	Yes	No	$9,200,000	$9,900,000
Interchange 6: South 27th Street	**U-6**	Traffic Operations & Lane Balance	Construct additional EB and WB mainline lanes under and through the South 27th Street Interchange Other elements include: • Restripe EB off-ramp at South Billings Boulevard Interchange	2028	Long Term	No	No	$1,800,000	$1,900,000

Location	Option ID[1]	Option Type[2]	Improvement Option Description	Deficiency Year[3]	Planning Priority[4]	Impacts to Environmental Resources[5]	Right-of-Way Acquisition[6]	Low Cost Estimate[7]	High Cost Estimate[7]
Mainline Segment 6	**M-6**	Capacity	Construct EB and WB auxiliary lanes on the mainline segment between the South 27th Street and Lockwood Interchanges Other elements include: • Construct additional WB off-ramp lane at South 27th Street Interchange ramp gore • Construct additional EB off-ramp lane at Lockwood Interchange ramp gore • Reconstruct EB and WB I-90 bridge crossing of rail facility	2023	Long Term	Yes	No	$8,400,000	$9,100,000
Mainline Segment 6	**B-6**	Capacity Geometric	Reconstruct EB and WB I-90 bridges crossing the Yellowstone River	2012	Near Term	Yes	Yes	$32,600,000	$35,200,000
Interchange 7: Lockwood	**U-7**	Traffic Operations & Lane Balance	Construct additional EB and WB mainline lane under and through the Lockwood Interchange	2027	Long Term	Yes	No	$1,800,000	$1,900,000
Mainline Segment 7	**M-7**	Capacity	Construct EB and WB auxiliary lanes on the mainline segment between the Lockwood and Johnson Lane interchanges Other elements include: • Construct additional WB off-ramp lane at Lockwood Interchange ramp gore • Construct additional EB off-ramp lane at Johnson Lane Interchange ramp gore	2027	Long-Term	No	No	$5,600,000	$6,000,000

Options are listed from west to east throughout the corridor.

[1] Option ID: M = Improvement to a mainline segment between gore areas of two interchanges; U = Mainline Interstate improvement occurring underneath or through an interchange (i.e., between the gore areas of an interchange); B = Bridge Improvement Option; I = Interchange Improvement Option. Improvement option numbering reflects the segment or interchange number within the study corridor.

[2] Option Type corresponds to the need identified in a specific location, including capacity, geometric, traffic operations, and safety needs.

[3] Deficiency Year indicates the year that the condition occurs or is expected to occur; it does not indicate the year that the improvement option would be implemented.

[4] Planning Priority does not imply projects will be programmed or implemented. Project programming is based on funding availability and other system priorities. Planning Priority categories are defined as follows.

- Near Term: Implementation is recommended in the near term (5-10 years) to address a documented need.
- Long Term: Implementation is recommended in the long term (10-20 years) to address a documented need.
- As Needed: Options can be implemented as funding allows to meet current MDT design standards. Options are not associated with a documented crash trend or capacity need.

[5] "No" indicates an option that is anticipated to result in negligible impacts to environmental resources. "Yes" indicates an option involving impacts to environmental resources that may require permitting or coordination with regulatory agencies. Construction phase permitting is not identified.

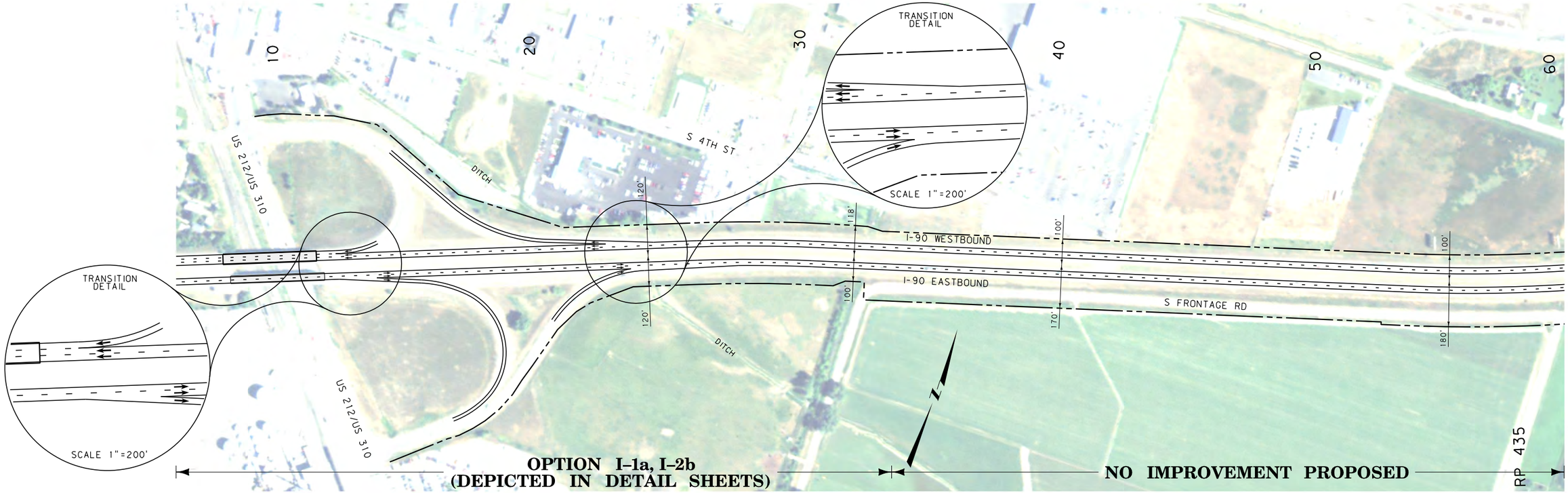
[6] "No" indicates an option that is anticipated to remain within the existing MDT right-of-way. "Yes" indicates an option may require new right-of-way.

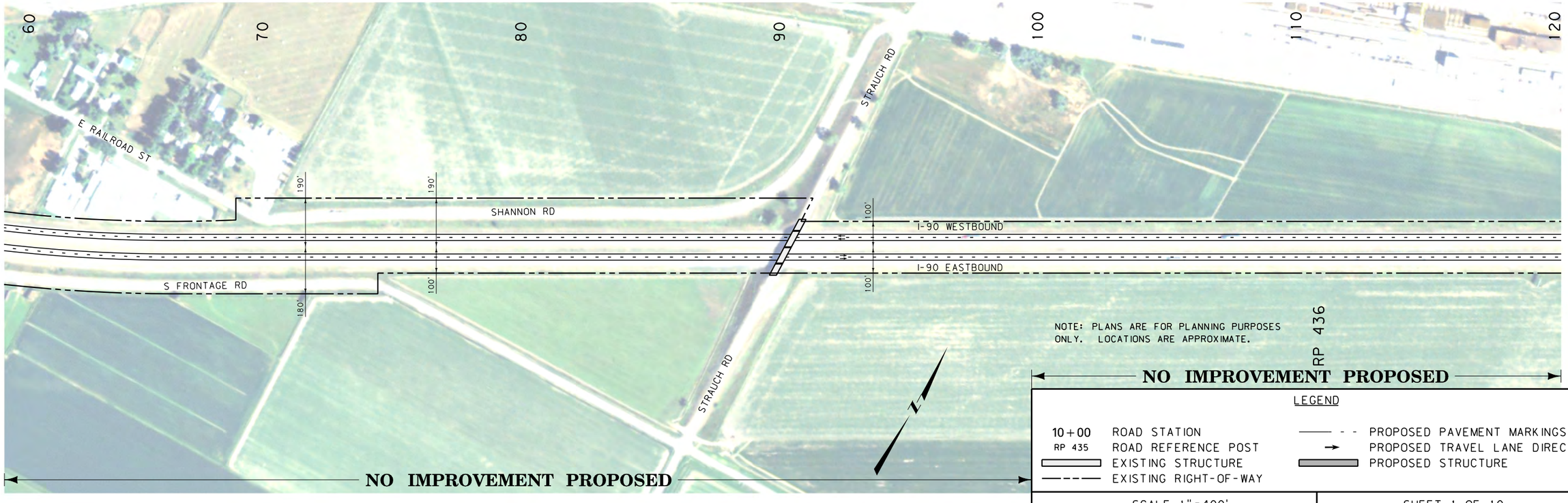
[7] Planning level cost estimates are listed in 2012 dollars and are rounded for planning purposes. Cost estimates reflect construction costs only based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances. Low and high cost estimate ranges were used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate. Costs associated with right-of-way acquisition, design or utility relocations are not included. Detailed cost estimates are provided in Appendix 6.

Appendix 1

Mainline Plan Sheets

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS





LEGEND

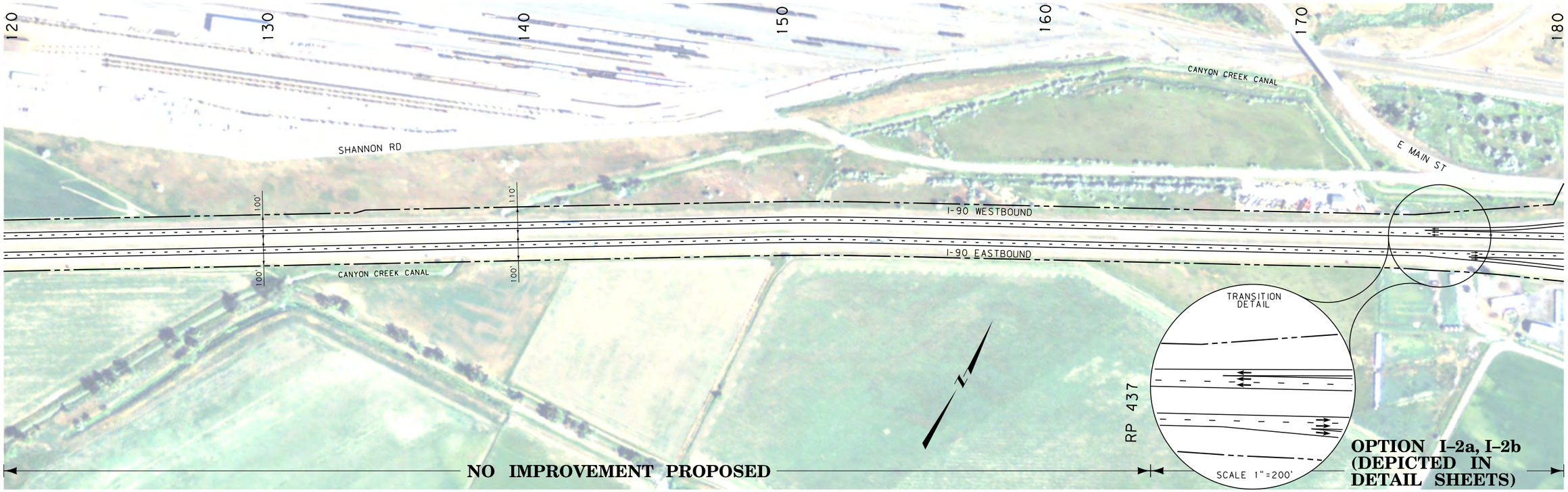
10+00	ROAD STATION	- - -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		

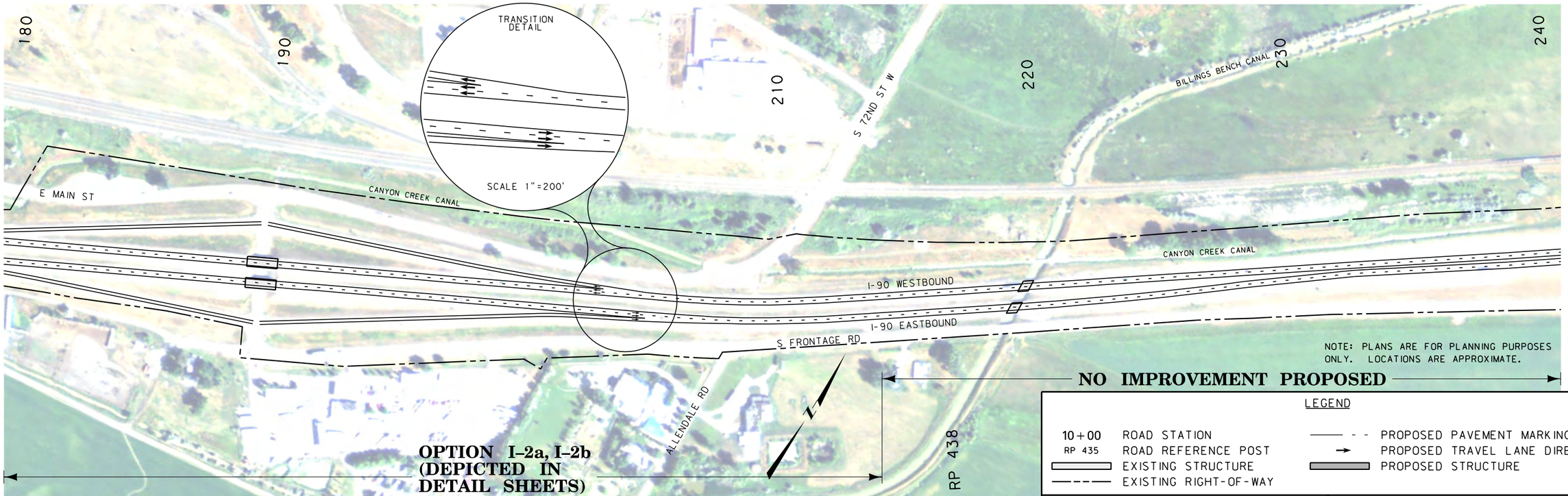
SCALE 1"=400'

SHEET 1 OF 10

DOWL HKM

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS



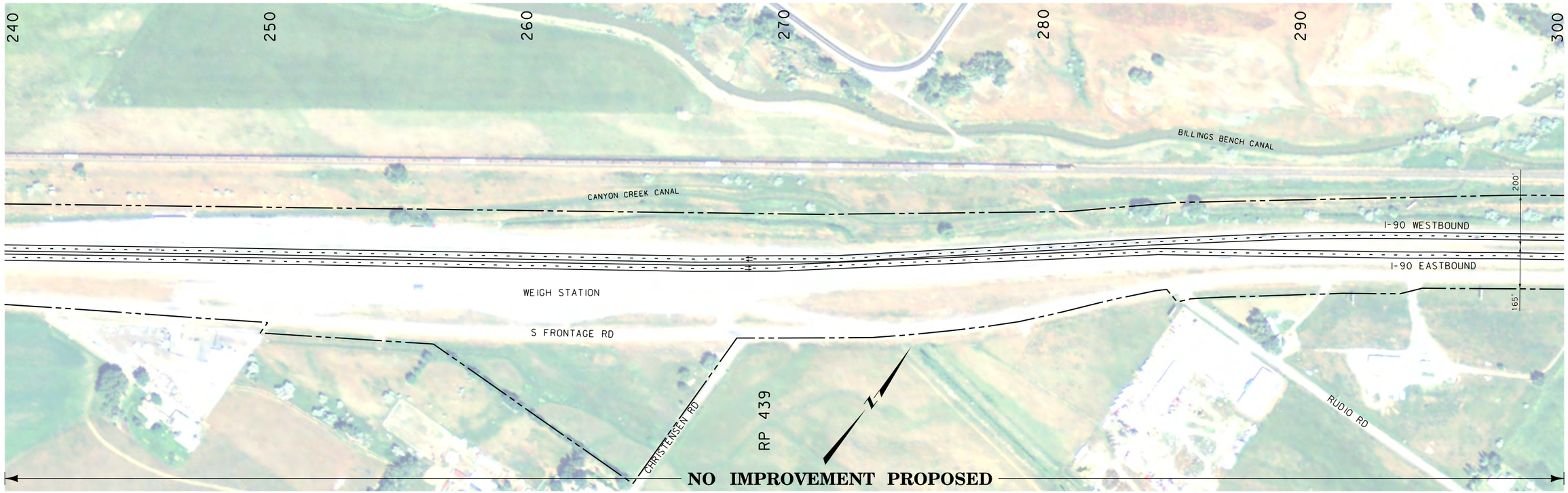


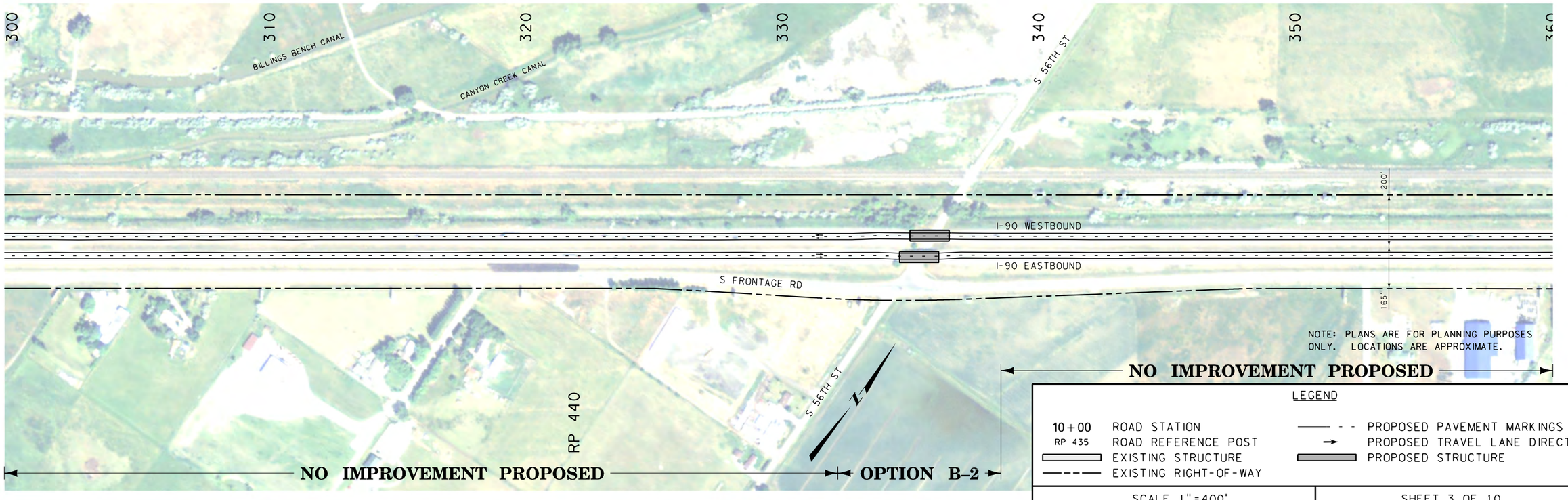
LEGEND

10+00	ROAD STATION	- -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		

SCALE 1"=400'

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS





LEGEND

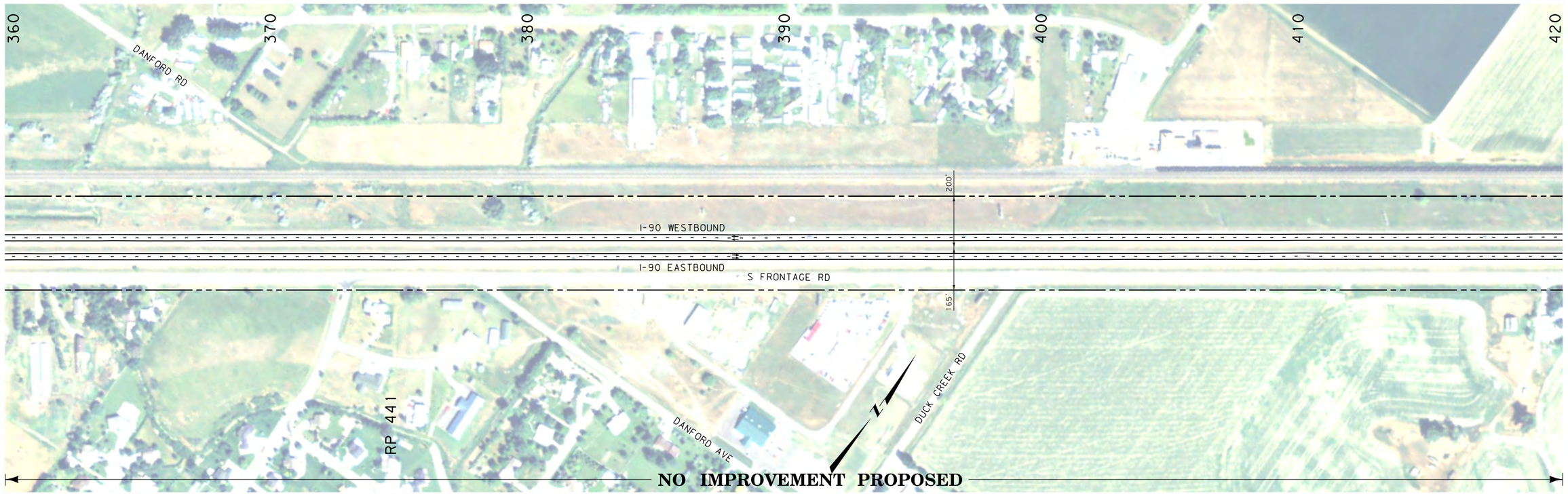
10+00	ROAD STATION	- - -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		

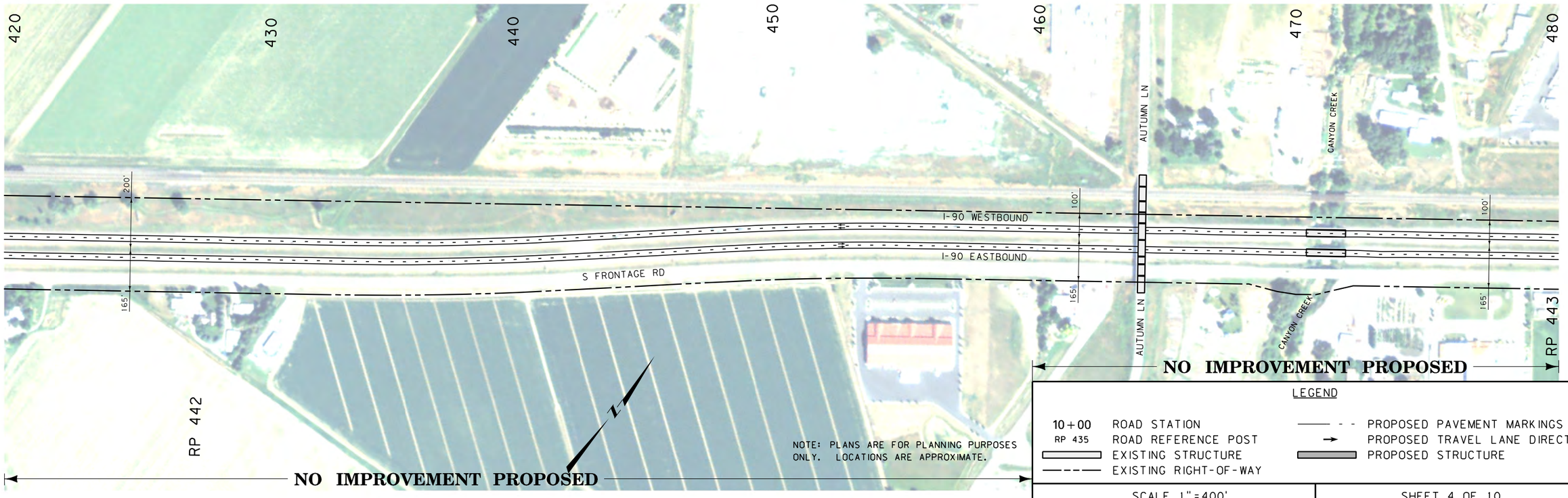
SCALE 1"=400'

SHEET 3 OF 10

DOWL HKM

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS





NOTE: PLANS ARE FOR PLANNING PURPOSES ONLY. LOCATIONS ARE APPROXIMATE.

LEGEND

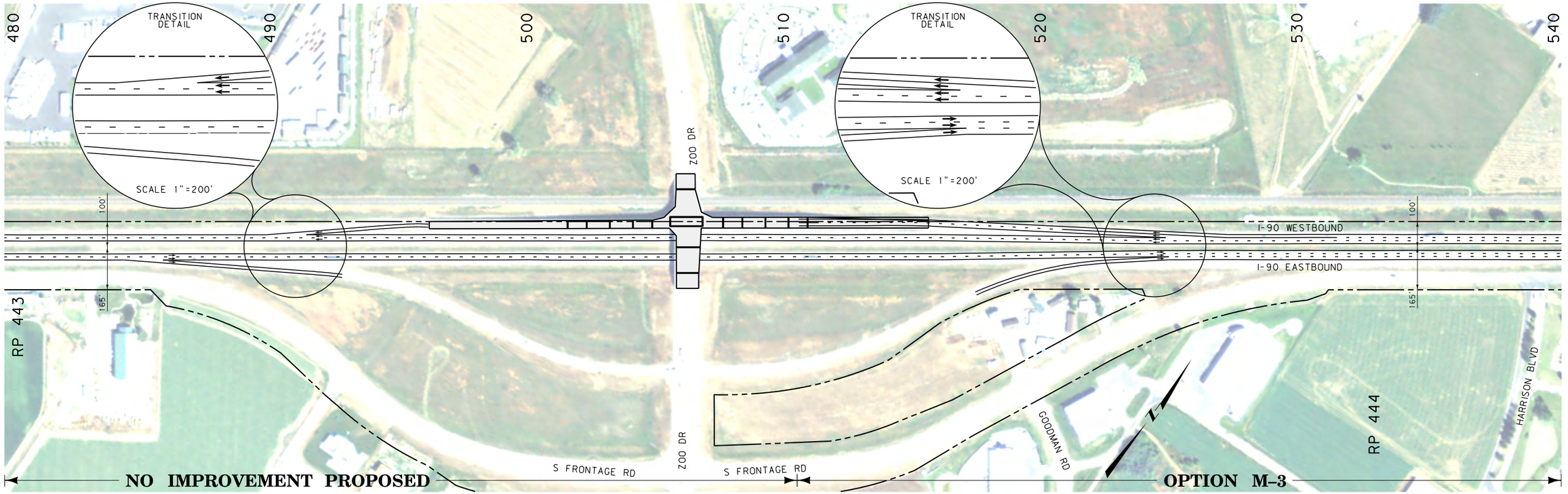
10+00	ROAD STATION	- -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		

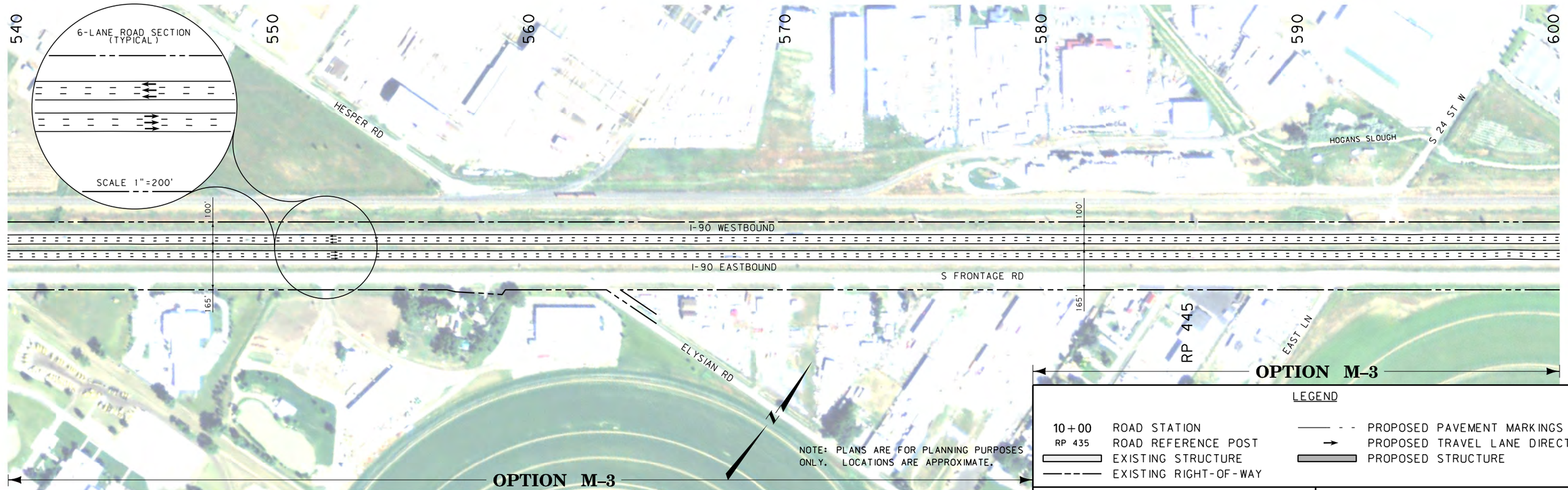
SCALE 1"=400'

SHEET 4 OF 10

DOWL HKM

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS



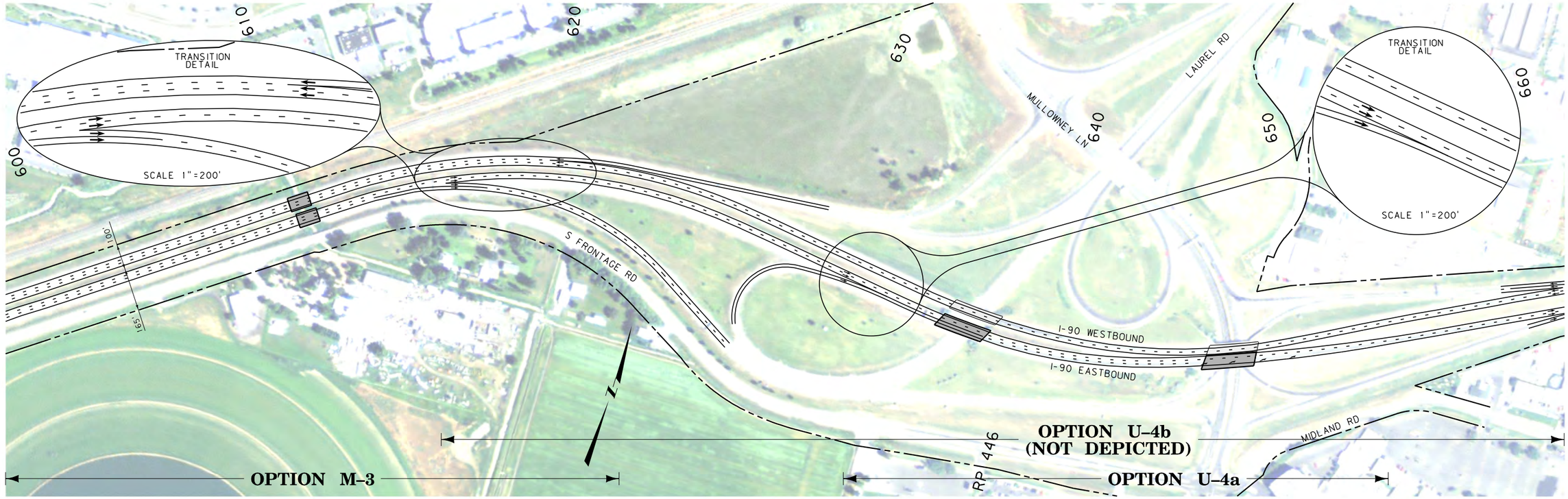


LEGEND

10+00	ROAD STATION	- -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		

SCALE 1"=400'

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS



NOTE: PLANS ARE FOR PLANNING PURPOSES ONLY. LOCATIONS ARE APPROXIMATE.

LEGEND

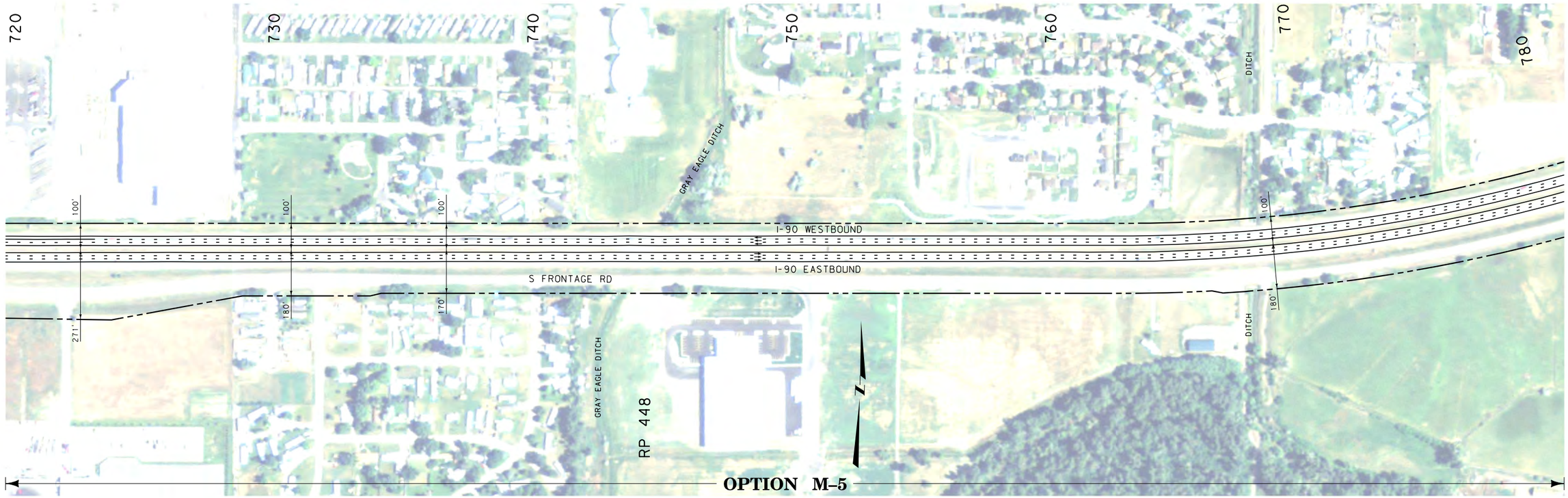
10+00	ROAD STATION
RP 435	ROAD REFERENCE POST
	EXISTING STRUCTURE
	EXISTING RIGHT-OF-WAY
	PROPOSED PAVEMENT MARKINGS
	PROPOSED TRAVEL LANE DIRECTION
	PROPOSED STRUCTURE

SCALE 1"=400'

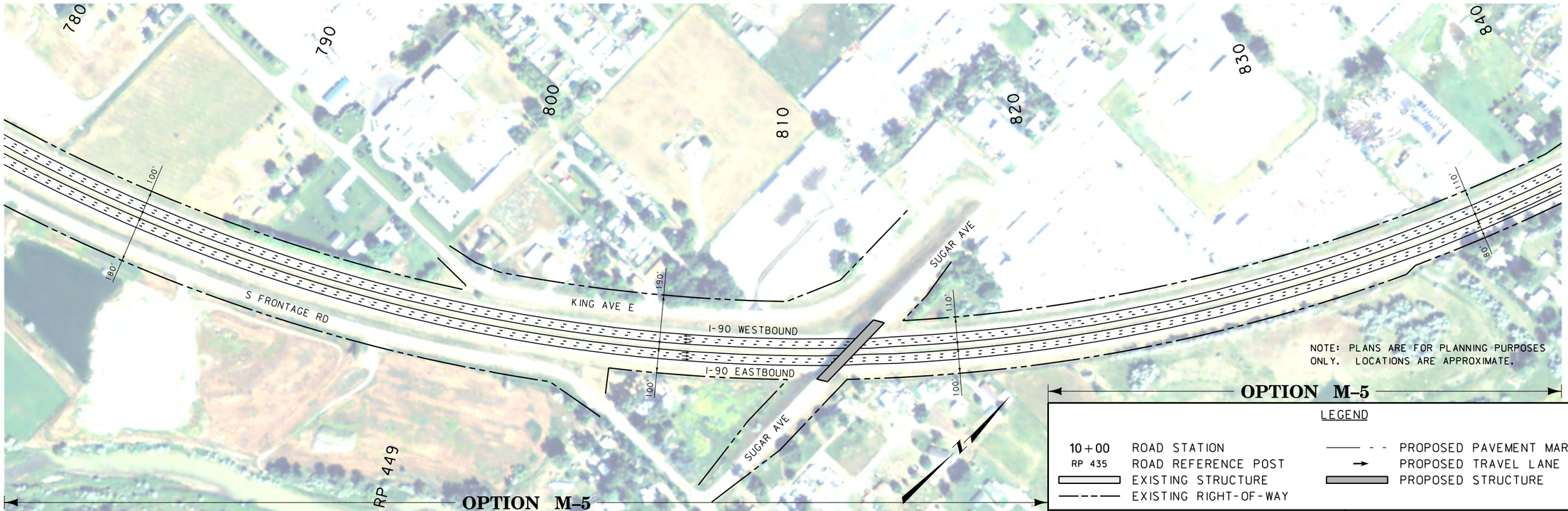
SHEET 6 OF 10

DOWL HKM

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS



OPTION M–5



OPTION M–5

OPTION M–5

LEGEND

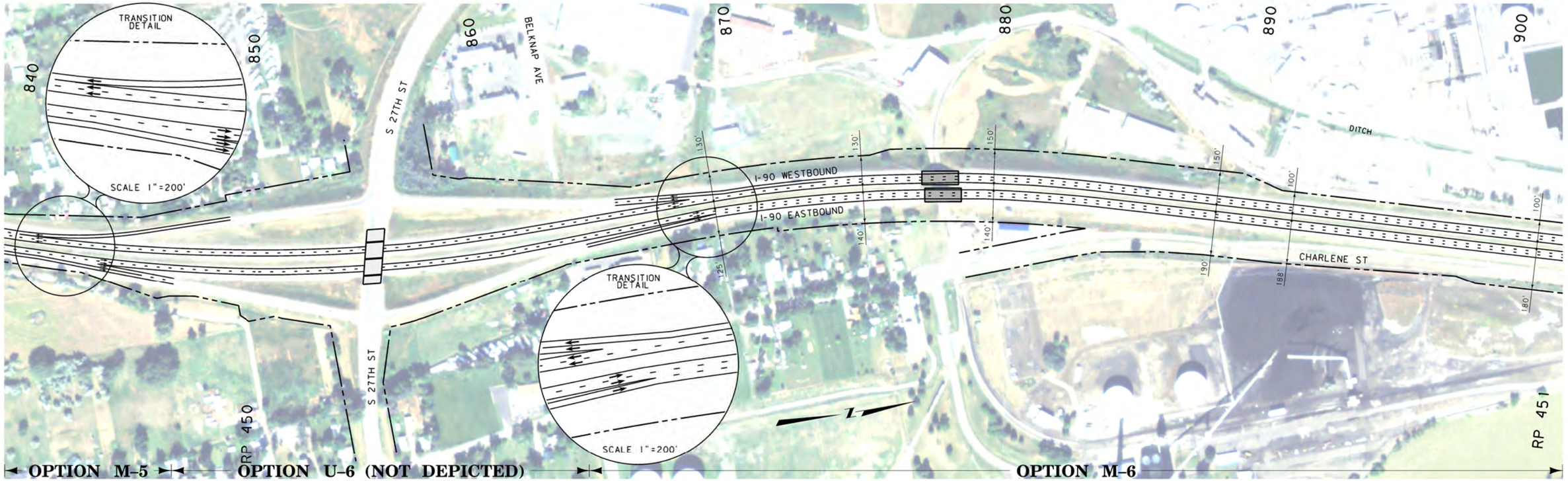
10+00	ROAD STATION	- -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		

SCALE 1"=400'

SHEET 7 OF 10

BOWL HKM

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS

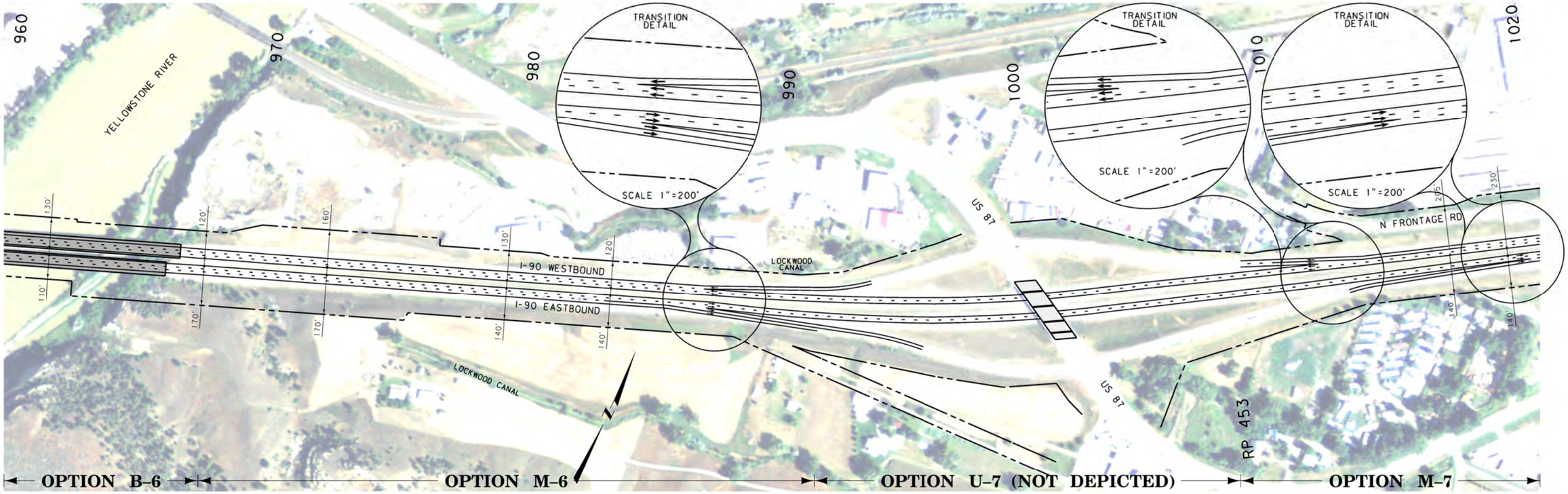


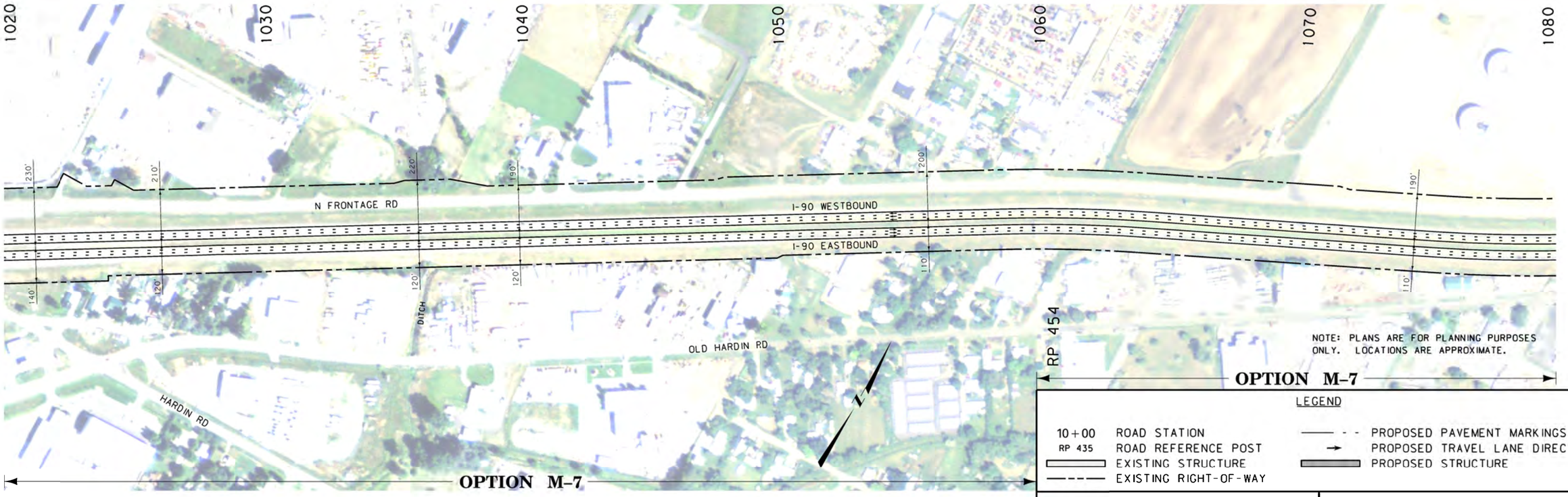
LEGEND

10+00	ROAD STATION	- -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		

SCALE 1"=400'

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS





NOTE: PLANS ARE FOR PLANNING PURPOSES ONLY. LOCATIONS ARE APPROXIMATE.

LEGEND

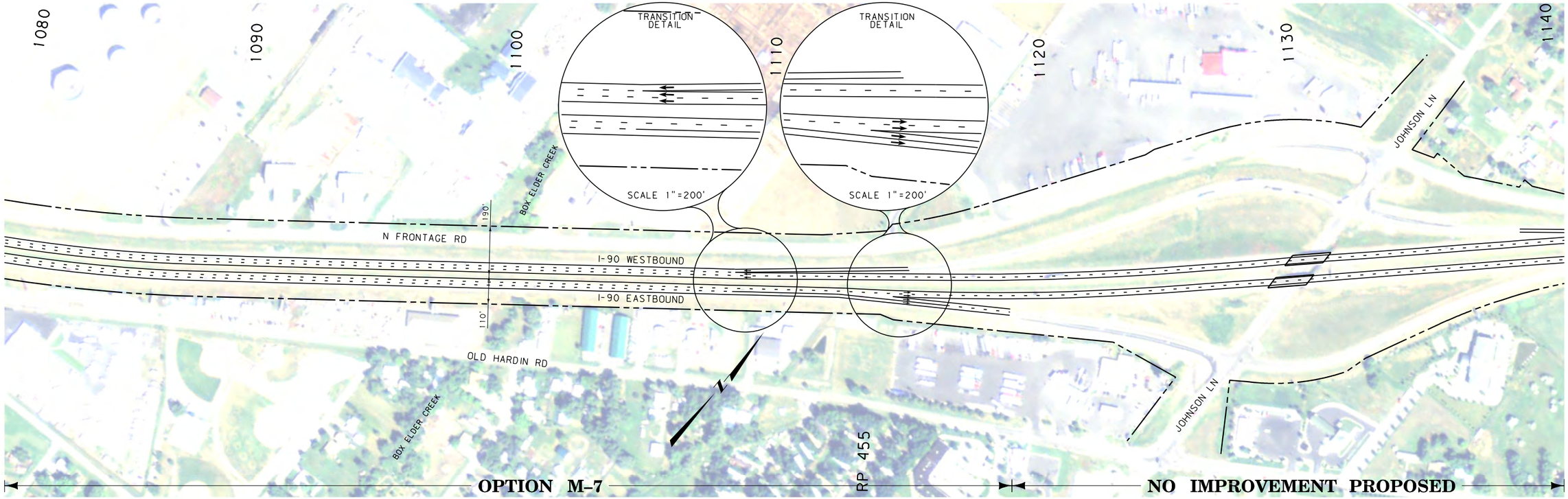
10+00	ROAD STATION	- - -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		

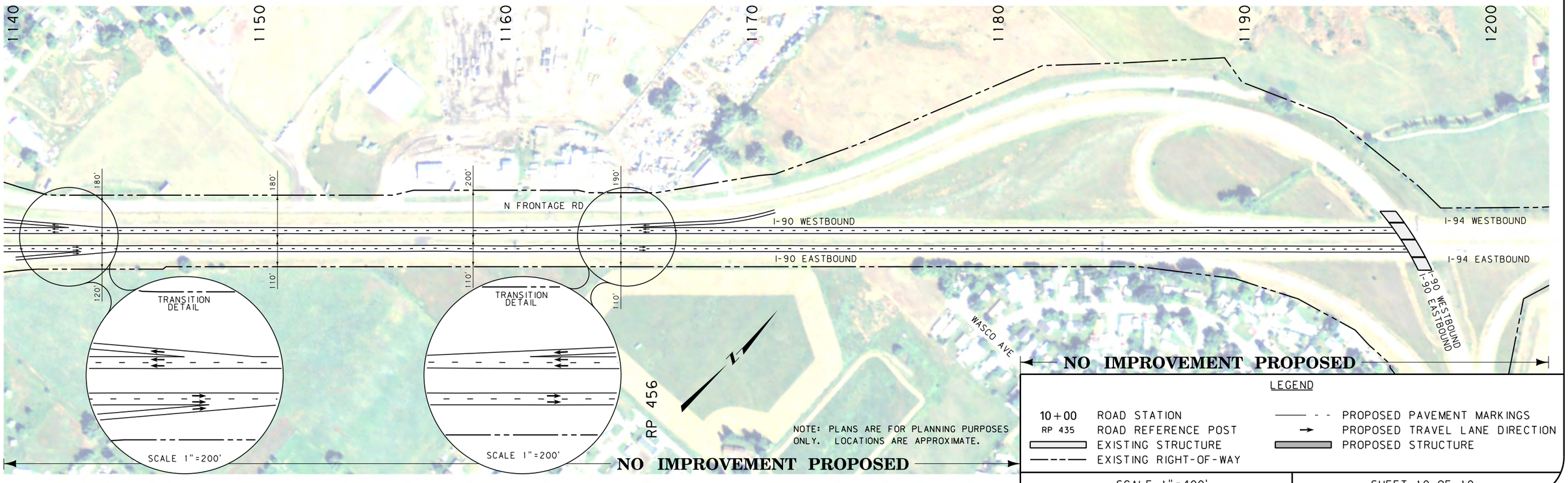
SCALE 1"=400'

SHEET 9 OF 10

BOWL HKM

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED IMPROVEMENT OPTIONS





LEGEND

10+00	ROAD STATION	- - -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		

SCALE 1"=400'

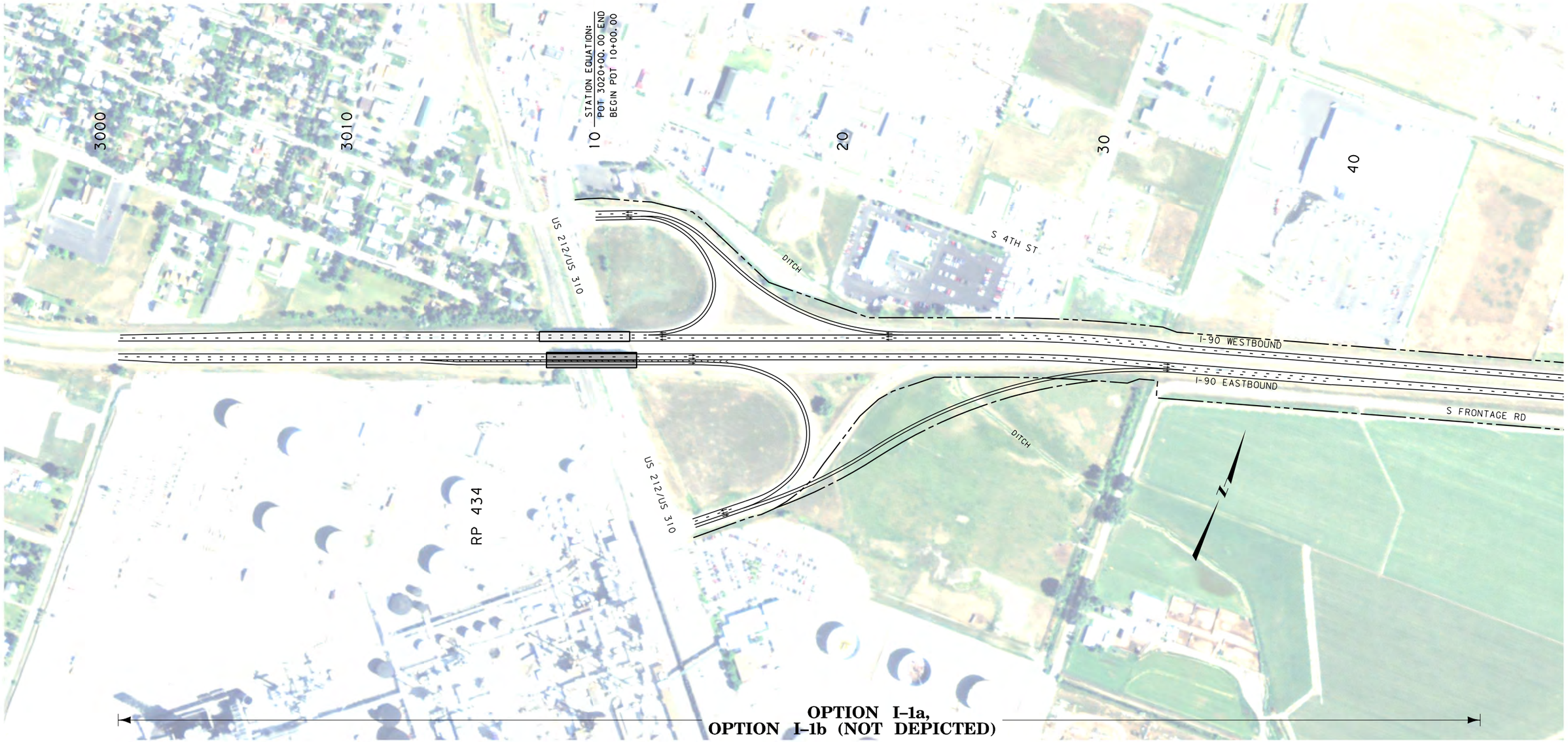
SHEET 10 OF 10

DOWL HKM

Appendix 2

Interchange Detail Sheets

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY DETAILED INTERCHANGE IMPROVEMENT OPTIONS



OPTION I–1a,
OPTION I–1b (NOT DEPICTED)

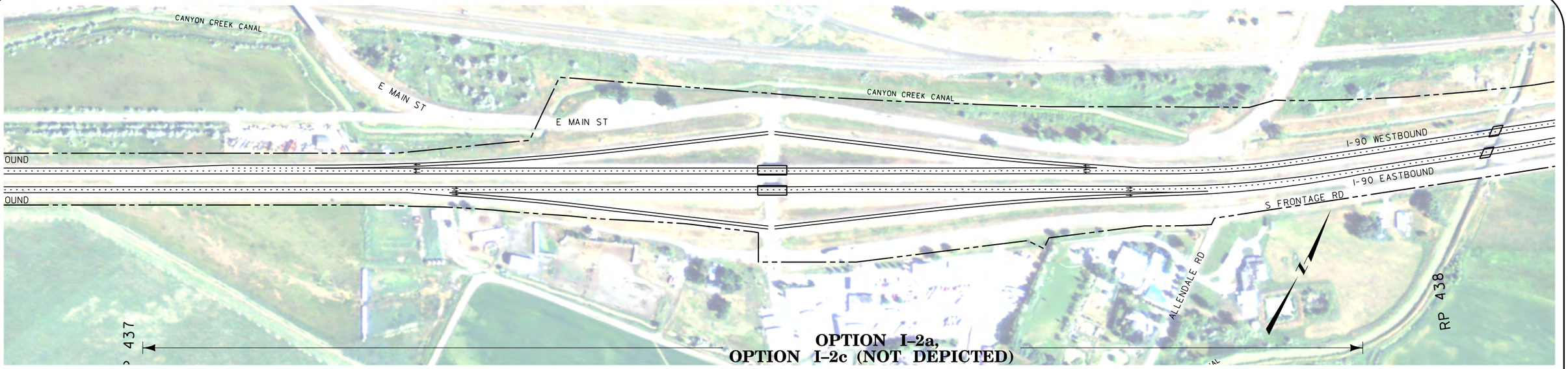
NOTE: PLANS ARE FOR PLANNING PURPOSES ONLY. LOCATIONS ARE APPROXIMATE.

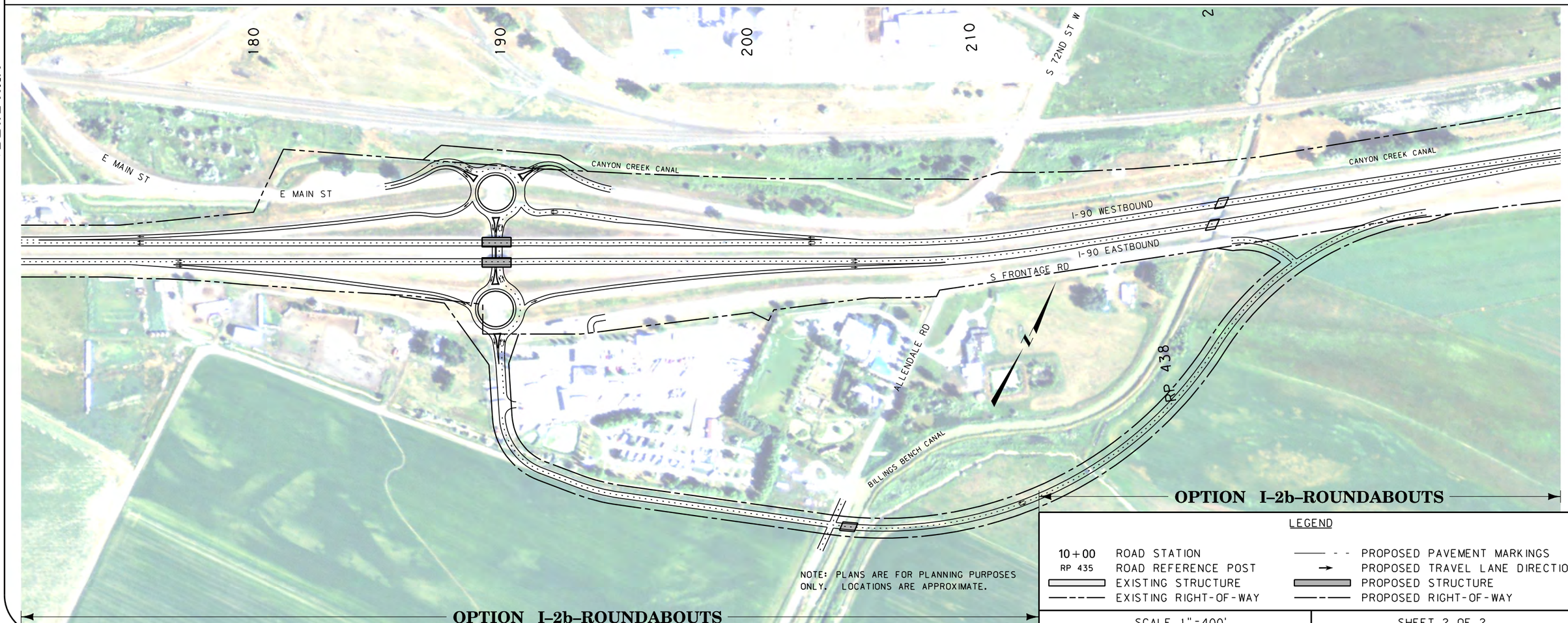
LEGEND

10+00	ROAD STATION	- -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		PROPOSED RIGHT-OF-WAY

SCALE 1"=400'

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY DETAILED INTERCHANGE IMPROVEMENT OPTIONS





LEGEND

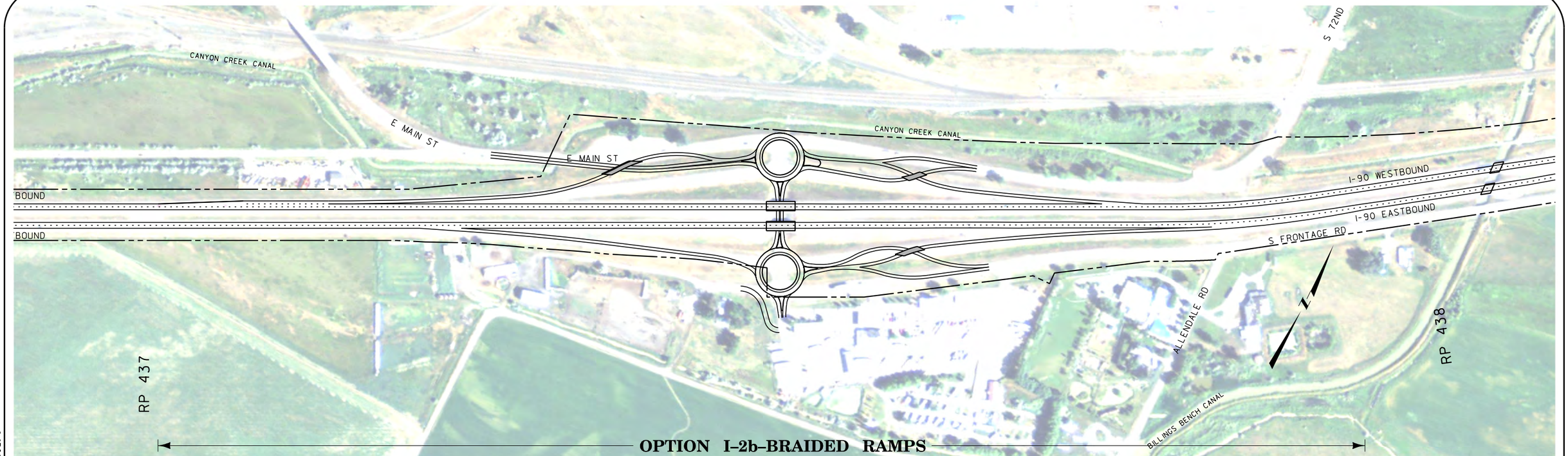
10+00	ROAD STATION	——— - -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
▭	EXISTING STRUCTURE	▭	PROPOSED STRUCTURE
———	EXISTING RIGHT-OF-WAY	———	PROPOSED RIGHT-OF-WAY

SCALE 1"=400'

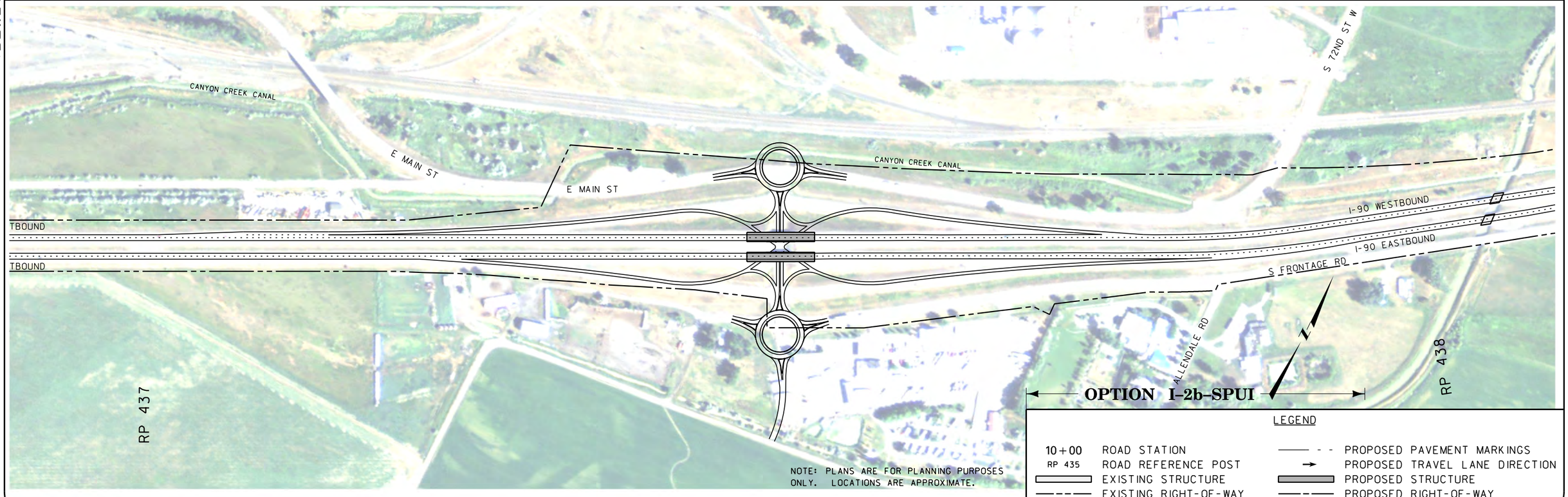
SHEET 2 OF 2

DOWL HKM

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY DETAILED INTERCHANGE IMPROVEMENT OPTIONS



OPTION I–2b–BRAIDED RAMPS



OPTION I–2b–SPUI

OPTION I–2b–SINGLE POINT URBAN INTERCHANGE (SPUI)

LEGEND

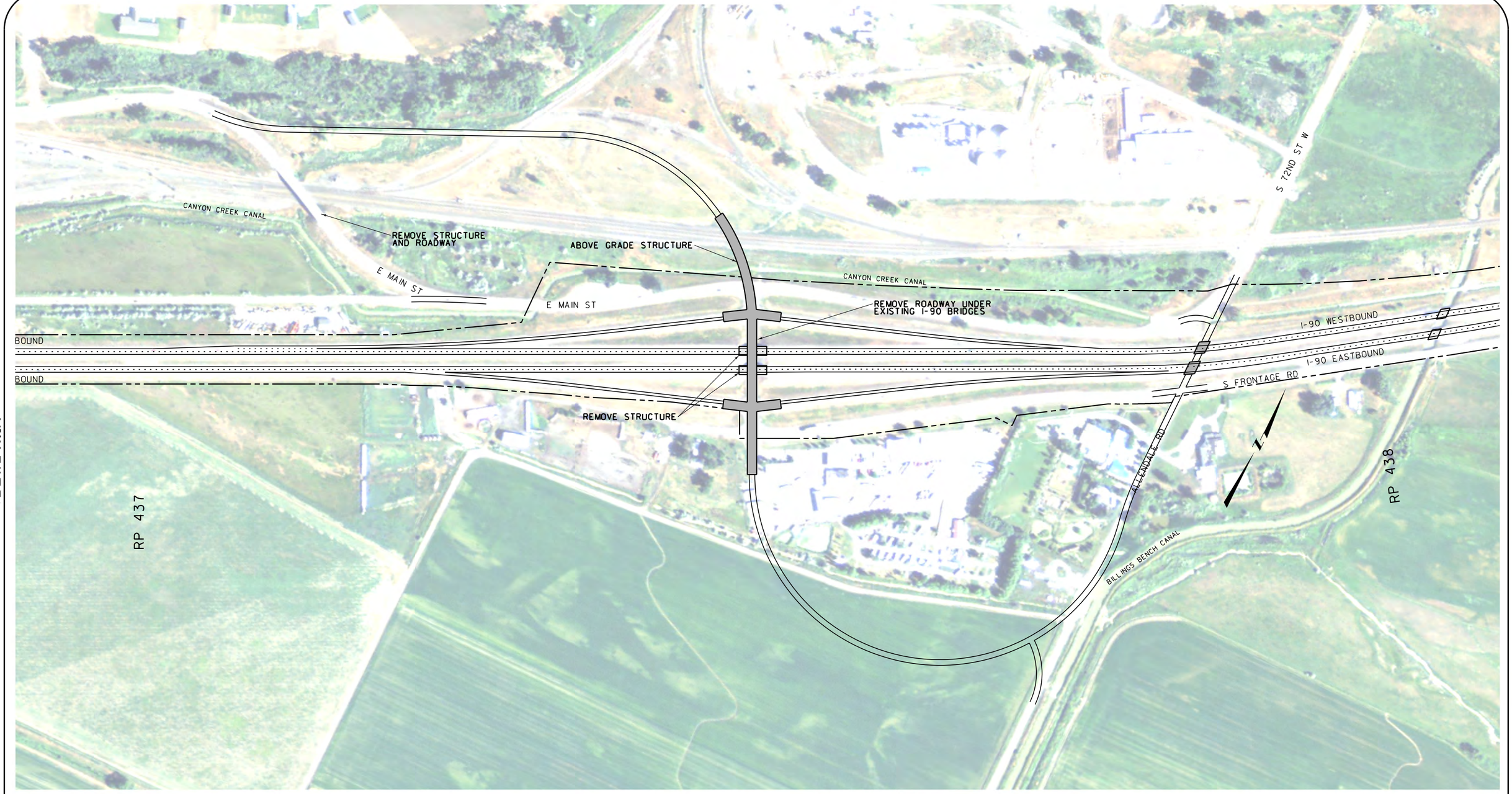
10+00	ROAD STATION	- -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		PROPOSED RIGHT-OF-WAY

SCALE 1"=400'

SHEET 1 OF 2

DOWL HKM

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY DETAILED INTERCHANGE IMPROVEMENT OPTIONS



DOWL HKM

NOTE: PLANS ARE FOR PLANNING PURPOSES ONLY. LOCATIONS ARE APPROXIMATE.

OPTION I–2b–RECONSTRUCTION OF FRONTAGE ROADS

OPTION I–2b–RECONSTRUCTION OF FRONTAGE ROADS

LEGEND

10+00	ROAD STATION	- -	PROPOSED PAVEMENT MARKINGS
RP 435	ROAD REFERENCE POST	→	PROPOSED TRAVEL LANE DIRECTION
	EXISTING STRUCTURE		PROPOSED STRUCTURE
	EXISTING RIGHT-OF-WAY		PROPOSED RIGHT-OF-WAY

SCALE 1"=400'

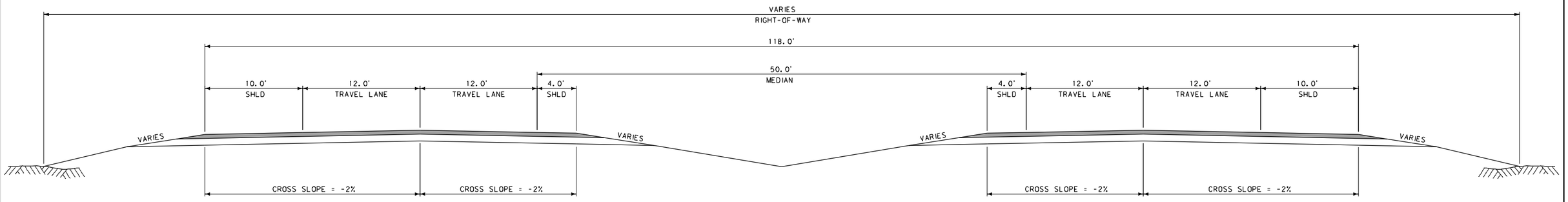
SHEET 2 OF 2

Appendix 3

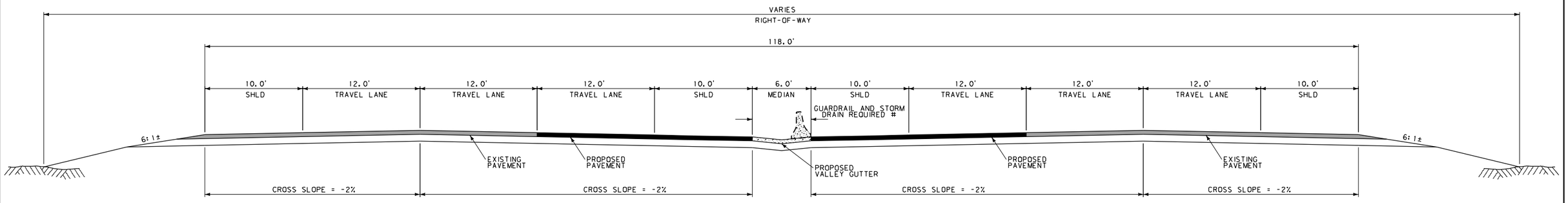
Typical Sections

BILLINGS AREA I–90 CORRIDOR PLANNING STUDY PROPOSED TYPICAL SECTION IMPROVEMENT OPTIONS

INTERSTATE 90 – EXISTING CONDITIONS

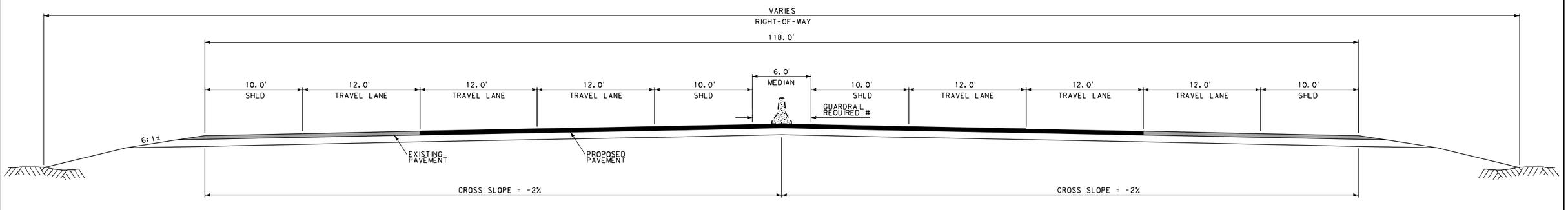


INTERSTATE 90 – PROPOSED 6–LANE SECTION
ROADWAY DRAINAGE TOWARDS MEDIAN



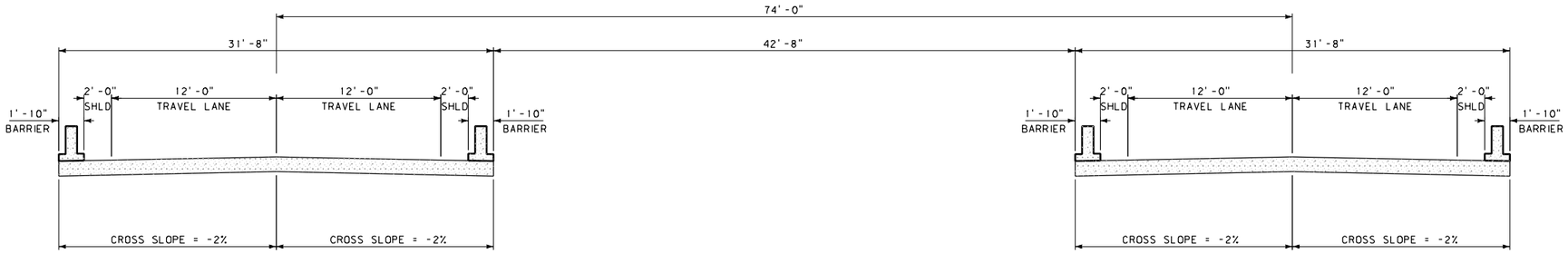
GUARDRAIL LOCATION TO BE DETERMINED DURING DESIGN.

INTERSTATE 90 – PROPOSED 6–LANE SECTION
ROADWAY DRAINAGE AWAY FROM MEDIAN

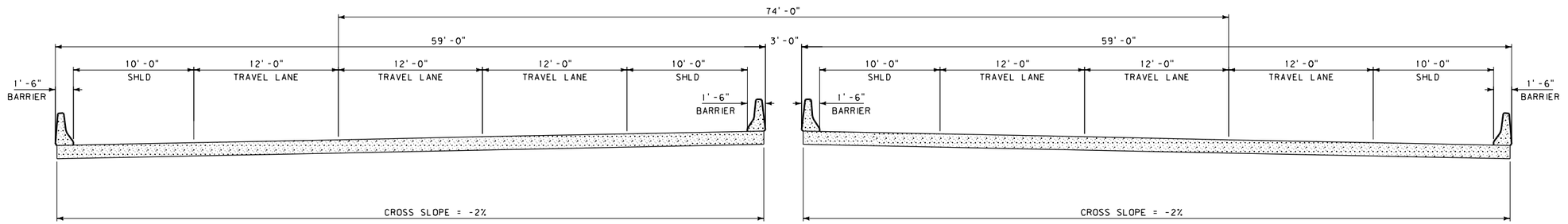


GUARDRAIL LOCATION TO BE DETERMINED DURING DESIGN.

INTERSTATE 90 – EXISTING CONDITIONS
56TH ST AND YELLOWSTONE RIVER BRIDGES



INTERSTATE 90 – PROPOSED 6–LANE SECTION
I–90 MAINLINE BRIDGES



Appendix 4

Excerpts from

Billings I-90 Interchanges Project

Table 19
Recommended O&M Improvements
Shiloh Interchange - Exit 443

Recommended Improvement	Location	Category
Add stop sign in median to increase visibility	Zoo Dr / S Frontage Rd	Safety
Add Speed Limit Sign	Zoo Dr	Traffic Control
Add Advance I-90 Guide Signs	Zoo Dr	
Remove Stop Bar; Re-stripe as yield condition	NB Shiloh Rd to EB Zoo Dr	
Add Road Closed signing behind Type 3 barrier	Zoo Dr south of S Frontage Rd	
Add Road Closed signing behind Type 3 barrier	Future entrance legs	
Replace Shiloh Road advance street name sign *	NB & SB S Frontage Rd at Zoo Dr	

* Replace at end of existing sign maintenance cycle

Table 20
Recommended O&M Improvements
South Billings Boulevard Interchange - Exit 447

Deficiency	Location	Category
Lack of I-90 advance directional sign	SB S Billings Blvd north of I-90 EB ramps	Traffic Control
Add posted speed limit in SB direction	SB S Billings Blvd	
Add lane control sign for wide thru-right lane on mast arm	SB S Billings Blvd at King Ave	
Add lane control signs for thru and right turns on mast arm	EB King Ave at S Billings Blvd	
Add end of guardrail object marker	NB & SB S Billings Blvd overpass	
Improve pedestrian push button accessibility	SW corner of S Billings Blvd / King Ave	Pedestrian
Reconfigure guard rail to improve access to sidewalk	NB S Billings Blvd on I-90 bridge	

Table 21
Recommended O&M Improvements
27th Street Interchange - Exit 450

Deficiency	Location	Category
Modify guard rail to improve intersection sight distance	I-90 EB off-ramp at 27th St	Geometry
Add Advance I-90 Guide Signs between ramps	27th Street / I-90 WB ramps	Traffic Control
Add Advance I-90 Guide Signs between ramps	27th Street / I-90 EB ramps	
Add speed limit sign for NB (or WB) direction	27th Street	
Add lane control signs on mast arm	EB State Ave at 27th St	
Add end of guardrail object marker	SB 27th St north of I-90 WB	
Add signs and markings for lane drop	SB 27th St south of I-90 EB ramps	

Table 22
Recommended O&M Improvements
US 87 Lockwood Interchange - Exit 452

Deficiency	Location	Time Frame	Category
Add lane control signs on mast arm	NB and SB US 87 at N Frontage Rd	Existing	Traffic Control
Add lane control signs on mast arm	NB and SB US 87 at I-90 WB ramps	Existing	
Add lane control signs on mast arm	NB and SB US 87 at I-90 EB ramps	Existing	
Replace existing inappropriate advance turn arrow sign*	facing I-90 WB off-ramp on US 87	Existing	
Add intersection lane control signs and markings	NB gas station approach at US 87 / N Frontage Rd	Existing	

* Replace at end of existing sign maintenance cycle

Table 23
Recommended O&M Improvements
Johnson Lane Interchange - Exit 455

Deficiency	Location	Time Frame	Category
Add left turn lane control signs	Johnson Ln at N Frontage Rd	Existing	Traffic Control
Add left turn lane control signs	Johnson Ln at I-90 WB ramps	Existing	
Add left turn lane control signs	Johnson Ln at I-90 EB ramps	Existing	
Add speed limit sign	SB Johnson Ln before I-90 EB ramps	Existing	
Add end of guardrail object marker	NB & SB Johnson Ln between ramps	Existing	

SEH

MDT

Table 24
Recommended Project/STIP Improvements
Shiloh Interchange - Exit 443

Type	Project ID	Improvement Description	Location	Anticipated Time Frame	General Planning Priority	Estimated Cost	Potential Funding Sources
Safety Related	S S1	Construct sidewalks through corridor	Zoo Dr., I-90 WB ramps to Gabel Rd	5-15 Years (d)	M	$ 150,000	STPP, CTEP, P, L
	S S2	Upgrade I-90 mainline highway lighting to CIL standards	I-90 at Zoo Dr	10-15 Years (d)	L	$ 750,000	STPP, IM
Capacity Related	S C1	Install traffic signal*	Zoo Dr / Gabel Rd	0-5 Years(d)	L	$ 150,000	STPP, STPU, P, L
	S C2	Install traffic signal*	Zoo Dr / future entrance	0-5 Years(d)	L	$ 150,000	P, L
	S C3	Install traffic signal*	Zoo Dr / I-90 WB ramps	5-10 Years (d)	M	$ 150,000	STPP, CMAQ
	S C4	Widen Zoo Dr. to 4 or 5 lanes	I-90 EB ramps to Gabel Rd	5-10 Years (d)	M	$ 600,000	STPP, STPU, CMAQ
	S C5	Add SB RT lane	Zoo Dr / I-90 WB ramps	5-10 Years (d)	M	$ 50,000	STPP, CMAQ, IM
	S C6	Add 2nd SB LT lane	Zoo Dr / Gabel Rd	5-10 Years (d)	L	$ 150,000	P, L
	S C7	Install traffic signal*	Zoo Dr / I-90 EB ramps	10-15 Years (d)	M	$ 150,000	STPP, CMAQ
	S C8	Coordinate signal system	Zoo Dr	10-15 Years (d)	M	$ 50,000	STPP, STPU, CMAQ, P
	S C9	Add 2nd SB LT lane and 2nd EB LT (off ramp) lane ; widen EB on-ramp	Zoo Dr / I-90 EB ramps	10-15 Years (d)	M	$ 400,000	STPP, CMAQ
	S C10	Install traffic signal*	Zoo Dr / Shiloh Rd	10-15 Years (d)	L	$ 150,000	STPP, STPU, CMAQ, P, L
	S C11	Install traffic signal*	Zoo Dr / S Frontage Rd	10-15 Years (d)	L	$ 150,000	STPP, STPU, P, L
	S C12	Add 2nd SB LT lane	Zoo Dr / Shiloh Rd	10-15 Years (d)	L	$ 100,000	STPP, STPU, P, L
	S C13	Widen Zoo Dr. to 4 or 5 lanes	Gabel Rd to Shiloh Rd	10-20 Years (d)	L	$ 700,000	STPP, STPU, CMAQ
	S C14	Add WB RT "free" right turn (requires bridge structure widening)	Zoo Dr / I-90 WB ramps	15-20 Years (d)	H	$ 800,000	STPP, CMAQ, BR
	S C15	Add 2nd EB LT lane and NB RT lane	Zoo Dr / S Frontage Rd	15-20 Years (d)	L	$ 200,000	STPP, STPU, SMAQ, P

(d) Timing dependent upon commercial development growth along Zoo Drive and Shiloh Road
* These intersections currently have signal poles installed (no mast arms) with the existing street lighting.

Funding Source Codes:

STPP = Surface Transportation Program Primary
STPU = Surface Transportation Program Urban
STPHS = Surface Transportation Program Hazard Elimination Program
CTEP = Surface Transportation Enhancement Program
CMAQ = Congestion Mitigation and Air Quality Improvement Program
NH = National Highway System Program
BR= Bridge Replacement Program
IM= Interstate Maintenance Program
L = Local Funds
P = Private Funds

Priority Codes:

H = **High**: Safety project based on a documented accident trend, or capacity improvement involving structure widening and/or advanced planning
M = **Medium**: Project need is imminent, but not related to a documented safety issue and/or advanced planning not required
L = **Low**: Project need is projected, but not related to a documented safety issue and/or advanced planning not required

Table 25
Recommended Project/STIP Improvements
South Billings Boulevard Interchange - Exit 447

Type	Project ID	Improvement Description	Location	Anticipated Time Frame *	General Planning Priority	Estimated Cost	Potential Funding Sources
Safety Related	SB S1	Upgrade crossroad and ramp lighting to CIL standards	I-90 at S Billings Blvd	0-5 Years	L	$ 250,000	STPP
	SB S2	Upgrade I-90 mainline highway lighting to CIL standards	I-90 at S Billings Blvd	0-5 Years	L	$ 750,000	STPP, IM
	SB S3	Construct sidewalks through corridor (utilize existing sidewalks on I-90 bridge)	S Billings Blvd	0-10 Years	L	$ 100,000	STPP, CTEP, L, P
Capacity Related	SB C1	Coordinated signal system	S Billings Blvd	5-10 Years	M	$ 25,000	STPP, STPU, CMAQ
	SB C2	Add NB & WB RT lanes	S Billings Blvd / King Ave	15-20 Years	M	$ 150,000	L, P
	SB C3	Widen/restripe S. Billings to 4 thru lanes; extend/restripe LT lanes at I-90 on-ramps	S. Billings, King Blvd. to south of project	15-20 Years	M	$ 800,000	STPP, STPU, CMAQ, L
	SB C4	Install traffic signal	Southgate Dr / King Ave	15-20 Years (d)	L	$ 200,000	L,P
	SB C5	Add 2nd EB LT lane & WB RT lane	S Billings Blvd / S Frontage - Midland	15-20 Years	L	$ 200,000	L

(a) With opening of City of Billings Traffic Operations Center
(d) Timing dependent upon commercial development growth along Zoo Drive and Shiloh Road

Funding Source Codes:

STPP = Surface Transportation Program Primary
STPU = Surface Transportation Program Urban
STPHS = Surface Transportation Program Hazard Elimination Program
CTEP = Surface Transportation Enhancement Program
CMAQ = Congestion Mitigation and Air Quality Improvement Program
NH = National Highway System Program
BR= Bridge Replacement Program
IM= Interstate Maintenance Program
L = Local Funds
P = Private Funds

Priority Codes:

H = **High**; Safety project based on a documented accident trend, or capacity improvement involving structure widening and/or advanced planning
M = **Medium**; Project need is imminent, but not related to a documented safety issue and/or advanced planning not required
L = **Low**; Project need is projected, but not related to a documented safety issue and/or advanced planning not required

Table 26
Recommended Project/STIP Improvements
27th Street Interchange - Exit 450

Type	Project ID	Improvement Description	Location	Anticipated Time Frame	General Planning Priority	Estimated Cost	Potential Funding Sources
Safety Related	27 S1	Widen EB on-ramp for truck turns	27th St / I-90 EB on-ramp	0 Years	H	$ 150,000	STPP, STPHS, IM, NH
	27 S2	Modify barriers to improve intersection sight distance	27th St	0 Years	L	$ 50,000	STPP, STPHS, BR, NH
	27 S3	Construct sidewalks (except on I-90 bridge) and crosswalks at ramp terminals	27th St	0-5 Years	L	$ 100,000	STPP, CTEP, L, P, NH
Capacity Related	27 C1	Install traffic signal	27th St / I-90 WB ramps	10-15 Years	M	$ 200,000	STPP, CMAQ
	27 C2	Install traffic signal	27th St / I-90 EB ramps	10-15 Years	M	$ 200,000	STPP, CMAQ
	27 C3	Coordinate signal system	27th St	10-15 Years	M	$ 25,000	STPP, CMAQ

Funding Source Codes:

STPP = Surface Transportation Program Primary
STPU = Surface Transportation Program Urban
STPHS = Surface Transportation Program Hazard Elimination Program
CTEP = Surface Transportation Enhancement Program
CMAQ = Congestion Mitigation and Air Quality Improvement Program
NH = National Highway System Program
BR= Bridge Replacement Program
IM= Interstate Maintenance Program
L = Local Funds
P = Private Funds

Priority Codes:

H = **High**; Safety project based on a documented accident trend, or capacity improvement involving structure widening and/or advanced planning
M = **Medium**; Project need is imminent, but not related to a documented safety issue and/or advanced planning not required
L = **Low**; Project need is projected, but not related to a documented safety issue and/or advanced planning not required

Table 27
Recommended Project/STIP Improvements
US 87 Lockwood Interchange - Exit 452

Type	Project ID	Improvement Description	Location	Anticipated Time Frame	General Planning Priority	Estimated Cost	Potential Funding Sources
Safety Related	LK S1	Interim safety improvements to mitigate SB LT (EB on ramp) accidents	I-90 EB Ramps / US 87	0 Years	H	$ 25,000	STPP, STPHS, NH
	LK S2	Construct sidewalks & crosswalks except on I-90 bridge	I-90 at US 87	0-10 Years	L	$ 100,000	STPP, CTEP, L, P, NH
	LK S3	Upgrade crossroad and ramp lighting to meet CIL standards	I-90 at US 87	15-20 Years	L	$ 250,000	STPP, NH
	LK S4	I-90 mainline highway lighting does not meet CIL standards	I-90 at US 87	15-20 Years	L	$ 750,000	STPP, IM
Capacity Related	LK C1	Construct roundabout interchange (2 roundabouts) / remove signals / incorporate Coburn Rd	I-90 Interchange	5-10 Years	H	$ 4,000,000	STPP, STPHS, CMAQ, NH

Funding Source Codes:

STPP = Surface Transportation Program Primary
STPU = Surface Transportation Program Urban
STPHS = Surface Transportation Program Hazard Elimination Program
CTEP = Surface Transportation Enhancement Program
CMAQ = Congestion Mitigation and Air Quality Improvement Program
NH = National Highway System Program
BR= Bridge Replacement Program
IM= Interstate Maintenance Program
L = Local Funds
P = Private Funds

Priority Codes:

H = **High**; Safety project based on a documented accident trend, or capacity improvement involving structure widening and/or advanced planning
M = **Medium**; Project need is imminent, but not related to a documented safety issue and/or advanced planning not required
L = **Low**; Project need is projected, but not related to a documented safety issue and/or advanced planning not required

Table 28
Recommended Project/STIP Improvements
Johnson Lane Interchange - Exit 455

Type	Project ID	Improvement Description	Location	Anticipated Time Frame	General Planning Priority	Estimated Cost	Potential Funding Sources
Safety Related	JL S1	Improve vertical clearance; lower Johnson Lane	I-90 bridge over Johnson Ln	0 Years	H	$ 200,000	STPP, STPHS
	JL S2	Add intersection streetlight	Johnson Ln / I-90 WB ramp	0 Years	M	$ 10,000	STPP
	JL S3	Add crosswalk & ped push buttons / signal indications	north leg of Old Hardin Rd at Johnson Ln	0 Years	M	$ 15,000	STPP, CTEP
	JL S4	Construct sidewalks & crosswalks	Johnson Ln	0-10 Years	L	$ 100,000	STPP, CTEP, L, P
	JL S5	Upgrade crossroad and ramp lighting to meet CIL standards	Johnson Ln	5-10 Years (d)	L	$ 250,000	STPP
	JL C1	Upgrade I-90 mainline highway lighting to meet CIL standards	I-90 at Johnson Ln	5-10 Years (d)	L	$ 750,000	STPP, IM
Capacity Related	JL C2	Access management at Flying J service station	Old Hardin Rd west of Johnson Ln	0-5 Years	M	Requires coordination with private owner	STPP, L, P
	JL C3	Construct roundabout interchange (2 roundabouts) / incorporate N Frontage Rd	I-90 Interchange	5-15 Years (d)	H	$ 5,000,000	STPP, CMAQ, L, P, IM
	JL C4	Add 2nd SB LT lane and WB LT lane	Johnson Ln / Old Hardin Rd	10-15 Years	M	$ 200,000	STPP, CMAQ, L

(d) Timing dependent upon development growth north of I-90 along N Frontage Rd

Funding Source Codes:

STPP = Surface Transportation Program Primary
STPU = Surface Transportation Program Urban
STPHS = Surface Transportation Program Hazard Elimination Program
CTEP = Surface Transportation Enhancement Program
CMAQ = Congestion Mitigation and Air Quality Improvement Program
NH = National Highway System Program
BR= Bridge Replacement Program
IM= Interstate Maintenance Program
L = Local Funds
P = Private Funds

Priority Codes:

H = **High**; Safety project based on a documented accident trend, or capacity improvement involving structure widening and/or advanced planning
M = **Medium**; Project need is imminent, but not related to a documented safety issue and/or advanced planning not required
L = **Low**; Project need is projected, but not related to a documented safety issue and/or advanced planning not required

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option M-3

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	2D) Shiloh On Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp
☐ Yes ☐ On		Acceleration Lane Length, L_A	1160	☐ Yes ☐ On
☑ No ☐ Off		Deceleration Lane Length L_D		☑ No ☐ Off
L_{up} =	ft	Freeway Volume, V_F	1460	L_{down} = ft
V_u =	veh/h	Ramp Volume, V_R	1158	V_D = veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0	
		Ramp Free-Flow Speed, S_{FR}	70.0	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1460	0.82	Level	17	0	0.922	1.00	1932
Ramp	1158	0.72	Level	6	0	0.971	1.00	1657
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.610 using Equation (Exhibit 13-6)

V_{12} = 1178 pc/h

V_3 or V_{av34} = 754 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	3589	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	2835	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 19.6 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.225 (Exibit 13-11)

S_R = 63.7 mph (Exhibit 13-11)

S_0 = 69.1 mph (Exhibit 13-11)

S = 64.8 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	2B) Shiloh Off Ramp
Date Performed	10/13/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	242	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1413	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	954	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	67.8		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1413	0.83	Level	14	0	0.935	1.00	1822
Ramp	954	0.82	Level	6	0	0.971	1.00	1198
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.450 using Equation (Exhibit 13-7)

V_{12} = 1479 pc/h

V_3 or V_{av34} 343 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	1822	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	624	Exhibit 13-8	7200	No
V_R	1198	Exhibit 13-10	4400	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1479	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 12.6 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.109 (Exhibit 13-12)

S_R = 66.9 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 68.6 mph (Exhibit 13-13)

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BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Eastbound*
Agency or Company	*DOWL HKM*	From/To	*3) Shiloh to West Billings*
Date Performed	*10/20/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*2472*	veh/h	Peak-Hour Factor, PHF	*0.85*
AADT		veh/day	%Trucks and Buses, P_T	*13*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.939*

Speed Inputs			Calc Speed Adj and FFS		
Lane Width		ft			
Rt-Side Lat. Clearance		ft	f_{LW}		mph
Number of Lanes, N	*3*		f_{LC}		mph
Total Ramp Density, TRD		ramps/mi	TRD Adjustment		mph
FFS (measured)	*74.8*	mph	FFS	*74.8*	mph
Base free-flow Speed, BFFS		mph			

LOS and Performance Measures			Design (N)		
Operational (LOS)			Design (N)		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*1032*	pc/h/ln	Design LOS		
S	*75.0*	mph	v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
D = v_p / S	*13.8*	pc/mi/ln	S		mph
LOS	*B*		D = v_p / S		pc/mi/ln
			Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Westbound*
Agency or Company	*DOWL HKM*	From/To	*3) Shiloh to West Billings*
Date Performed	*10/20/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*2375*	veh/h	Peak-Hour Factor, PHF	*0.89*
AADT		veh/day	%Trucks and Buses, P_T	*12*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.943*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*70.8*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*70.8*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*943*	pc/h/ln
S	*70.0*	mph
D = v_p / S	*13.5*	pc/mi/ln
LOS	*B*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	3E) West Billings Off Ramp EB
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	278	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	834	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	1846	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	70.0		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	834	0.82	Level	22	0	0.901	0.95	1188
Ramp	1846	0.82	Level	3	0	0.985	0.95	2405
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.450 using Equation (Exhibit 13-7)

V_{12} = 1857 pc/h

V_3 or V_{av34} -669 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	1188	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	-1217	Exhibit 13-8	7200	No
V_R	2405	Exhibit 13-10	4400	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1857	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 15.2 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.189 (Exhibit 13-12)

S_R = 64.7 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 59.4 mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	3A) West Billings On Ramp King
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp			Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N	3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A	582	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D		L_{down} = ft
V_u = veh/h	Freeway Volume, V_F	1319	V_D = veh/h
	Ramp Volume, V_R	1016	
	Freeway Free-Flow Speed, S_{FF}	70.0	
	Ramp Free-Flow Speed, S_{FR}	68.7	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1319	0.93	Level	18	0	0.917	0.95	1627
Ramp	1016	0.85	Level	3	0	0.985	1.00	1213
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.594 using Equation (Exhibit 13-6)

V_{12} = 966 pc/h

V_3 or V_{av34} = 661 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2840	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	2179	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 18.3 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.275 (Exibit 13-11)

S_R = 62.3 mph (Exhibit 13-11)

S_0 = 69.4 mph (Exhibit 13-11)

S = 63.8 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option ID M-5

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	4D) South Billings On Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A: 1200	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D:	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 1621	V_D = veh/h
	Ramp Volume, V_R: 953	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 68.9	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1621	0.96	Level	15	0	0.930	0.95	1911
Ramp	953	0.83	Level	5	0	0.976	1.00	1177
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.611 using Equation (Exhibit 13-6)

V_{12} = 1168 pc/h

V_3 or V_{av34} = 743 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	3088	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	2345	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 15.7 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.196 (Exibit 13-11)

S_R = 64.5 mph (Exhibit 13-11)

S_0 = 69.1 mph (Exhibit 13-11)

S = 65.6 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	4B) South Billings Off Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	202	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1988	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	254	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	67.6		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1988	0.93	Level	14	0	0.935	0.95	2408
Ramp	254	0.77	Level	6	0	0.971	0.95	358
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.450 using Equation (Exhibit 13-7)

V_{12} = 1280 pc/h

V_3 or V_{av34} 1128 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☑ Yes ☐ No

If Yes, V_{12a} = 1376 pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	2408	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	2050	Exhibit 13-8	7200	No
V_R	358	Exhibit 13-10	4400	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1280	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 12.4 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.036 (Exhibit 13-12)

S_R = 69.0 mph (Exhibit 13-12)

S_0 = 76.7 mph (Exhibit 13-12)

S = 72.1 mph (Exhibit 13-13)

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Eastbound*
Agency or Company	*DOWL HKM*	From/To	*5) South Billings to 27th St*
Date Performed	*10/20/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*2257*	veh/h	Peak-Hour Factor, PHF	*0.94*
AADT		veh/day	%Trucks and Buses, P_T	*13*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.939*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*65.5*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*65.5*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*852*	pc/h/ln
S	*65.0*	mph
D = v_p / S	*13.1*	pc/mi/ln
LOS	*B*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Westbound*
Agency or Company	*DOWL HKM*	From/To	*5) South Billings to 27th St*
Date Performed	*10/20/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*2059*	veh/h	Peak-Hour Factor, PHF	*0.88*
AADT		veh/day	%Trucks and Buses, P_T	*12*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.943*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*71.2*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*71.2*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*827*	pc/h/ln
S	*70.0*	mph
D = v_p / S	*11.8*	pc/mi/ln
LOS	*B*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	5E) 27th Street Off Ramp EB
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	235	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1966	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	214	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	67.3		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1966	0.93	Level	15	0	0.930	1.00	2273
Ramp	214	0.77	Level	8	0	0.962	1.00	289
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.450 using Equation (Exhibit 13-7)

V_{12} = 1182 pc/h

V_3 or V_{av34} 1091 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☑ Yes ☐ No

If Yes, V_{12a} = 1298 pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	2273	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	1984	Exhibit 13-8	7200	No
V_R	289	Exhibit 13-10	4400	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1182	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 11.2 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.034 (Exhibit 13-12)

S_R = 69.0 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 72.2 mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	5A) 27th Street On Ramp
Date Performed	10/13/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp
☐ Yes	☐ On	Acceleration Lane Length, L_A	568	☐ Yes ☐ On
☑ No	☐ Off	Deceleration Lane Length L_D		☑ No ☐ Off
L_{up} =	ft	Freeway Volume, V_F	1451	L_{down} = ft
V_u =	veh/h	Ramp Volume, V_R	331	V_D = veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0	
		Ramp Free-Flow Speed, S_{FR}	68.2	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1451	0.85	Level	15	0	0.930	1.00	1835
Ramp	331	0.87	Level	4	0	0.980	1.00	388
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.593 using Equation (Exhibit 13-6)

V_{12} = 1089 pc/h

V_3 or V_{av34} = 746 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2223	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	1477	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 13.3 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.261 (Exibit 13-11)

S_R = 62.7 mph (Exhibit 13-11)

S_0 = 69.1 mph (Exhibit 13-11)

S = 64.7 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option M-6

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	5D) 27th Street On Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A: 713	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D:	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 1966	V_D = veh/h
	Ramp Volume, V_R: 455	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 67.0	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1966	0.93	Level	15	0	0.930	1.00	2273
Ramp	455	0.70	Level	10	0	0.952	1.00	683
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.597 using Equation (Exhibit 13-6)

V_{12} = 1358 pc/h

V_3 or V_{av34} 915 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2956	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	2041	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 16.6 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.255 (Exibit 13-11)

S_R = 62.8 mph (Exhibit 13-11)

S_0 = 68.5 mph (Exhibit 13-11)

S = 64.5 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	5B) 27th Street Off Ramp
Date Performed	7/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	139	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1451	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	370	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	68.2		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1451	0.85	Level	15	0	0.930	1.00	1835
Ramp	370	0.68	Level	18	0	0.917	1.00	593
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.450 using Equation (Exhibit 13-7)

V_{12} = 1152 pc/h

V_3 or V_{av34} 683 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	1835	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	1242	Exhibit 13-8	7200	No
V_R	593	Exhibit 13-10	4400	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1152	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 11.7 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.050 (Exhibit 13-12)

S_R = 68.6 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 71.4 mph (Exhibit 13-13)

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Eastbound*
Agency or Company	*DOWL HKM*	From/To	*6) 27th Street to Lockwood*
Date Performed	*10/20/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*2974*	veh/h	Peak-Hour Factor, PHF	*0.91*
AADT		veh/day	%Trucks and Buses, P_T	*14*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.935*

Speed Inputs			Calc Speed Adj and FFS		
Lane Width		ft			
Rt-Side Lat. Clearance		ft	f_{LW}		mph
Number of Lanes, N	*3*		f_{LC}		mph
Total Ramp Density, TRD		ramps/mi	TRD Adjustment		mph
FFS (measured)	*72.9*	mph	FFS	*72.9*	mph
Base free-flow Speed, BFFS		mph			

LOS and Performance Measures			Design (N)		
Operational (LOS)			Design (N)		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*1166*	pc/h/ln	Design LOS		
S	*74.7*	mph	v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
D = v_p / S	*15.6*	pc/mi/ln	S		mph
LOS	*B*		D = v_p / S		pc/mi/ln
			Required Number of Lanes, N		

Glossary		Factor Location	
N - Number of lanes	S - Speed	E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
V - Hourly volume	D - Density	E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
v_p - Flow rate	FFS - Free-flow speed	f_p - Page 11-18	TRD - Page 11-11
LOS - Level of service	BFFS - Base free-flow speed	LOS, S, FFS, v_p - Exhibits 11-2, 11-3	
DDHV - Directional design hour volume			

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Westbound*
Agency or Company	*DOWL HKM*	From/To	*6) 27th Street to Lockwood*
Date Performed	*10/14/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*2118*	veh/h	Peak-Hour Factor, PHF	*0.87*
AADT		veh/day	%Trucks and Buses, P_T	*18*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.917*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*73.4*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*73.4*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*885*	pc/h/ln
S	*75.0*	mph
D = v_p / S	*11.8*	pc/mi/ln
LOS	*B*	

Design (N)

Design (N)

Design LOS	
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	pc/h/ln
S	mph
D = v_p / S	pc/mi/ln
Required Number of Lanes, N	

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	6E) Lockwood Off Ramp EB
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	155	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	2089	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	909	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	67.4		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	2089	0.95	Level	19	0	0.913	1.00	2408
Ramp	909	0.79	Level	10	0	0.952	1.00	1208
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.450 using Equation (Exhibit 13-7)

V_{12} = 1748 pc/h

V_3 or V_{av34} 660 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	2408	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	1200	Exhibit 13-8	7200	No
V_R	1208	Exhibit 13-10	4400	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1748	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = 16.5 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.116 (Exhibit 13-12)

S_R = 66.8 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 69.2 mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	6A) Lockwood On Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A	750	☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D		☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1692	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	367	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	68.0		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	1692	0.88	Level	18	0	0.917	1.00	2096
Ramp	367	0.63	Level	18	0	0.917	1.00	635
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.599 using Equation (Exhibit 13-6)

V_{12} = 1254 pc/h

V_3 or V_{av34} = 842 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2731	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	1889	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 15.2 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.245 (Exibit 13-11)

S_R = 63.1 mph (Exhibit 13-11)

S_0 = 68.8 mph (Exhibit 13-11)

S = 64.8 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option M-7

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	6D) Lockwood On Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp
☐ Yes	☐ On	Acceleration Lane Length, L_A	850	☐ Yes ☐ On
☑ No	☐ Off	Deceleration Lane Length L_D		☑ No ☐ Off
L_{up} =	ft	Freeway Volume, V_F	2089	L_{down} = ft
V_u =	veh/h	Ramp Volume, V_R	342	V_D = veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0	
		Ramp Free-Flow Speed, S_{FR}	67.0	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	2089	0.95	Level	19	0	0.913	1.00	2408
Ramp	342	0.95	Level	10	0	0.952	1.00	378
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.601 using Equation (Exhibit 13-6)

V_{12} = 1448 pc/h

V_3 or V_{av34} = 960 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2786	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	1826	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 14.2 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.231 (Exibit 13-11)

S_R = 63.5 mph (Exhibit 13-11)

S_0 = 68.3 mph (Exhibit 13-11)

S = 65.1 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	6B) Lockwood Off Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	174	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1692	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	750	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	68.0		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	1692	0.88	Level	18	0	0.917	1.00	2096
Ramp	750	0.88	Level	9	0	0.957	1.00	891
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.450 using Equation (Exhibit 13-7)

V_{12} = 1433 pc/h

V_3 or V_{av34} 663 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	2096	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	1205	Exhibit 13-8	7200	No
V_R	891	Exhibit 13-10	4400	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1433	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = 13.4 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.079 (Exhibit 13-12)

S_R = 67.8 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 70.4 mph (Exhibit 13-13)

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Eastbound*
Agency or Company	*DOWL HKM*	From/To	*7) Lockwood to Johnson Lane*
Date Performed	*10/20/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*2121*	veh/h	Peak-Hour Factor, PHF	*0.95*
AADT		veh/day	%Trucks and Buses, P_T	*15*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.930*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*72.2*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*72.2*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*800*	pc/h/ln
S	*70.0*	mph
D = v_p / S	*11.4*	pc/mi/ln
LOS	*B*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 10-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Westbound*
Agency or Company	*DOWL HKM*	From/To	*7) Lockwood to Johnson Lane*
Date Performed	*10/20/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*2408*	veh/h	Peak-Hour Factor, PHF	*0.88*
AADT		veh/day	%Trucks and Buses, P_T	*15*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.930*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*73.6*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*73.6*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*981*	pc/h/ln
S	*75.0*	mph
D = v_p / S	*13.1*	pc/mi/ln
LOS	*B*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	7E) Johnson Lane Off Ramp EB
Date Performed	7/19/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A:	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D: 208	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 1689	V_D = veh/h
	Ramp Volume, V_R: 538	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 67.3	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	1689	0.92	Level	16	0	0.926	1.00	1983
Ramp	538	0.96	Level	13	0	0.939	1.00	597
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.450 using Equation (Exhibit 13-7)

V_{12} = 1221 pc/h

V_3 or V_{av34} 762 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	1983	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	1386	Exhibit 13-8	7200	No
V_R	597	Exhibit 13-10	4400	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1221	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = 11.0 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.062 (Exhibit 13-12)

S_R = 68.3 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 71.3 mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	7A) Johnson Lane On Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A: 750	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D:	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 964	V_D = veh/h
	Ramp Volume, V_R: 1471	
	Freeway Free-Flow Speed, S_{FF}: 69.9	
	Ramp Free-Flow Speed, S_{FR}: 64.9	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	964	0.84	Level	14	0	0.935	1.00	1228
Ramp	1471	0.87	Level	16	0	0.926	1.00	1826
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.599 using Equation (Exhibit 13-6)

V_{12} = 735 pc/h

V_3 or V_{av34} 493 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	3054	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	2561	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 19.9 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.274 (Exibit 13-11)

S_R = 62.3 mph (Exhibit 13-11)

S_0 = 69.9 mph (Exhibit 13-11)

S = 63.4 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option U-4a

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	3D) West Billings On Ramp
Date Performed	7/19/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A: 1500	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D:	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 834	V_D = veh/h
	Ramp Volume, V_R: 45	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 70.0	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	834	0.82	Level	22	0	0.901	0.95	1188
Ramp	45	0.80	Level	5	0	0.976	0.95	61
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.619 using Equation (Exhibit 13-6)

V_{12} = 736 pc/h

V_3 or V_{av34} 452 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	1249	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	797	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 2.3 (pc/mi/ln)

LOS = A (Exhibit 13-2)

Speed Determination

M_S = 0.120 (Exibit 13-11)

S_R = 66.6 mph (Exhibit 13-11)

S_0 = 70.0 mph (Exhibit 13-11)

S = 67.8 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Eastbound*
Agency or Company	*DOWL HKM*	From/To	*3F) West Billings Over Part 2*
Date Performed	*7/11/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*861*	veh/h	Peak-Hour Factor, PHF	*0.82*
AADT		veh/day	%Trucks and Buses, P_T	*22*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*0.95*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.901*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*2*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*70.0*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*70.0*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*613*	pc/h/ln
S	*70.0*	mph
D = v_p / S	*8.8*	pc/mi/ln
LOS	*A*	

Design (N)

Design (N)

Design LOS	
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	pc/h/ln
S	mph
D = v_p / S	pc/mi/ln
Required Number of Lanes, N	

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option U-4b

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	3E) West Billings Off Ramp EB
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	121	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	834	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	1846	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	70.0		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	834	0.82	Level	22	0	0.901	0.95	1188
Ramp	1846	0.82	Level	3	0	0.985	0.95	2405
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.620 using Equation (Exhibit 13-7)

V_{12} = 1651 pc/h

V_3 or V_{av34} -463 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	1188	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	-1217	Exhibit 13-8	7200	No
V_R	2405	Exhibit 13-10	2200	Yes

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1651	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 17.4 (pc/mi/ln)

LOS = F (Exhibit 13-2)

Speed Determination

D_s = 0.189 (Exhibit 13-12)

S_R = 64.7 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 61.0 mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	3B) West Billings Off Ramp
Date Performed	7/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	150	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1319	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	1754	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	68.6		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1319	0.93	Level	18	0	0.917	0.95	1627
Ramp	1754	0.85	Level	3	0	0.985	1.00	2094
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.623 using Equation (Exhibit 13-7)

V_{12} = 1803 pc/h

V_3 or V_{av34} -176 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	1627	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	-467	Exhibit 13-8	7200	No
V_R	2094	Exhibit 13-10	2200	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1803	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 18.4 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.180 (Exhibit 13-12)

S_R = 65.0 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 63.9 mph (Exhibit 13-13)

BASIC FREEWAY SEGMENTS WORKSHEET

General Information

Analyst	*David Stoner*
Agency or Company	*DOWL HKM*
Date Performed	*7/11/2011*
Analysis Time Period	*Peak Hour*

Site Information

Highway/Direction of Travel	*Eastbound*
From/To	*3C) West Billings Over*
Jurisdiction	*Yellowstone County Montana*
Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*834*	veh/h	Peak-Hour Factor, PHF	*0.82*
AADT		veh/day	%Trucks and Buses, P_T	*22*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*0.95*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.901*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*75.0*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*75.0*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*396*	pc/h/ln
S	*75.0*	mph
D = v_p / S	*5.3*	pc/mi/ln
LOS	*A*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Westbound*
Agency or Company	*DOWL HKM*	From/To	*3C) West Billings Over*
Date Performed	*7/11/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*1319*	veh/h	Peak-Hour Factor, PHF	*0.93*
AADT		veh/day	%Trucks and Buses, P_T	*18*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*0.95*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.917*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*73.7*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*73.7*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*542*	pc/h/ln
S	*75.0*	mph
D = v_p / S	*7.2*	pc/mi/ln
LOS	*A*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	3D) West Billings On Ramp
Date Performed	7/19/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A: 415	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D:	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 834	V_D = veh/h
	Ramp Volume, V_R: 45	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 70.0	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	834	0.82	Level	22	0	0.901	0.95	1188
Ramp	45	0.80	Level	5	0	0.976	0.95	61
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F(P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.589 using Equation (Exhibit 13-6)

V_{12} = 700 pc/h

V_3 or V_{av34} = 488 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * $V_{12}/2$ ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	1249	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	761	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 8.8 (pc/mi/ln)

LOS = A (Exhibit 13-2)

Speed Determination

M_S = 0.271 (Exibit 13-11)

S_R = 62.4 mph (Exhibit 13-11)

S_0 = 70.0 mph (Exhibit 13-11)

S = 65.2 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * $V_{12}/2$ ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Eastbound*
Agency or Company	*DOWL HKM*	From/To	*3F) West Billings Over Part 2*
Date Performed	*7/11/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*861*	veh/h	Peak-Hour Factor, PHF	*0.82*
AADT		veh/day	%Trucks and Buses, P_T	*22*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*0.95*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.901*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*70.0*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*70.0*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*409*	pc/h/ln
S	*70.0*	mph
D = v_p / S	*5.8*	pc/mi/ln
LOS	*A*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	3G) W Billings On Ramp @ Mullo
Date Performed	11/15/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A: 1500	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D:	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 861	V_D = veh/h
	Ramp Volume, V_R: 1307	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 65.0	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	861	0.82	Level	22	0	0.901	0.95	1227
Ramp	1307	0.80	Level	5	0	0.976	0.95	1763
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F(P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.619 using Equation (Exhibit 13-6)

V_{12} = 760 pc/h

V_3 or V_{av34} 467 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2990	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	2523	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 14.9 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.175 (Exibit 13-11)

S_R = 65.1 mph (Exhibit 13-11)

S_0 = 70.0 mph (Exhibit 13-11)

S = 65.8 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	3B) West Billings Off Ramp
Date Performed	7/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	150	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1319	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	1754	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	68.6		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	1319	0.93	Level	18	0	0.917	0.95	1627
Ramp	1754	0.85	Level	3	0	0.985	1.00	2094
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.623 using Equation (Exhibit 13-7)

V_{12} = 1803 pc/h

V_3 or V_{av34} -176 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	1627	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	-467	Exhibit 13-8	7200	No
V_R	2094	Exhibit 13-10	2200	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1803	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 18.4 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.180 (Exhibit 13-12)

S_R = 65.0 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 63.9 mph (Exhibit 13-13)

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option U-5

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	4E) South Billings Off Ramp E8
Date Performed	7/19/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	165	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1621	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	783	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	68.8		
		Ramp Free-Flow Speed, S_{FR}	70.0		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1621	0.96	Level	15	0	0.930	0.95	1911
Ramp	783	0.85	Level	5	0	0.976	1.00	944
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.669 using Equation (Exhibit 13-7)

V_{12} = 1591 pc/h

V_3 or V_{av34} 320 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	1911	Exhibit 13-8	7164	No
$V_{FO} = V_F - V_R$	967	Exhibit 13-8	7164	No
V_R	944	Exhibit 13-10	2200	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1591	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 16.4 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_S = 0.058 (Exhibit 13-12)

S_R = 67.2 mph (Exhibit 13-12)

S_0 = 75.5 mph (Exhibit 13-12)

S = 68.5 mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	4A) South Billings On Ramp
Date Performed	7/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp
☐ Yes ☐ On		Acceleration Lane Length, L_A	1500	☐ Yes ☐ On
☑ No ☐ Off		Deceleration Lane Length L_D		☑ No ☐ Off
L_{up} =	ft	Freeway Volume, V_F	1988	L_{down} = ft
V_u =	veh/h	Ramp Volume, V_R	552	V_D = veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0	
		Ramp Free-Flow Speed, S_{FR}	67.6	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1988	0.93	Level	14	0	0.935	0.95	2408
Ramp	552	0.80	Level	5	0	0.976	0.95	744
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.619 using Equation (Exhibit 13-6)

V_{12} = 1492 pc/h

V_3 or V_{av34} = 916 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	3152	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	2236	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 13.2 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.155 (Exibit 13-11)

S_R = 65.7 mph (Exhibit 13-11)

S_0 = 68.5 mph (Exhibit 13-11)

S = 66.5 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Eastbound*
Agency or Company	*DOWL HKM*	From/To	*4C) South Billings Under*
Date Performed	*7/11/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*1621*	veh/h	Peak-Hour Factor, PHF	*0.96*
AADT		veh/day	%Trucks and Buses, P_T	*15*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*0.95*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.930*

Speed Inputs			Calc Speed Adj and FFS		
Lane Width		ft			
Rt-Side Lat. Clearance		ft	f_{LW}		mph
Number of Lanes, N	*3*		f_{LC}		mph
Total Ramp Density, TRD		ramps/mi	TRD Adjustment		mph
FFS (measured)	*73.8*	mph	FFS	*73.8*	mph
Base free-flow Speed, BFFS		mph			

LOS and Performance Measures			Design (N)	
Operational (LOS)			Design (N)	
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*637*	pc/h/ln	Design LOS	
S	*75.0*	mph	v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	pc/h/ln
D = v_p / S	*8.5*	pc/mi/ln	S	mph
LOS	*A*		D = v_p / S	pc/mi/ln
			Required Number of Lanes, N	

Glossary		Factor Location	
N - Number of lanes	S - Speed	E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
V - Hourly volume	D - Density	E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
v_p - Flow rate	FFS - Free-flow speed	f_p - Page 11-18	TRD - Page 11-11
LOS - Level of service	BFFS - Base free-flow speed	LOS, S, FFS, v_p - Exhibits 11-2, 11-3	
DDHV - Directional design hour volume			

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Westbound*
Agency or Company	*DOWL HKM*	From/To	*4C) South Billings Under*
Date Performed	*7/11/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*1988*	veh/h	Peak-Hour Factor, PHF	*0.93*
AADT		veh/day	%Trucks and Buses, P_T	*14*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*0.95*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.935*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*72.6*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*72.6*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*803*	pc/h/ln
S	*75.0*	mph
D = v_p / S	*10.7*	pc/mi/ln
LOS	*A*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	4D) South Billings On Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A: 1200	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D:	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 1621	V_D = veh/h
	Ramp Volume, V_R: 953	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 68.9	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1621	0.96	Level	15	0	0.930	0.95	1911
Ramp	953	0.83	Level	5	0	0.976	1.00	1177
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.611 using Equation (Exhibit 13-6)

V_{12} = 1168 pc/h

V_3 or V_{av34} = 743 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	3088	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	2345	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 15.7 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.196 (Exibit 13-11)

S_R = 64.5 mph (Exhibit 13-11)

S_0 = 69.1 mph (Exhibit 13-11)

S = 65.6 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	4B) South Billings Off Ramp
Date Performed	7/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A:	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D: 200	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 1988	V_D = veh/h
	Ramp Volume, V_R: 254	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 67.6	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	1988	0.93	Level	14	0	0.935	0.95	2408
Ramp	254	0.77	Level	6	0	0.971	0.95	358
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.683 using Equation (Exhibit 13-7)

V_{12} = 1759 pc/h

V_3 or V_{av34} 649 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	2408	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	2050	Exhibit 13-8	7200	No
V_R	358	Exhibit 13-10	2200	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1759	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = 17.6 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.036 (Exhibit 13-12)

S_R = 69.0 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 70.9 mph (Exhibit 13-13)

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option U-6

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	5E) 27th Street Off Ramp EB
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	150	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1966	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	214	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	67.3		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1966	0.93	Level	15	0	0.930	1.00	2273
Ramp	214	0.77	Level	8	0	0.962	1.00	289
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.690 using Equation (Exhibit 13-7)

V_{12} = 1658 pc/h

V_3 or V_{av34} 615 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	2273	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	1984	Exhibit 13-8	7200	No
V_R	289	Exhibit 13-10	2200	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1658	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 17.2 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.034 (Exhibit 13-12)

S_R = 69.0 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 71.0 mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	5A) 27th Street On Ramp
Date Performed	7/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A: 568	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D:	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 1451	V_D = veh/h
	Ramp Volume, V_R: 331	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 68.2	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1451	0.85	Level	15	0	0.930	1.00	1835
Ramp	331	0.87	Level	4	0	0.980	1.00	388
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.593 using Equation (Exhibit 13-6)

V_{12} = 1089 pc/h

V_3 or V_{av34} = 746 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2223	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	1477	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 13.3 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.261 (Exibit 13-11)

S_R = 62.7 mph (Exhibit 13-11)

S_0 = 69.1 mph (Exhibit 13-11)

S = 64.7 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Eastbound*
Agency or Company	*DOWL HKM*	From/To	*5C) 27th Street Under*
Date Performed	*7/11/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*1966*	veh/h	Peak-Hour Factor, PHF	*0.93*
AADT		veh/day	%Trucks and Buses, P_T	*15*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.930*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*72.3*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*72.3*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*758*	pc/h/ln
S	*70.0*	mph
D = v_p / S	*10.8*	pc/mi/ln
LOS	*A*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

BASIC FREEWAY SEGMENTS WORKSHEET

General Information

Analyst	*David Stoner*
Agency or Company	*DOWL HKM*
Date Performed	*7/11/2011*
Analysis Time Period	*Peak Hour*

Site Information

Highway/Direction of Travel	*Westbound*
From/To	*5C) 27th Street Under*
Jurisdiction	*Yellowstone County Montana*
Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*1451*	veh/h	Peak-Hour Factor, PHF	*0.85*
AADT		veh/day	%Trucks and Buses, P_T	*15*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.930*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*73.2*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*73.2*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*612*	pc/h/ln
S	*75.0*	mph
D = v_p / S	*8.2*	pc/mi/ln
LOS	*A*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	5D) 27th Street On Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N: 3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A: 713	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D:	L_{down} = ft
V_u = veh/h	Freeway Volume, V_F: 1966	V_D = veh/h
	Ramp Volume, V_R: 455	
	Freeway Free-Flow Speed, S_{FF}: 70.0	
	Ramp Free-Flow Speed, S_{FR}: 67.0	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1966	0.93	Level	15	0	0.930	1.00	2273
Ramp	455	0.70	Level	10	0	0.952	1.00	683
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.597 using Equation (Exhibit 13-6)

V_{12} = 1358 pc/h

V_3 or V_{av34} = 915 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2956	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	2041	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 16.6 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.255 (Exibit 13-11)

S_R = 62.8 mph (Exhibit 13-11)

S_0 = 68.5 mph (Exhibit 13-11)

S = 64.5 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} = pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	5B) 27th Street Off Ramp
Date Performed	7/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	250	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	1451	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	370	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	68.2		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	1451	0.85	Level	15	0	0.930	1.00	1835
Ramp	370	0.68	Level	18	0	0.917	1.00	593
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.687 using Equation (Exhibit 13-7)

V_{12} = 1446 pc/h

V_3 or V_{av34} 389 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	1835	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	1242	Exhibit 13-8	7200	No
V_R	593	Exhibit 13-10	2200	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1446	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = 14.4 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.050 (Exhibit 13-12)

S_R = 68.6 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 70.2 mph (Exhibit 13-13)

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option U-7

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	6E) Lockwood Off Ramp EB
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp		Number of Lanes, N	3	Downstream Adj Ramp	
☐ Yes	☐ On	Acceleration Lane Length, L_A		☐ Yes	☐ On
☑ No	☐ Off	Deceleration Lane Length L_D	170	☑ No	☐ Off
L_{up} =	ft	Freeway Volume, V_F	2089	L_{down} =	ft
V_u =	veh/h	Ramp Volume, V_R	909	V_D =	veh/h
		Freeway Free-Flow Speed, S_{FF}	70.0		
		Ramp Free-Flow Speed, S_{FR}	67.4		

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	2089	0.95	Level	19	0	0.913	1.00	2408
Ramp	909	0.79	Level	10	0	0.952	1.00	1208
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.644 using Equation (Exhibit 13-7)

V_{12} = 1981 pc/h

V_3 or V_{av34} 427 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	2408	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	1200	Exhibit 13-8	7200	No
V_R	1208	Exhibit 13-10	2200	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1981	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = 19.8 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.116 (Exhibit 13-12)

S_R = 66.8 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 68.3 mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	6A) Lockwood On Ramp
Date Performed	7/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp			Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N	3	☐ Yes ☐ On
	Acceleration Lane Length, L_A	750	
☑ No ☐ Off	Deceleration Lane Length L_D		☑ No ☐ Off
L_{up} = ft	Freeway Volume, V_F	1692	L_{down} = ft
	Ramp Volume, V_R	367	
V_u = veh/h	Freeway Free-Flow Speed, S_{FF}	70.0	V_D = veh/h
	Ramp Free-Flow Speed, S_{FR}	68.0	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	1692	0.88	Level	18	0	0.917	1.00	2096
Ramp	367	0.63	Level	18	0	0.917	1.00	635
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.599 using Equation (Exhibit 13-6)

V_{12} = 1254 pc/h

V_3 or V_{av34} 842 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2731	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	1889	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 15.2 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.245 (Exibit 13-11)

S_R = 63.1 mph (Exhibit 13-11)

S_0 = 68.8 mph (Exhibit 13-11)

S = 64.8 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

BASIC FREEWAY SEGMENTS WORKSHEET

General Information		Site Information	
Analyst	*David Stoner*	Highway/Direction of Travel	*Eastbound*
Agency or Company	*DOWL HKM*	From/To	*6C) Lockwood Under*
Date Performed	*7/11/2011*	Jurisdiction	*Yellowstone County Montana*
Analysis Time Period	*Peak Hour*	Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*2089*	veh/h	Peak-Hour Factor, PHF	*0.95*
AADT		veh/day	%Trucks and Buses, P_T	*19*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.913*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*72.4*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*72.4*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*803*	pc/h/ln
S	*70.0*	mph
D = v_p / S	*11.5*	pc/mi/ln
LOS	*B*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

BASIC FREEWAY SEGMENTS WORKSHEET

General Information

Analyst	*David Stoner*
Agency or Company	*DOWL HKM*
Date Performed	*7/11/2011*
Analysis Time Period	*Peak Hour*

Site Information

Highway/Direction of Travel	*Westbound*
From/To	*6C) Lockwood Under*
Jurisdiction	*Yellowstone County Montana*
Analysis Year	*2035*

Project Description *Billings Area I-90 Corridor Planning Study*

☑ Oper.(LOS) ☐ Des.(N) ☐ Planning Data

Flow Inputs

Volume, V	*1692*	veh/h	Peak-Hour Factor, PHF	*0.88*
AADT		veh/day	%Trucks and Buses, P_T	*18*
Peak-Hr Prop. of AADT, K			%RVs, P_R	*0*
Peak-Hr Direction Prop, D			General Terrain:	*Level*
DDHV = AADT x K x D		veh/h	Grade % Length Up/Down %	*mi*

Calculate Flow Adjustments

f_p	*1.00*	E_R	*1.2*
E_T	*1.5*	$f_{HV} = 1/[1+P_T(E_T - 1) + P_R(E_R - 1)]$	*0.917*

Speed Inputs

Lane Width		ft
Rt-Side Lat. Clearance		ft
Number of Lanes, N	*3*	
Total Ramp Density, TRD		ramps/mi
FFS (measured)	*73.0*	mph
Base free-flow Speed, BFFS		mph

Calc Speed Adj and FFS

f_{LW}		mph
f_{LC}		mph
TRD Adjustment		mph
FFS	*73.0*	mph

LOS and Performance Measures

Operational (LOS)

v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)	*699*	pc/h/ln
S	*75.0*	mph
D = v_p / S	*9.3*	pc/mi/ln
LOS	*A*	

Design (N)

Design (N)

Design LOS		
v_p = (V or DDHV) / (PHF x N x f_{HV} x f_p)		pc/h/ln
S		mph
D = v_p / S		pc/mi/ln
Required Number of Lanes, N		

Glossary

N - Number of lanes	S - Speed
V - Hourly volume	D - Density
v_p - Flow rate	FFS - Free-flow speed
LOS - Level of service	BFFS - Base free-flow speed
DDHV - Directional design hour volume	

Factor Location

E_R - Exhibits 11-10, 11-12	f_{LW} - Exhibit 11-8
E_T - Exhibits 11-10, 11-11, 11-13	f_{LC} - Exhibit 11-9
f_p - Page 11-18	TRD - Page 11-11
LOS, S, FFS, v_p - Exhibits 11-2, 11-3	

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Eastbound
Agency or Company	DOWL HKM	Junction	6D) Lockwood On Ramp
Date Performed	10/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp			Downstream Adj Ramp
☐ Yes ☐ On	Number of Lanes, N	3	☐ Yes ☐ On
☑ No ☐ Off	Acceleration Lane Length, L_A	850	☑ No ☐ Off
L_{up} = ft	Deceleration Lane Length L_D		L_{down} = ft
V_u = veh/h	Freeway Volume, V_F	2089	V_D = veh/h
	Ramp Volume, V_R	342	
	Freeway Free-Flow Speed, S_{FF}	70.0	
	Ramp Free-Flow Speed, S_{FR}	67.0	

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	$v = V/PHF \times f_{HV} \times f_p$
Freeway	2089	0.95	Level	19	0	0.913	1.00	2408
Ramp	342	0.95	Level	10	0	0.952	1.00	378
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = 0.601 using Equation (Exhibit 13-6)

V_{12} = 1448 pc/h

V_3 or V_{av34} 960 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}	2786	Exhibit 13-8		No

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}	1826	Exhibit 13-8	4600:All	No

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\, v_R + 0.0078\, V_{12} - 0.00627\, L_A$

D_R = 14.2 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

M_S = 0.231 (Exibit 13-11)

S_R = 63.5 mph (Exhibit 13-11)

S_0 = 68.3 mph (Exhibit 13-11)

S = 65.1 mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = using Equation (Exhibit 13-7)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F		Exhibit 13-8		
$V_{FO} = V_F - V_R$		Exhibit 13-8		
V_R		Exhibit 13-10		

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\, V_{12} - 0.009\, L_D$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

D_s = (Exhibit 13-12)

S_R = mph (Exhibit 13-12)

S_0 = mph (Exhibit 13-12)

S = mph (Exhibit 13-13)

RAMPS AND RAMP JUNCTIONS WORKSHEET

General Information / Site Information

Analyst	David Stoner	Freeway/Dir of Travel	Westbound
Agency or Company	DOWL HKM	Junction	6B) Lockwood Off Ramp
Date Performed	7/20/2011	Jurisdiction	Yellowstone County Montana
Analysis Time Period	Peak Hour	Analysis Year	2035

Project Description: Billings Area I-90 Corridor Planning Study

Inputs

Upstream Adj Ramp: ☐ Yes ☐ On ☑ No ☐ Off; L_{up} = ft; V_u = veh/h

Number of Lanes, N	3
Acceleration Lane Length, L_A	
Deceleration Lane Length L_D	180
Freeway Volume, V_F	1692
Ramp Volume, V_R	750
Freeway Free-Flow Speed, S_{FF}	70.0
Ramp Free-Flow Speed, S_{FR}	68.0

Downstream Adj Ramp: ☐ Yes ☐ On ☑ No ☐ Off; L_{down} = ft; V_D = veh/h

Conversion to pc/h Under Base Conditions

(pc/h)	V (Veh/hr)	PHF	Terrain	%Truck	%Rv	f_{HV}	f_p	v = V/PHF x f_{HV} x f_p
Freeway	1692	0.88	Level	18	0	0.917	1.00	2096
Ramp	750	0.88	Level	9	0	0.957	1.00	891
UpStream								
DownStream								

Merge Areas

Estimation of v_{12}

$V_{12} = V_F (P_{FM})$

L_{EQ} = (Equation 13-6 or 13-7)

P_{FM} = using Equation (Exhibit 13-6)

V_{12} = pc/h

V_3 or V_{av34} pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☐ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☐ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_{FO}		Exhibit 13-8		

Flow Entering Merge Influence Area

	Actual	Max Desirable		Violation?
V_{R12}		Exhibit 13-8		

Level of Service Determination (if not F)

$D_R = 5.475 + 0.00734\ v_R + 0.0078\ V_{12} - 0.00627\ L_A$

D_R = (pc/mi/ln)

LOS = (Exhibit 13-2)

Speed Determination

M_S = (Exibit 13-11)

S_R = mph (Exhibit 13-11)

S_0 = mph (Exhibit 13-11)

S = mph (Exhibit 13-13)

Diverge Areas

Estimation of v_{12}

$V_{12} = V_R + (V_F - V_R)P_{FD}$

L_{EQ} = (Equation 13-12 or 13-13)

P_{FD} = 0.667 using Equation (Exhibit 13-7)

V_{12} = 1694 pc/h

V_3 or V_{av34} 402 pc/h (Equation 13-14 or 13-17)

Is V_3 or V_{av34} > 2,700 pc/h? ☐ Yes ☑ No

Is V_3 or V_{av34} > 1.5 * V_{12}/2 ☐ Yes ☑ No

If Yes, V_{12a} = pc/h (Equation 13-16, 13-18, or 13-19)

Capacity Checks

	Actual	Capacity		LOS F?
V_F	2096	Exhibit 13-8	7200	No
$V_{FO} = V_F - V_R$	1205	Exhibit 13-8	7200	No
V_R	891	Exhibit 13-10	2200	No

Flow Entering Diverge Influence Area

	Actual	Max Desirable		Violation?
V_{12}	1694	Exhibit 13-8	4400:All	No

Level of Service Determination (if not F)

$D_R = 4.252 + 0.0086\ V_{12} - 0.009\ L_D$

D_R = 17.2 (pc/mi/ln)

LOS = B (Exhibit 13-2)

Speed Determination

D_s = 0.079 (Exhibit 13-12)

S_R = 67.8 mph (Exhibit 13-12)

S_0 = 76.8 mph (Exhibit 13-12)

S = 69.3 mph (Exhibit 13-13)

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option I-2b
Braided Ramps

Intersection	
Intersection Delay (sec/veh)	97.5
Intersection LOS	F

Approach	EB	WB	NB
Entry Lanes	1	1	1
Conflicting Circle Lanes	1	1	1
Adjusted Approach Flow (vph)	412	698	774
Demand Flow Rate (pc/h)	429	726	805
Vehicles Circulating (pc/h)	173	805	156
Vehicles Exiting (pc/h)	1358	156	446
Follow-Up Headway (s)	3.186	3.186	3.186
Ped Vol. Crossing Leg (#/hr)	0	0	0
Ped Capacity Adjustment	1.000	1.000	1.000
Approach Delay (sec/veh)	9.4	231.0	24.0
Approach LOS	A	F	C

Lane	Left	Left	Left
Designated moves	LTR	LT	LR
Assumed Moves	LTR	LT	LR
Right Turn Channelized			
Lane Utilization	1.000	1.000	1.000
Critical Headway (s)	5.193	5.193	5.193
Entry Flow Rate (pc/h)	429	726	805
Capacity, Entry Lane (pc/h)	950	505	967
Entry HV Adjustment Factor	0.962	0.962	0.961
Flow Rate, Entry (vph)	413	698	774
Capacity, Entry (vph)	914	486	930
Volume to Capacity Ratio	0.451	1.437	0.833
Control Delay (sec/veh)	9.4	231.0	24.0
Level of Service	A	F	C
95th-Percentile Queue (veh)	2	34	10

Intersection	
Intersection Delay (sec/veh)	17.0
Intersection LOS	C

Approach	EB	WB	NB	SB
Entry Lanes	1	1	1	1
Conflicting Circle Lanes	1	1	1	1
Adjusted Approach Flow (vph)	326	811	54	281
Demand Flow Rate (pc/h)	340	843	56	293
Vehicles Circulating (pc/h)	333	122	556	40
Vehicles Exiting (pc/h)	0	490	117	925
Follow-Up Headway (s)	3.186	3.186	3.186	3.186
Ped Vol. Crossing Leg (#/hr)	0	0	0	0
Ped Capacity Adjustment	1.000	1.000	1.000	1.000
Approach Delay (sec/veh)	10.0	24.3	6.7	6.1
Approach LOS	B	C	A	A

Lane	Left	Left	Left	Left
Designated moves	LTR	LR	TR	LT
Assumed Moves	LTR	LR	TR	LT
Right Turn Channelized				
Lane Utilization	1.000	1.000	1.000	1.000
Critical Headway (s)	5.193	5.193	5.193	5.193
Entry Flow Rate (pc/h)	340	843	56	293
Capacity, Entry Lane (pc/h)	810	1000	648	1086
Entry HV Adjustment Factor	0.960	0.961	0.964	0.960
Flow Rate, Entry (vph)	326	811	54	281
Capacity, Entry (vph)	777	962	625	1042
Volume to Capacity Ratio	0.420	0.843	0.086	0.270
Control Delay (sec/veh)	10.0	24.3	6.7	6.1
Level of Service	B	C	A	A
95th-Percentile Queue (veh)	2	10	0	1

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option I-2b
Roundabouts

Intersection	
Intersection Delay (sec/veh)	12.1
Intersection LOS	B

Approach	EB	WB	NB	SB
Entry Lanes	1	2	0	1
Conflicting Circle Lanes	2	2	2	2
Adjusted Approach Flow (vph)	437	588	0	150
Demand Flow Rate (pc/h)	455	612	0	155
Vehicles Circulating (pc/h)	484	932	553	1379
Vehicles Exiting (pc/h)	1050	0	386	165
Follow-Up Headway (s)	3.186	3.186	3.186	3.186
Ped Vol. Crossing Leg (#/hr)	0	0	0	0
Ped Capacity Adjustment	1.000	1.000	1.000	1.000
Approach Delay (sec/veh)	13.4	16.4	0.0	15.3
Approach LOS	B	C	-	C

Lane	Left	Left	Right	Left
Designated moves	LR	LT	TR	LTR
Assumed Moves	LR	LT	TR	LTR
Right Turn Channelized				
Lane Utilization	1.000	0.471	0.529	1.000
Critical Headway (s)	4.113	4.293	4.113	4.113
Entry Flow Rate (pc/h)	455	288	324	155
Capacity, Entry Lane (pc/h)	805	562	588	430
Entry HV Adjustment Factor	0.960	0.960	0.962	0.966
Flow Rate, Entry (vph)	437	277	312	150
Capacity, Entry (vph)	773	539	566	416
Volume to Capacity Ratio	0.565	0.513	0.551	0.360
Control Delay (sec/veh)	13.4	16.1	16.6	15.3
Level of Service	B	C	C	C
95th-Percentile Queue (veh)	4	3	3	2

Intersection	
Intersection Delay (sec/veh)	
Intersection LOS	

Approach	NW
Entry Lanes	2
Conflicting Circle Lanes	2
Adjusted Approach Flow (vph)	818
Demand Flow Rate (pc/h)	851
Vehicles Circulating (pc/h)	81
Vehicles Exiting (pc/h)	472
Follow-Up Headway (s)	3.186
Ped Vol. Crossing Leg (#/hr)	0
Ped Capacity Adjustment	1.000
Approach Delay (sec/veh)	7.9
Approach LOS	A

Lane	Left	Right
Designated moves	L	LTR
Assumed Moves	L	LTR
Right Turn Channelized		
Lane Utilization	0.530	0.470
Critical Headway (s)	4.293	4.113
Entry Flow Rate (pc/h)	451	400
Capacity, Entry Lane (pc/h)	1063	1068
Entry HV Adjustment Factor	0.962	0.962
Flow Rate, Entry (vph)	434	385
Capacity, Entry (vph)	1023	1027
Volume to Capacity Ratio	0.424	0.375
Control Delay (sec/veh)	8.2	7.5
Level of Service	A	A
95th-Percentile Queue (veh)	2	2

Intersection	
Intersection Delay (sec/veh)	9.0
Intersection LOS	A

Approach	EB	WB	NB	SB
Entry Lanes	1	0	2	1
Conflicting Circle Lanes	2	2	2	2
Adjusted Approach Flow (vph)	346	0	912	298
Demand Flow Rate (pc/h)	360	0	949	310
Vehicles Circulating (pc/h)	310	980	221	0
Vehicles Exiting (pc/h)	0	190	449	980
Follow-Up Headway (s)	3.186	3.186	3.186	3.186
Ped Vol. Crossing Leg (#/hr)	0	0	0	0
Ped Capacity Adjustment	1.000	1.000	1.000	1.000
Approach Delay (sec/veh)	8.8	0.0	10.1	5.9
Approach LOS	A	-	B	A

Lane	Left	Left	Right	Left
Designated moves	LTR	LT	TR	LT
Assumed Moves	LTR	LT	TR	LT
Right Turn Channelized				
Lane Utilization	1.000	0.470	0.530	1.000
Critical Headway (s)	4.113	4.293	4.113	4.113
Entry Flow Rate (pc/h)	360	446	503	310
Capacity, Entry Lane (pc/h)	910	957	968	1130
Entry HV Adjustment Factor	0.960	0.961	0.961	0.962
Flow Rate, Entry (vph)	346	429	483	298
Capacity, Entry (vph)	873	920	930	1087
Volume to Capacity Ratio	0.396	0.466	0.520	0.274
Control Delay (sec/veh)	8.8	9.6	10.6	5.9
Level of Service	A	A	B	A
95th-Percentile Queue (veh)	2	3	3	1

Appendix 5

Improvement Options Operational LOS Analysis Sheets

Option I-2b
Single Point Urban Interchange (SPUI)

Intersection	
Intersection Delay (sec/veh)	27.0
Intersection LOS	D

Approach	EB	WB	NB
Entry Lanes	1	1	1
Conflicting Circle Lanes	1	1	1
Adjusted Approach Flow (vph)	412	143	953
Demand Flow Rate (pc/h)	429	148	991
Vehicles Circulating (pc/h)	95	912	76
Vehicles Exiting (pc/h)	965	155	448
Follow-Up Headway (s)	3.186	3.186	3.186
Ped Vol. Crossing Leg (#/hr)	0	0	0
Ped Capacity Adjustment	1.000	1.000	1.000
Approach Delay (sec/veh)	8.3	13.8	37.1
Approach LOS	A	B	E

Lane	Left	Left	Left
Designated moves	TR	LT	LR
Assumed Moves	TR	LT	LR
Right Turn Channelized			
Lane Utilization	1.000	1.000	1.000
Critical Headway (s)	5.193	5.193	5.193
Entry Flow Rate (pc/h)	429	148	991
Capacity, Entry Lane (pc/h)	1028	454	1047
Entry HV Adjustment Factor	0.961	0.964	0.961
Flow Rate, Entry (vph)	412	143	953
Capacity, Entry (vph)	987	438	1007
Volume to Capacity Ratio	0.418	0.326	0.946
Control Delay (sec/veh)	8.3	13.8	37.1
Level of Service	A	B	E
95th-Percentile Queue (veh)	2	1	16

Intersection	
Intersection Delay (sec/veh)	15.8
Intersection LOS	C

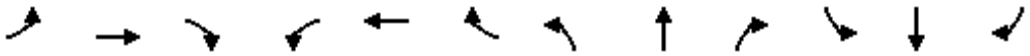
Approach	EB	WB	NB	SB
Entry Lanes	1	1	1	1
Conflicting Circle Lanes	1	1	1	1
Adjusted Approach Flow (vph)	18	817	64	424
Demand Flow Rate (pc/h)	18	849	66	440
Vehicles Circulating (pc/h)	436	80	332	8
Vehicles Exiting (pc/h)	12	318	122	921
Follow-Up Headway (s)	3.186	3.186	3.186	3.186
Ped Vol. Crossing Leg (#/hr)	0	0	0	0
Ped Capacity Adjustment	1.000	1.000	1.000	1.000
Approach Delay (sec/veh)	5.2	21.2	5.4	7.4
Approach LOS	A	C	A	A

Lane	Left	Left	Left	Left
Designated moves	LTR	LTR	TR	LTR
Assumed Moves	LTR	LTR	TR	LTR
Right Turn Channelized				
Lane Utilization	1.000	1.000	1.000	1.000
Critical Headway (s)	5.193	5.193	5.193	5.193
Entry Flow Rate (pc/h)	18	849	66	440
Capacity, Entry Lane (pc/h)	731	1043	811	1121
Entry HV Adjustment Factor	0.987	0.962	0.963	0.962
Flow Rate, Entry (vph)	18	817	64	423
Capacity, Entry (vph)	721	1003	780	1078
Volume to Capacity Ratio	0.025	0.814	0.081	0.393
Control Delay (sec/veh)	5.2	21.2	5.4	7.4
Level of Service	A	C	A	A
95th-Percentile Queue (veh)	0	9	0	2

Appendix 5

Improvement Options Operational LOS Analysis Sheets

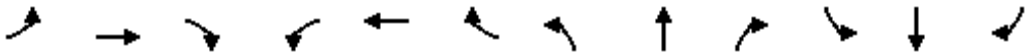
Option ID I-2b
Reconstruction of Frontage Roads



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (veh/h)	0	0	0	80	5	415	277	393	0	0	215	34
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			0%	
Peak Hour Factor	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Hourly flow rate (vph)	0	0	0	89	6	461	308	437	0	0	239	38
Pedestrians												
Lane Width (ft)												
Walking Speed (ft/s)												
Percent Blockage												
Right turn flare (veh)												
Median type								None			None	
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	1774	1310	258	1310	1329	437	277			437		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	1774	1310	258	1310	1329	437	277			437		
tC, single (s)	7.1	6.5	6.2	7.1	6.5	6.2	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	100	100	100	19	95	25	76			100		
cM capacity (veh/h)	13	119	776	110	116	616	1275			1113		

Direction, Lane #	WB 1	NB 1	SB 1
Volume Total	556	744	277
Volume Left	89	308	0
Volume Right	461	0	38
cSH	346	1275	1700
Volume to Capacity	1.61	0.24	0.16
Queue Length 95th (ft)	816	24	0
Control Delay (s)	314.2	5.3	0.0
Lane LOS	F	A	
Approach Delay (s)	314.2	5.3	0.0
Approach LOS	F		

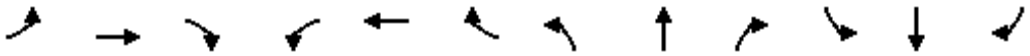
Intersection Summary				
Average Delay	113.2			
Intersection Capacity Utilization	99.1%	ICU Level of Service	F	
Analysis Period (min)	15			



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (veh/h)	57	9	227	0	0	0	0	610	50	96	176	0
Sign Control		Stop			Stop			Free			Free	
Grade		0%			0%			0%			0%	
Peak Hour Factor	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Hourly flow rate (vph)	63	10	252	0	0	0	0	678	56	107	196	0
Pedestrians												
Lane Width (ft)												
Walking Speed (ft/s)												
Percent Blockage												
Right turn flare (veh)												
Median type								None			None	
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	1114	1142	196	1372	1114	706	196			733		
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	1114	1142	196	1372	1114	706	196			733		
tC, single (s)	7.1	6.5	6.2	7.1	6.5	6.2	4.1			4.1		
tC, 2 stage (s)												
tF (s)	3.5	4.0	3.3	3.5	4.0	3.3	2.2			2.2		
p0 queue free %	62	94	70	100	100	100	100			88		
cM capacity (veh/h)	166	174	841	74	181	433	1365			862		

Direction, Lane #	EB 1	NB 1	SB 1
Volume Total	326	733	302
Volume Left	63	0	107
Volume Right	252	56	0
cSH	441	1700	862
Volume to Capacity	0.74	0.43	0.12
Queue Length 95th (ft)	150	0	11
Control Delay (s)	32.9	0.0	4.3
Lane LOS	D		A
Approach Delay (s)	32.9	0.0	4.3
Approach LOS	D		

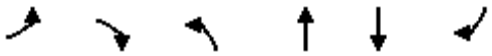
Intersection Summary				
Average Delay	8.8			
Intersection Capacity Utilization	85.3%	ICU Level of Service	E	
Analysis Period (min)	15			



Movement	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Volume (veh/h)	2	2	47	583	20	22	90	46	215	0	23	19
Sign Control		Free			Free			Stop			Stop	
Grade		0%			0%			0%			0%	
Peak Hour Factor	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
Hourly flow rate (vph)	2	2	52	648	22	24	100	51	239	0	26	21
Pedestrians												
Lane Width (ft)												
Walking Speed (ft/s)												
Percent Blockage												
Right turn flare (veh)												
Median type		None			None							
Median storage veh)												
Upstream signal (ft)												
pX, platoon unblocked												
vC, conflicting volume	47			54			1397	1375	28	1627	1389	34
vC1, stage 1 conf vol												
vC2, stage 2 conf vol												
vCu, unblocked vol	47			54			1397	1375	28	1627	1389	34
tC, single (s)	4.1			4.1			7.1	6.5	6.2	7.1	6.5	6.2
tC, 2 stage (s)												
tF (s)	2.2			2.2			3.5	4.0	3.3	3.5	4.0	3.3
p0 queue free %	100			58			0	39	77	100	69	98
cM capacity (veh/h)	1548			1538			60	83	1041	22	82	1033

Direction, Lane #	EB 1	WB 1	NB 1	SB 1
Volume Total	57	694	390	47
Volume Left	2	648	100	0
Volume Right	52	24	239	21
cSH	1548	1538	155	140
Volume to Capacity	0.00	0.42	2.52	0.33
Queue Length 95th (ft)	0	54	844	34
Control Delay (s)	0.3	8.7	749.3	43.1
Lane LOS	A	A	F	E
Approach Delay (s)	0.3	8.7	749.3	43.1
Approach LOS			F	E

Intersection Summary				
Average Delay	252.8			
Intersection Capacity Utilization	81.8%	ICU Level of Service	D	
Analysis Period (min)	15			



Movement	EBL	EBR	NBL	NBT	SBT	SBR
Lane Configurations						
Volume (veh/h)	66	5	5	68	42	51
Sign Control	Stop			Free	Free	
Grade	0%			0%	0%	
Peak Hour Factor	0.90	0.90	0.90	0.90	0.90	0.90
Hourly flow rate (vph)	73	6	6	76	47	57
Pedestrians						
Lane Width (ft)						
Walking Speed (ft/s)						
Percent Blockage						
Right turn flare (veh)						
Median type				None	None	
Median storage veh)						
Upstream signal (ft)						
pX, platoon unblocked						
vC, conflicting volume	162	75	103			
vC1, stage 1 conf vol						
vC2, stage 2 conf vol						
vCu, unblocked vol	162	75	103			
tC, single (s)	6.4	6.2	4.1			
tC, 2 stage (s)						
tF (s)	3.5	3.3	2.2			
p0 queue free %	91	99	100			
cM capacity (veh/h)	821	981	1476			

Direction, Lane #	EB 1	NB 1	SB 1
Volume Total	79	81	103
Volume Left	73	6	0
Volume Right	6	0	57
cSH	831	1476	1700
Volume to Capacity	0.09	0.00	0.06
Queue Length 95th (ft)	8	0	0
Control Delay (s)	9.8	0.5	0.0
Lane LOS	A	A	
Approach Delay (s)	9.8	0.5	0.0
Approach LOS	A		

Intersection Summary			
Average Delay	3.1		
Intersection Capacity Utilization	19.7%	ICU Level of Service	A
Analysis Period (min)	15		

Appendix 6

Cost Estimate Spreadsheets

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION I-1a
Planning Level Estimate of Costs

Item Description	Approx. Quantity	Unit	Average Bid Prices [1]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [2]
			Dollars	Dollars	Dollars	Dollars
RAMPS - SINGLE 12' LANE (EASTBOUND ON-RAMP)						
CRUSHED AGGREGATE COURSE	5,812.35	CUYD	$17.33	$100,728.03		$100,700
TOP SURF 3/4 IN GR 3B	362.90	CUYD	$27.90	$10,124.91		$10,100
COVER - TYPE 2	5,936.00	SQYD	$0.52	$3,086.72		$3,100
DUST PALLIATIVE	9.62	TON		$0.00	$115.00	$1,100
PLANT MIX BIT SURF GR S-3/4 IN	1,671.60	TON	$24.40	$40,787.04		$40,800
ASPHALT CEMENT PG 64 64-28	90.20	TON	$614.80	$55,454.96		$55,500
EMULS ASPHALT CRS-2P	10.06	TON	$512.76	$5,158.37		$5,200
STRIPING-WHITE EPOXY	27.00	GAL	$54.71	$1,477.17		$1,500
STRIPING-YELLOW EPOXY	27.00	GAL	$55.68	$1,503.36		$1,500
EASTBOUND ON-RAMP SUBTOTAL				$218,320.55		$219,500
RAMPS - SINGLE 12' LANE (EASTBOUND OFF-RAMP)						
2 FOOT RETAINING WALL	2,300.00	SQFT			$54.00	$124,200
4 FOOT RETAINING WALL	4,800.00	SQFT			$54.00	$259,200
CRUSHED AGGREGATE COURSE	2,528.50	CUYD	$17.33	$43,818.91		$43,800
TOP SURF 3/4 IN GR 3B	217.75	CUYD	$27.90	$6,075.23		$6,100
COVER - TYPE 2	4,322.50	SQYD	$0.52	$2,247.70		$2,200
DUST PALLIATIVE	7.15	TON		$0.00	$115.00	$800
PLANT MIX BIT SURF GR S-3/4 IN	1,114.75	TON	$24.40	$27,199.90		$27,200
ASPHALT CEMENT PG 64 64-28	60.13	TON	$614.80	$36,964.85		$37,000
EMULS ASPHALT CRS-2P	7.48	TON	$512.76	$3,832.88		$3,800
STRIPING-WHITE EPOXY	32.50	GAL	$54.71	$1,778.08		$1,800
STRIPING-YELLOW EPOXY	32.50	GAL	$55.68	$1,809.60		$1,800
EASTBOUND OFF-RAMP SUBTOTAL				$123,727.14		$507,900
RAMPS - SINGLE 12' LANE (WESTBOUND ON-RAMP)						
2 FOOT RETAINING WALL	2,000.00	SQFT			$54.00	$108,000
CRUSHED AGGREGATE COURSE	778.00	CUYD	$17.33	$13,482.74		$13,500
TOP SURF 3/4 IN GR 3B	67.00	CUYD	$27.90	$1,869.30		$1,900
COVER - TYPE 2	1,330.00	SQYD	$0.52	$691.60		$700
DUST PALLIATIVE	2.20	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	343.00	TON	$24.40	$8,369.20		$8,400
ASPHALT CEMENT PG 64 64-28	18.50	TON	$614.80	$11,373.80		$11,400
EMULS ASPHALT CRS-2P	2.30	TON	$512.76	$1,179.35		$1,200
STRIPING-WHITE EPOXY	10.00	GAL	$54.71	$547.10		$500
STRIPING-YELLOW EPOXY	10.00	GAL	$55.68	$556.80		$600
WESTBOUND ON-RAMP SUBTOTAL				$38,069.89		$146,500
RAMPS - SINGLE 12' LANE (WESTBOUND OFF-RAMP)						
CRUSHED AGGREGATE COURSE	2,779.05	CUYD	$17.33	$48,160.94		$48,200
TOP SURF 3/4 IN GR 3B	188.20	CUYD	$27.90	$5,250.78		$5,300
COVER - TYPE 2	3,265.00	SQYD	$0.52	$1,697.80		$1,700
DUST PALLIATIVE	5.33	TON		$0.00	$115.00	$600
PLANT MIX BIT SURF GR S-3/4 IN	894.30	TON	$24.40	$21,820.92		$21,800
ASPHALT CEMENT PG 64 64-28	48.25	TON	$614.80	$29,664.10		$29,700
EMULS ASPHALT CRS-2P	5.57	TON	$512.76	$2,856.07		$2,900
STRIPING-WHITE EPOXY	18.00	GAL	$54.71	$984.78		$1,000
STRIPING-YELLOW EPOXY	18.00	GAL	$55.68	$1,002.24		$1,000
ADDITIONAL EMBANKMENT	50,000.00	CUYD	$6.60	$330,000.00		$330,000
WESTBOUND OFF-RAMP SUBTOTAL				$441,437.63		$442,200
BRIDGE	**LENGTH (FT.)**	**WIDTH (FT.)**	**COST PER SQUARE FOOT [3]**		**SUBTOTAL**	
INT LAUREL-P 4, BN RAIL						
EASTBOUND STRUCTURE	366.00	44.00	$150.00		$2,400,000	
BRIDGE COST SUBTOTAL					$2,400,000	

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION I-1a
Planning Level Estimate of Costs

Item Description	Approx. Quantity	Unit	Average Bid Prices [1]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [2]
			Dollars	Dollars	Dollars	Dollars
SUBTOTAL 1					$3,700,000	
ADDITIONAL COSTS						
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [3]					20%	$740,000
MOBILIZATION @ 10% OF SUBTOTAL 1 [4]					10%	$370,000
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1					10%	$370,000
SUBTOTAL 2						$5,200,000
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [5]					9.64%	$501,000
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [6]					20%	$1,040,000
					30%	$1,560,000
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [7]					**$6,700,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [7]					**$7,300,000**	

[1] Average MDT bid prices provided for the period November 2010 to July 2011.
[2] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.
[3] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[4] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[5] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[6] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[7] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION I-1b
Planning Level Estimate of Costs

Item Description	Approx. Quantity	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
LUMINAIRES (200' OC [1]) MAINLINE						
CONCRETE-CLASS DD ROAD	29.12	CUYD	$903.00	$26,295.36		$26,300
CONDUIT-PLASTIC 1 1/2 IN	11,200.00	LNFT	$5.32	$59,584.00		$59,600
PULL BOX-CONCRETE TYPE 2	0.00	EACH	$505.28	$0.00		$0
CONDUCTER-COPPER AWG10-600V	33,600.00	LNFT	$0.69	$23,184.00		$23,200
LUMINAIRE ASSEMBLY-400 W S.V.	56.00	EACH	$446.57	$25,007.92		$25,000
SERVE ASSEMB-100 AMP	0.00	EACH	$526.57	$0.00		$0
PHOTO ELECTRIC CONTROL	0.00	EACH	$205.88	$0.00		$0
MAINLINE SUBTOTAL				$134,071.28		$134,100
LUMINAIRES (200' OC [1]) RAMPS						
CONCRETE-CLASS DD ROAD	16.64	CUYD	$903.00	$15,025.92		$15,000
CONDUIT-PLASTIC 1 1/2 IN	6,400.00	LNFT	$5.32	$34,048.00		$34,000
PULL BOX-CONCRETE TYPE 2	0.00	EACH	$505.28	$0.00		$0
CONDUCTER-COPPER AWG10-600V	19,200.00	LNFT	$0.69	$13,248.00		$13,200
LUMINAIRE ASSEMBLY-400 W S.V.	32.00	EACH	$446.57	$14,290.24		$14,300
SERVE ASSEMB-100 AMP	0.00	EACH	$526.57	$0.00		$0
PHOTO ELECTRIC CONTROL	0.00	EACH	$205.88	$0.00		$0
RAMPS SUBTOTAL				$76,612.16		$76,500
SUBTOTAL 1					$210,600	
ADDITIONAL COSTS						
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [4]					20%	$42,100
MOBILIZATION @ 10% OF SUBTOTAL 1 [5]					10%	$21,100
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1					10%	$21,100
SUBTOTAL 2						$294,900
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [6]					9.64%	$28,400
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [7]					20%	$59,000
					30%	$88,500
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [8]					**$380,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [8]					**$410,000**	

[1] On center
[2] Average MDT bid prices provided for the period November 2010 to July 2011.
[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.
[4] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[5] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[6] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[7] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[8] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION I-2a
Planning Level Estimate of Costs

Item Description	Approx. Quantity	Unit	Average Bid Prices [1]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [2]
			Dollars	Dollars	Dollars	Dollars
RAMPS - SINGLE 12' LANE (EASTBOUND ON-RAMP)						
CRUSHED AGGREGATE COURSE	3,493.15	CUYD	$17.33	$60,536.29		$60,500
TOP SURF 3/4 IN GR 3B	226.10	CUYD	$27.90	$6,308.19		$6,300
COVER - TYPE 2	3,800.00	SQYD	$0.52	$1,976.00		$2,000
DUST PALLIATIVE	6.18	TON		$0.00	$115.00	$700
PLANT MIX BIT SURF GR S-3/4 IN	1,056.40	TON	$24.40	$25,776.16		$25,800
ASPHALT CEMENT PG 64 64-28	57.00	TON	$614.80	$35,043.60		$35,000
EMULS ASPHALT CRS-2P	6.46	TON	$512.76	$3,312.43		$3,300
STRIPING-WHITE EPOXY	19.00	GAL	$54.71	$1,039.49		$1,000
STRIPING-YELLOW EPOXY	19.00	GAL	$55.68	$1,057.92		$1,100
EASTBOUND ON-RAMP SUBTOTAL				$135,050.08		$135,700
RAMPS - SINGLE 12' LANE (EASTBOUND OFF-RAMP)						
CRUSHED AGGREGATE COURSE	1,248.05	CUYD	$17.33	$21,628.71		$21,600
TOP SURF 3/4 IN GR 3B	79.95	CUYD	$27.90	$2,230.61		$2,200
COVER - TYPE 2	1,333.50	SQYD	$0.52	$693.42		$700
DUST PALLIATIVE	2.17	TON		$0.00	$115.00	$200
PLANT MIX BIT SURF GR S-3/4 IN	372.05	TON	$24.40	$9,078.02		$9,100
ASPHALT CEMENT PG 64 64-28	20.08	TON	$614.80	$12,342.11		$12,300
EMULS ASPHALT CRS-2P	2.27	TON	$512.76	$1,161.40		$1,200
STRIPING-WHITE EPOXY	6.50	GAL	$54.71	$355.62		$400
STRIPING-YELLOW EPOXY	6.50	GAL	$55.68	$361.92		$400
EASTBOUND OFF-RAMP SUBTOTAL				$47,851.80		$48,100
RAMPS - SINGLE 12' LANE (WESTBOUND ON-RAMP)						
CRUSHED AGGREGATE COURSE	3,532.05	CUYD	$17.33	$61,210.43		$61,200
TOP SURF 3/4 IN GR 3B	229.45	CUYD	$27.90	$6,401.66		$6,400
COVER - TYPE 2	3,866.50	SQYD	$0.52	$2,010.58		$2,000
DUST PALLIATIVE	6.29	TON		$0.00	$115.00	$700
PLANT MIX BIT SURF GR S-3/4 IN	1,073.55	TON	$24.40	$26,194.62		$26,200
ASPHALT CEMENT PG 64 64-28	57.93	TON	$614.80	$35,612.29		$35,600
EMULS ASPHALT CRS-2P	6.58	TON	$512.76	$3,371.40		$3,400
STRIPING-WHITE EPOXY	19.50	GAL	$54.71	$1,066.85		$1,100
STRIPING-YELLOW EPOXY	19.50	GAL	$55.68	$1,085.76		$1,100
WESTBOUND ON-RAMP SUBTOTAL				$136,953.57		$137,700
RAMPS - SINGLE 12' LANE (WESTBOUND OFF-RAMP)						
CRUSHED AGGREGATE COURSE	1,750.05	CUYD	$17.33	$30,328.37		$30,300
TOP SURF 3/4 IN GR 3B	107.45	CUYD	$27.90	$2,997.86		$3,000
COVER - TYPE 2	1,734.50	SQYD	$0.52	$901.94		$900
DUST PALLIATIVE	2.81	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	491.55	TON	$24.40	$11,993.82		$12,000
ASPHALT CEMENT PG 64 64-28	26.53	TON	$614.80	$16,307.57		$16,300
EMULS ASPHALT CRS-2P	2.94	TON	$512.76	$1,504.95		$1,500
STRIPING-WHITE EPOXY	7.50	GAL	$54.71	$410.33		$400
STRIPING-YELLOW EPOXY	7.50	GAL	$55.68	$417.60		$400
ADDITIONAL EMBANKMENT	2,000.00	CUYD	$6.60	$13,200.00		$13,200
WESTBOUND OFF-RAMP SUBTOTAL				$78,062.43		$78,300

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION I-2a
Planning Level Estimate of Costs

Item Description	Approx. Quantity	Unit	Average Bid Prices [1]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [2]
			Dollars	Dollars	Dollars	Dollars
SUBTOTAL 1					$399,800	
ADDITIONAL COSTS						
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [3]					20%	$80,000
MOBILIZATION @ 10% OF SUBTOTAL 1 [4]					10%	$40,000
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1					10%	$40,000
SUBTOTAL 2						$559,800
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [5]					9.64%	$54,000
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [6]					20%	$112,000
					30%	$167,900
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [7]					**$730,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [7]					**$780,000**	

[1] Average MDT bid prices provided for the period November 2010 to July 2011.
[2] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.
[3] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[4] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[5] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[6] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[7] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION I-2b
Planning Level Estimate of Costs

Item Description	Approx. Quantity	Unit	Average Bid Prices [1]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [2]
			Dollars	Dollars	Dollars	Dollars
4-LANE INTERSTATE RECONSTRUCT						
ADDITIONAL EMBANKMENT	50,000.00	CUYD	$6.60	$330,000.00		$330,000
EXCAVATION-UNCLASSIFIED	11,250.00	CUYD	$4.07	$45,787.50		$45,800
CRUSHED AGGREGATE COURSE	33,894.00	CUYD	$17.33	$587,383.02		$587,400
TOP SURF 3/4 IN GR 3B	1,029.00	CUYD	$27.90	$28,709.10		$28,700
COVER - TYPE 2	33,060.00	SQYD	$0.52	$17,191.20		$17,200
DUST PALLIATIVE	53.70	TON		$0.00	$115.00	$6,200
PLANT MIX BIT SURF GR S-3/4 IN	10,887.00	TON	$24.40	$265,642.80		$265,600
ASPHALT CEMENT PG 64-28	588.00	TON	$614.80	$361,502.40		$361,500
EMULS ASPHALT CRS-2P	56.10	TON	$512.76	$28,765.84		$28,800
STRIPING-WHITE EPOXY	90.00	GAL	$54.71	$4,923.90		$4,900
STRIPING-YELLOW EPOXY	90.00	GAL	$55.68	$5,011.20		$5,000
4-LANE INTERSTATE RECONSTRUCT SUBTOTAL				$1,344,916.96		$1,681,100
RAMPS - SINGLE 12' LANE (EASTBOUND ON-RAMP)						
4 FOOT RETAINING WALL	2,000.00	SQFT			$54.00	$108,000
CRUSHED AGGREGATE COURSE	3,928.00	CUYD	$17.33	$68,072.24		$68,100
TOP SURF 3/4 IN GR 3B	251.75	CUYD	$27.90	$7,023.83		$7,000
COVER - TYPE 2	4,200.50	SQYD	$0.52	$2,184.26		$2,200
DUST PALLIATIVE	6.82	TON		$0.00	$115.00	$800
PLANT MIX BIT SURF GR S-3/4 IN	1,171.75	TON	$24.40	$28,590.70		$28,600
ASPHALT CEMENT PG 64 64-28	63.23	TON	$614.80	$38,870.73		$38,900
EMULS ASPHALT CRS-2P	7.14	TON	$512.76	$3,658.54		$3,700
STRIPING-WHITE EPOXY	20.50	GAL	$54.71	$1,121.56		$1,100
STRIPING-YELLOW EPOXY	20.50	GAL	$55.68	$1,141.44		$1,100
EASTBOUND ON-RAMP SUBTOTAL				$150,663.29		$259,500
RAMPS - SINGLE 12' LANE (EASTBOUND OFF-RAMP)						
4 FOOT RETAINING WALL	2,000.00	SQFT			$54.00	$108,000
CRUSHED AGGREGATE COURSE	3,132.40	CUYD	$17.33	$54,284.49		$54,300
TOP SURF 3/4 IN GR 3B	191.10	CUYD	$27.90	$5,331.69		$5,300
COVER - TYPE 2	3,069.00	SQYD	$0.52	$1,595.88		$1,600
DUST PALLIATIVE	4.96	TON		$0.00	$115.00	$600
PLANT MIX BIT SURF GR S-3/4 IN	871.90	TON	$24.40	$21,274.36		$21,300
ASPHALT CEMENT PG 64 64-28	47.05	TON	$614.80	$28,926.34		$28,900
EMULS ASPHALT CRS-2P	5.19	TON	$512.76	$2,661.22		$2,700
STRIPING-WHITE EPOXY	13.00	GAL	$54.71	$711.23		$700
STRIPING-YELLOW EPOXY	13.00	GAL	$55.68	$723.84		$700
EASTBOUND OFF-RAMP SUBTOTAL				$115,509.06		$224,100
RAMPS - SINGLE 12' LANE (WESTBOUND ON-RAMP)						
4 FOOT RETAINING WALL	2,000.00	SQFT			$54.00	$108,000
CRUSHED AGGREGATE COURSE	4,546.70	CUYD	$17.33	$78,794.31		$78,800
TOP SURF 3/4 IN GR 3B	289.30	CUYD	$27.90	$8,071.47		$8,100
COVER - TYPE 2	4,801.00	SQYD	$0.52	$2,496.52		$2,500
DUST PALLIATIVE	7.79	TON		$0.00	$115.00	$900
PLANT MIX BIT SURF GR S-3/4 IN	1,342.70	TON	$24.40	$32,761.88		$32,800
ASPHALT CEMENT PG 64 64-28	72.45	TON	$614.80	$44,542.26		$44,500
EMULS ASPHALT CRS-2P	8.15	TON	$512.76	$4,178.99		$4,200
STRIPING-WHITE EPOXY	23.00	GAL	$54.71	$1,258.33		$1,300
STRIPING-YELLOW EPOXY	23.00	GAL	$55.68	$1,280.64		$1,300
WESTBOUND ON-RAMP SUBTOTAL				$173,384.41		$282,400

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION I-2b
Planning Level Estimate of Costs

Item Description	Approx. Quantity	Unit	Average Bid Prices [1]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [2]
			Dollars	Dollars	Dollars	Dollars
RAMPS - SINGLE 12' LANE (WESTBOUND OFF-RAMP)						
4 FOOT RETAINING WALL	2,000.00	SQFT			$54.00	$108,000
CRUSHED AGGREGATE COURSE	5,073.25	CUYD	$17.33	$87,919.42		$87,900
TOP SURF 3/4 IN GR 3B	299.25	CUYD	$27.90	$8,349.08		$8,300
COVER - TYPE 2	4,672.50	SQYD	$0.52	$2,429.70		$2,400
DUST PALLIATIVE	7.53	TON		$0.00	$115.00	$900
PLANT MIX BIT SURF GR S-3/4 IN	1,345.75	TON	$24.40	$32,836.30		$32,800
ASPHALT CEMENT PG 64 64-28	72.63	TON	$614.80	$44,652.92		$44,700
EMULS ASPHALT CRS-2P	7.88	TON	$512.76	$4,040.55		$4,000
STRIPING-WHITE EPOXY	17.50	GAL	$54.71	$957.43		$1,000
STRIPING-YELLOW EPOXY	17.50	GAL	$55.68	$974.40		$1,000
WESTBOUND OFF-RAMP SUBTOTAL				$182,159.80		$291,000
INTERCHANGE CROSS ROAD						
UNCLASSIFIED EXCAVATION	3,000.00	CUYD			$5.00	$15,000
CRUSHED AGGREGATE COURSE	869.70	CUYD	$17.33	$15,071.90		$15,100
TOP SURF 3/4 IN GR 3B	51.30	CUYD	$27.90	$1,431.27		$1,400
COVER - TYPE 2	801.00	SQYD	$0.52	$416.52		$400
DUST PALLIATIVE	1.29	TON		$0.00	$115.00	$100
PLANT MIX BIT SURF GR S-3/4 IN	230.70	TON	$24.40	$5,629.08		$5,600
ASPHALT CEMENT PG 64 64-28	12.45	TON	$614.80	$7,654.26		$7,700
EMULS ASPHALT CRS-2P	1.35	TON	$512.76	$692.23		$700
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200
STRIPING-YELLOW EPOXY	3.00	GAL	$55.68	$167.04		$200
INTERCHANGE CROSSROAD SUBTOTAL				$31,226.43		$46,400
ROUNDABOUT - 200 FOOT INSCRIBED CIRCLE DIAMETER	2.00	LS		$0.00	$200,000.00	$400,000
EAST MAIN STREET						
CRUSHED AGGREGATE COURSE	1,739.40	CUYD	$17.33	$30,143.80		$30,100
TOP SURF 3/4 IN GR 3B	102.60	CUYD	$27.90	$2,862.54		$2,900
COVER - TYPE 2	1,602.00	SQYD	$0.52	$833.04		$800
DUST PALLIATIVE	2.58	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	461.40	TON	$24.40	$11,258.16		$11,300
ASPHALT CEMENT PG 64 64-28	24.90	TON	$614.80	$15,308.52		$15,300
EMULS ASPHALT CRS-2P	2.70	TON	$512.76	$1,384.45		$1,400
STRIPING-WHITE EPOXY	6.00	GAL	$54.71	$328.26		$300
STRIPING-YELLOW EPOXY	6.00	GAL	$55.68	$334.08		$300
EAST MAIN STREET SUBTOTAL				$62,452.85		$62,700
EAST 72ND STREET						
CRUSHED AGGREGATE COURSE	1,739.40	CUYD	$17.33	$30,143.80		$30,100
TOP SURF 3/4 IN GR 3B	102.60	CUYD	$27.90	$2,862.54		$2,900
COVER - TYPE 2	1,602.00	SQYD	$0.52	$833.04		$800
DUST PALLIATIVE	2.58	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	461.40	TON	$24.40	$11,258.16		$11,300
ASPHALT CEMENT PG 64 64-28	24.90	TON	$614.80	$15,308.52		$15,300
EMULS ASPHALT CRS-2P	2.70	TON	$512.76	$1,384.45		$1,400
STRIPING-WHITE EPOXY	6.00	GAL	$54.71	$328.26		$300
STRIPING-YELLOW EPOXY	6.00	GAL	$55.68	$334.08		$300
EAST 72ND STREET SUBTOTAL				$62,452.85		$62,700
REROUTED SOUTH FRONTAGE ROAD						
UNCLASSIFIED EXCAVATION	16,850.00	CUYD			$5.00	$84,300
CRUSHED AGGREGATE COURSE	21,959.93	CUYD	$17.33	$380,565.59		$380,600
TOP SURF 3/4 IN GR 3B	1,295.33	CUYD	$27.90	$36,139.71		$36,100
COVER - TYPE 2	20,225.25	SQYD	$0.52	$10,517.13		$10,500
DUST PALLIATIVE	32.57	TON		$0.00	$115.00	$3,700
PLANT MIX BIT SURF GR S-3/4 IN	5,825.18	TON	$24.40	$142,134.39		$142,100
ASPHALT CEMENT PG 64 64-28	314.36	TON	$614.80	$193,268.53		$193,300
EMULS ASPHALT CRS-2P	34.09	TON	$512.76	$17,479.99		$17,500
STRIPING-WHITE EPOXY	75.75	GAL	$54.71	$4,144.28		$4,100
STRIPING-YELLOW EPOXY	75.75	GAL	$55.68	$4,217.76		$4,200
REROUTED SOUTH FRONTAGE ROAD SUBTOTAL				$788,467.37		$792,100

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION I-2b
Planning Level Estimate of Costs

Item Description	Approx. Quantity	Unit	Average Bid Prices [1]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [2]
			Dollars	Dollars	Dollars	Dollars
BRIDGE	**LENGTH (FT.)**	**WIDTH (FT.)**	**COST PER SQUARE FOOT [3]**		**SUBTOTAL**	
BILLINGS BENCH CANAL						
SINGLE EAST/WEST STRUCTURE	60.00	36.00	$150.00		$324,000	
INT MOSSMAIN ROAD-P 4						
EB STRUCTURE	120.00	41.00	$150.00		$738,000	
WB STRUCTURE	120.00	41.00	$150.00		$738,000	
BRIDGE COST					$1,476,000	
BRIDGE COST SUBTOTAL					$1,800,000	
				SUBTOTAL 1	$5,900,000	
			ADDITIONAL COSTS			
				MISCELLANEOUS @ 20% OF SUBTOTAL 1 [4]	20%	$1,200,000
				MOBILIZATION @ 10% OF SUBTOTAL 1 [5]	10%	$590,000
				CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1	10%	$590,000
				SUBTOTAL 2		$8,300,000
				INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [6]	9.64%	$800,000
				CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [7]	20%	$1,700,000
					30%	$2,500,000
				TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [8]	**$10,800,000**	
				TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [8]	**$11,600,000**	

[1] Average MDT bid prices provided for the period November 2010 to July 2011.
[2] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.
[3] Planning level costs for simple bridge structures range on average between $110 and $150 per square foot. A conservative estimate of $150 per square foot was utilized for this structure.

[4] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[5] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[6] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[7] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[8] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION I-2c
Planning Level Estimate of Costs

Item Description	Approx. Quantity	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
LUMINAIRES (200' OC [1]) MAINLINE						
CONCRETE-CLASS DD ROAD	26.00	CUYD	$903.03	$23,478.78		$23,500
CONDUIT-PLASTIC 1 1/2 IN	10,000.00	LNFT	$5.32	$53,200.00		$53,200
PULL BOX-CONCRETE TYPE 2	0.00	EACH	$505.28	$0.00		$0
CONDUCTOR-COPPER AWG10-600V	30,000.00	LNFT	$0.69	$20,700.00		$20,700
LUMINAIRE ASSEMBLY-400 W S.V.	50.00	EACH	$446.57	$22,328.50		$22,300
SERV ASSEMB-100 AMP	0.00	EACH	$526.33	$0.00		$0
PHOTO ELECTRIC CONTROL	0.00	EACH	$205.88	$0.00		$0
MAINLINE SUBTOTAL				$119,707.28		$119,700
LUMINAIRES (200' OC [1]) RAMPS						
CONCRETE-CLASS DD ROAD	20.80	CUYD	$903.03	$18,783.02		$18,800
CONDUIT-PLASTIC 1 1/2 IN	8,000.00	LNFT	$5.32	$42,560.00		$42,600
PULL BOX-CONCRETE TYPE 2	0.00	EACH	$505.28	$0.00		$0
CONDUCTOR-COPPER AWG10-600V	24,000.00	LNFT	$0.69	$16,560.00		$16,600
LUMINAIRE ASSEMBLY-400 W S.V.	40.00	EACH	$446.57	$17,862.80		$17,900
SERV ASSEMB-100 AMP	0.00	EACH	$526.33	$0.00		$0
PHOTO ELECTRIC CONTROL	0.00	EACH	$205.88	$0.00		$0
RAMPS SUBTOTAL				$95,765.82		$95,900
SUBTOTAL 1					$215,600	
ADDITIONAL COSTS						
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [4]					20%	$43,100
MOBILIZATION @ 10% OF SUBTOTAL 1 [5]					10%	$21,600
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1					10%	$21,600
SUBTOTAL 2						$301,900
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [6]					9.64%	$29,100
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [7]					20%	$60,400
					30%	$90,600
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [8]					**$390,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [8]					**$420,000**	

[1] On center
[2] Average MDT bid prices provided for the period November 2010 to July 2011.
[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.
[4] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[5] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[6] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[7] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[8] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION B-2
Planning Level Estimate of Costs

Bridge	Length (Ft.)	Width (Ft.)	Cost Per Square Foot [1]		Amount [2]	
SOUTH 56TH STREET						
EB STRUCTURE	153.00	31.60	$150.00		$725,200	
WB STRUCTURE	153.00	31.60	$150.00		$725,200	
ITEM DESCRIPTION	APPROX. QUANTITY	UNIT	AVERAGE BID PRICES		ADJUSTED UNIT PRICES	
			UNIT PRICE DOLLARS	AMOUNT DOLLARS	UNIT PRICE DOLLARS	AMOUNT DOLLARS
ADDITIONAL EMBANKMENT	2,000.00	CUYD	$6.60	$13,200.00		$13,200
				SUBTOTAL 1	$1,463,600	
				ADDITIONAL COSTS		
				MISCELLANEOUS @ 0% OF SUBTOTAL 1 [3]	0%	$0
				MOBILIZATION @ 10% OF SUBTOTAL 1 [4]	10%	$146,400
				CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1	10%	$146,400
				SUBTOTAL 2	$1,800,000	
				INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [5]	9.64%	$173,500
				CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [6]	20%	$360,000
					30%	$540,000
				TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [7]	**$2,300,000**	
				TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [7]	**$2,500,000**	

[1] Planning level costs for simple bridge structures range on average between $110 and $150 per square foot. A conservative estimate of $150 per square foot was utilized for this structure.

[2] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.

[3] Miscellaneous costs are assumed to be included within the per square foot cost.

[4] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.

[5] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.

[6] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.

[7] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION M-3
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
3RD LANE DEPRESSED MEDIAN						
EXCAVATION-UNCLASSIFIED	341.00	CUYD	$4.07	$1,387.87		$1,400
CRUSHED AGGREGATE COURSE	417.70	CUYD	$17.33	$7,238.74		$7,200
TOP SURF 3/4 IN GR 3B	32.60	CUYD	$27.90	$909.54		$900
COVER - TYPE 2	1,373.00	SQYD	$0.52	$713.96		$700
DUST PALLIATIVE	2.22	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	168.30	TON	$24.40	$4,106.52		$4,100
ASPHALT CEMENT PG 64-28	9.09	TON	$614.80	$5,588.53		$5,600
EMULS ASPHALT CRS-2P	2.33	TON	$512.76	$1,194.73		$1,200
GUTTER-CONC VALLEY	66.67	SQYD	$69.89	$4,659.57		$4,700
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
STORM DRAINAGE PER STATION	1.00	LS		$0.00	$200.00	$200
GUARD RAIL-CABLE	100.00	LNFT		$0.00	$14.00	$1,400
3RD LANE DEPRESSED MEDIAN SUBTOTAL				$26,019.27		$28,000
RAMPS - SINGLE 12' LANE						
CRUSHED AGGREGATE COURSE	77.80	CUYD	$17.33	$1,348.27		$1,300
TOP SURF 3/4 IN GR 3B	6.70	CUYD	$27.90	$186.93		$200
COVER - TYPE 2	133.00	SQYD	$0.52	$69.16		$100
DUST PALLIATIVE	0.22	TON		$0.00	$115.00	$0
PLANT MIX BIT SURF GR S-3/4 IN	34.30	TON	$24.40	$836.92		$800
ASPHALT CEMENT PG 64 64-28	1.85	TON	$614.80	$1,137.38		$1,100
EMULS ASPHALT CRS-2P	0.23	TON	$512.76	$117.93		$100
STRIPING-WHITE EPOXY	1.00	GAL	$54.71	$54.71		$100
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
RAMPS - SINGLE 12' LANE SUBTOTAL				$3,806.99		$3,800
ADDITIONAL EMBANKMENT	500.00	CUYD	$14.00	$7,000.00		$7,000
2 FOOT RETAINING WALL	2,000.00	SQFT			$54.00	$108,000
WB OFF-RAMP STRUCTURE & MSE RECONSTRUCTION [4]	1.00	LS		$0.00		$1,000,000

CATEGORY	LENGTH (STA.)	COST PER STATION	SUBTOTAL
3RD LANE DEPRESSED MEDIAN	99.18	28,000.00	$2,800,000
RAMPS - SINGLE 12' LANE LENGTH			
WEST BILLINGS EB OFF-RAMP	8.60		
TOTAL RAMP LENGTH	8.60	3,800.00	$32,700

BRIDGE	LENGTH (FT.)	WIDTH (FT.)	COST PER SQUARE FOOT [5]	SUBTOTAL
HOGANS SLOUGH				
EB STRUCTURE	82.00	56.00	$150.00	$688,800
WB STRUCTURE	82.00	56.00	$150.00	$688,800
BRIDGE COST SUBTOTAL				$1,400,000

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION M-3
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
SUBTOTAL 1					$5,300,000	
ADDITIONAL COSTS						
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [6]					20%	$1,060,000
MOBILIZATION @ 10% OF SUBTOTAL 1 [7]					10%	$530,000
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1					10%	$530,000
SUBTOTAL 2						$7,400,000
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [8]					9.64%	$713,400
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [9]					20%	$1,500,000
					30%	$2,200,000
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [10]					**$9,600,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [10]					**$10,300,000**	

[1] One station is equal to 100 feet.
[2] Average MDT bid prices provided for the period November 2010 to July 2011.
[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.
[4] Cost estimate includes deconstructing existing MSE structure, drainage, geotechnical considerations including preloading fill, and reconstructing MSE structure.

[5] Planning level costs for simple bridge structures range on average between $110 and $150 per square foot. A conservative estimate of $150 per square foot was utilized for this structure.
[6] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[7] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[8] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[9] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[10] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION U-4a
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
3RD LANE DEPRESSED MEDIAN						
EXCAVATION-UNCLASSIFIED	341.00	CUYD	$4.07	$1,387.87		$1,400.00
CRUSHED AGGREGATE COURSE	417.70	CUYD	$17.33	$7,238.74		$7,200.00
TOP SURF 3/4 IN GR 3B	32.60	CUYD	$27.90	$909.54		$900.00
COVER - TYPE 2	1373.00	SQYD	$0.52	$713.96		$700.00
DUST PALLIATIVE	2.22	TON		$0.00	$115.00	$300.00
PLANT MIX BIT SURF GR S-3/4 IN	168.30	TON	$24.40	$4,106.52		$4,100.00
ASPHALT CEMENT PG 64-28	9.09	TON	$614.80	$5,588.53		$5,600.00
EMULS ASPHALT CRS-2P	2.33	TON	$512.76	$1,194.73		$1,200.00
GUTTER-CONC VALLEY	66.67	SQYD	$69.89	$4,659.57		$4,700.00
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200.00
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100.00
STORM DRAINAGE PER STATION	1.00	LS		$0.00	$200.00	$200.00
GUARD RAIL-CABLE	100.00	LNFT		$0.00	$14.00	$1,400.00
3RD LANE DEPRESSED MEDIAN SUBTOTAL						$28,000
ADDITIONAL EMBANKMENT	2000.00	CUYD	$6.60	$13,200.00		$13,200
CATEGORY	**LENGTH (STA.)**		**COST PER STATION**		**SUBTOTAL**	
3RD LANE DEPRESSED MEDIAN	31.72		$28,000.00		$888,200	
BRIDGE	**LENGTH (FT.)**	**WIDTH (FT.)**	**COST PER SQUARE FOOT [4]**		**SUBTOTAL**	
INT W BILLINGS - U1020						
EB STRUCTURE	185.00	56.00	$150.00		$1,600,000	
SUBTOTAL BRIDGE COST					$1,600,000	
INT W BILLINGS - U1010						
EB STRUCTURE	143.00	56.00	$150.00		$1,200,000	
SUBTOTAL BRIDGE COST					$1,200,000	
				SUBTOTAL 1	$3,700,000	
ADDITIONAL COSTS						
				MISCELLANEOUS @ 20% OF SUBTOTAL 1 [5]	20%	$740,000
				MOBILIZATION @ 10% OF SUBTOTAL 1 [6]	10%	$370,000
				CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1	10%	$370,000
				SUBTOTAL 2		$5,200,000
				INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [7]	9.64%	$501,300
				CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [8]	20%	$1,000,000
					30%	$1,600,000
				TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [9]	**$6,700,000**	
				TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [9]	**$7,300,000**	

[1] One station is equal to 100 feet.
[2] Average MDT bid prices provided for the period November 2010 to July 2011.
[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.

[4] Planning level costs for simple bridge structures range on average between $110 and $150 per square foot. A conservative estimate of $150 per square foot was utilized for this structure.
[5] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[6] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[7] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[8] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[9] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION U-4b
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
3RD LANE DEPRESSED MEDIAN						
EXCAVATION-UNCLASSIFIED	341.00	CUYD	$4.07	$1,387.87		$1,400
CRUSHED AGGREGATE COURSE	417.70	CUYD	$17.33	$7,238.74		$7,200
TOP SURF 3/4 IN GR 3B	32.60	CUYD	$27.90	$909.54		$900
COVER - TYPE 2	1,373.00	SQYD	$0.52	$713.96		$700
DUST PALLIATIVE	2.22	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	168.30	TON	$24.40	$4,106.52		$4,100
ASPHALT CEMENT PG 64-28	9.09	TON	$614.80	$5,588.53		$5,600
EMULS ASPHALT CRS-2P	2.33	TON	$512.76	$1,194.73		$1,200
GUTTER-CONC VALLEY	66.67	SQYD	$69.89	$4,659.57		$4,700
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
STORM DRAINAGE PER STATION	1.00	LS		$0.00	$200.00	$0
GUARD RAIL-CABLE	100.00	LNFT		$0.00	$14.00	$0
3RD LANE DEPRESSED MEDIAN SUBTOTAL						$26,400

CATEGORY	LENGTH (STA.)	COST PER STATION	SUBTOTAL
3RD LANE DEPRESSED MEDIAN	41.72	$26,400	$1,100,000

BRIDGE	LENGTH (FT.)	WIDTH (FT.)	COST PER SQUARE FOOT [4]	SUBTOTAL
INT W BILLINGS - U1020				
EB STRUCTURE	185.00	56.00	$150	$1,600,000
WB STRUCTURE	185.00	56.00	$150	$1,600,000
SUBTOTAL BRIDGE COST				$3,200,000
INT W BILLINGS - U1010				
EB STRUCTURE	143.00	56.00	$150	$1,200,000
WB STRUCTURE	143.00	56.00	$150	$1,200,000
SUBTOTAL BRIDGE COST				$2,400,000

SUBTOTAL 1	$6,700,000	
ADDITIONAL COSTS		
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [5]	20%	$1,340,000
MOBILIZATION @ 10% OF SUBTOTAL 1 [6]	10%	$670,000
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1	10%	$670,000
SUBTOTAL 2		$9,400,000
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [7]	9.64%	$906,200
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [8]	20%	$1,900,000
	30%	$2,800,000
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [9]	**$12,200,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [9]	**$13,100,000**	

[1] One station is equal to 100 feet.
[2] Average MDT bid prices provided for the period November 2010 to July 2011.
[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.

[4] Planning level costs for simple bridge structures range on average between $110 and $150 per square foot. A conservative estimate of $150 per square foot was utilized for this structure.
[5] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[6] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[7] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[8] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[9] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION U-5
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
3RD LANE DEPRESSED MEDIAN						
EXCAVATION-UNCLASSIFIED	341.00	CUYD	$4.07	$1,387.87		$1,400
CRUSHED AGGREGATE COURSE	417.70	CUYD	$17.33	$7,238.74		$7,200
TOP SURF 3/4 IN GR 3B	32.60	CUYD	$27.90	$909.54		$900
COVER - TYPE 2	1,373.00	SQYD	$0.52	$713.96		$700
DUST PALLIATIVE	2.22	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	168.30	TON	$24.40	$4,106.52		$4,100
ASPHALT CEMENT PG 64-28	9.09	TON	$614.80	$5,588.53		$5,600
EMULS ASPHALT CRS-2P	2.33	TON	$512.76	$1,194.73		$1,200
GUTTER-CONC VALLEY	66.67	SQYD	$69.89	$4,659.57		$4,700
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
STORM DRAINAGE PER STATION	1.00	LS		$0.00	$200.00	$200
GUARD RAIL-CABLE	100.00	LNFT		$0.00	$14.00	$1,400
3RD LANE DEPRESSED MEDIAN SUBTOTAL						$28,000

CATEGORY	LENGTH (STA.)	COST PER STATION	SUBTOTAL
3RD LANE DEPRESSED MEDIAN	30.00	$28,000.00	$840,000
		SUBTOTAL 1	$840,000
		ADDITIONAL COSTS	
		MISCELLANEOUS @ 20% OF SUBTOTAL 1 [4]	20% $168,000
		MOBILIZATION @ 10% OF SUBTOTAL 1 [5]	10% $84,000
		CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1	10% $84,000
		SUBTOTAL 2	$1,200,000
		INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [6]	9.64% $115,700
		CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [7]	20% $200,000 / 30% $400,000
		TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [8]	**$1,500,000**
		TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [8]	**$1,700,000**

[1] One station is equal to 100 feet.
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[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.
[4] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[5] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[6] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[7] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[8] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION M-5
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
3RD LANE DEPRESSED MEDIAN						
EXCAVATION-UNCLASSIFIED	341.00	CUYD	$4.07	$1,387.87		$1,400
CRUSHED AGGREGATE COURSE	417.70	CUYD	$17.33	$7,238.74		$7,200
TOP SURF 3/4 IN GR 3B	32.60	CUYD	$27.90	$909.54		$900
COVER - TYPE 2	1,373.00	SQYD	$0.52	$713.96		$700
DUST PALLIATIVE	2.22	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	168.30	TON	$24.40	$4,106.52		$4,100
ASPHALT CEMENT PG 64-28	9.09	TON	$614.80	$5,588.53		$5,600
EMULS ASPHALT CRS-2P	2.33	TON	$512.76	$1,194.73		$1,200
GUTTER-CONC VALLEY	66.67	SQYD	$69.89	$4,659.57		$4,700
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
STORM DRAINAGE PER STATION	1.00	LS		$0.00	$200.00	$200
GUARD RAIL-CABLE	100.00	LNFT		$0.00	$14.00	$1,400
3RD LANE DEPRESSED MEDIAN SUBTOTAL				$26,019.27		$28,000
RAMPS - SINGLE 12' LANE						
CRUSHED AGGREGATE COURSE	77.80	CUYD	$17.33	$1,348.27		$1,300
TOP SURF 3/4 IN GR 3B	6.70	CUYD	$27.90	$186.93		$200
COVER - TYPE 2	133.00	SQYD	$0.52	$69.16		$100
DUST PALLIATIVE	0.22	TON		$0.00	$115.00	$0
PLANT MIX BIT SURF GR S-3/4 IN	34.30	TON	$24.40	$836.92		$800
ASPHALT CEMENT PG 64 64-28	1.85	TON	$614.80	$1,137.38		$1,100
EMULS ASPHALT CRS-2P	0.23	TON	$512.76	$117.93		$100
STRIPING-WHITE EPOXY	1.00	GAL	$54.71	$54.71		$100
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
RAMPS - SINGLE 12' LANE SUBTOTAL				$3,806.99		$3,800.00

CATEGORY	LENGTH (STA.)	COST PER STATION	SUBTOTAL
3RD LANE DEPRESSED MEDIAN	134.00	$28,000.00	$3,800,000
RAMPS - SINGLE 12' LANE LENGTH			
SOUTH 27TH STREET EB OFF-RAMP	3.50		
SOUTH BILLINGS WB OFF-RAMP	3.50		
TOTAL RAMP LENGTH	7.00	$3,800.00	$26,600

BRIDGE	LENGTH (FT.)	WIDTH (FT.)	COST PER SQUARE FOOT [4]	SUBTOTAL
SUGAR AVENUE				
SINGLE NORTH/SOUTH STRUCTURE	310.00	28.00	$150.00	$1,300,000
SUBTOTAL BRIDGE COST				$1,300,000

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION M-5
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
SUBTOTAL 1					$5,100,000	
ADDITIONAL COSTS						
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [5]					20%	$1,000,000
MOBILIZATION @ 10% OF SUBTOTAL 1 [6]					10%	$510,000
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1					10%	$510,000
SUBTOTAL 2						$7,100,000
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [7]					9.64%	$684,400
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [8]					20%	$1,400,000
					30%	$2,100,000
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [9]					**$9,200,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [9]					**$9,900,000**	

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[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.

[4] Planning level costs for simple bridge structures range on average between $110 and $150 per square foot. A conservative estimate of $150 per square foot was utilized for this structure.
[5] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[6] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[7] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[8] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[9] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION U-6
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
3RD LANE DEPRESSED MEDIAN						
EXCAVATION-UNCLASSIFIED	341.00	CUYD	$4.07	$1,387.87		$1,400
CRUSHED AGGREGATE COURSE	417.70	CUYD	$17.33	$7,238.74		$7,200
TOP SURF 3/4 IN GR 3B	32.60	CUYD	$27.90	$909.54		$900
COVER - TYPE 2	1,373.00	SQYD	$0.52	$713.96		$700
DUST PALLIATIVE	2.22	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	168.30	TON	$24.40	$4,106.52		$4,100
ASPHALT CEMENT PG 64-28	9.09	TON	$614.80	$5,588.53		$5,600
EMULS ASPHALT CRS-2P	2.33	TON	$512.76	$1,194.73		$1,200
GUTTER-CONC VALLEY	66.67	SQYD	$69.89	$4,659.57		$4,700
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
STORM DRAINAGE PER STATION	1.00	LS		$0.00	$200.00	$200
GUARD RAIL-CABLE	100.00	LNFT		$0.00	$14.00	$1,400
3RD LANE DEPRESSED MEDIAN SUBTOTAL						$28,000

CATEGORY	LENGTH (STA.)	COST PER STATION	SUBTOTAL
3RD LANE DEPRESSED MEDIAN	35.00	$28,000.00	$980,000
		SUBTOTAL 1	$980,000
		ADDITIONAL COSTS	
		MISCELLANEOUS @ 20% OF SUBTOTAL 1 [4]	20% $196,000
		MOBILIZATION @ 10% OF SUBTOTAL 1 [5]	10% $98,000
		CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1	10% $98,000
		SUBTOTAL 2	$1,400,000
		INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [6]	9.64% $135,000
		CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [7]	20% $300,000
			30% $400,000
		TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [8]	**$1,800,000**
		TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [8]	**$1,900,000**

[1] One station is equal to 100 feet.
[2] Average MDT bid prices provided for the period November 2010 to July 2011.
[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.
[4] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[5] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[6] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[7] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[8] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION M-6
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
3RD LANE DEPRESSED MEDIAN						
EXCAVATION-UNCLASSIFIED	341.00	CUYD	$4.07	$1,387.87		$1,400
CRUSHED AGGREGATE COURSE	417.70	CUYD	$17.33	$7,238.74		$7,200
TOP SURF 3/4 IN GR 3B	32.60	CUYD	$27.90	$909.54		$900
COVER - TYPE 2	1,373.00	SQYD	$0.52	$713.96		$700
DUST PALLIATIVE	2.22	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	168.30	TON	$24.40	$4,106.52		$4,100
ASPHALT CEMENT PG 64-28	9.09	TON	$614.80	$5,588.53		$5,600
EMULS ASPHALT CRS-2P	2.33	TON	$512.76	$1,194.73		$1,200
GUTTER-CONC VALLEY	66.67	SQYD	$69.89	$4,659.57		$4,700
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
STORM DRAINAGE PER STATION	1.00	LS		$0.00	$200.00	$200
GUARD RAIL-CABLE	100.00	LNFT		$0.00	$14.00	$1,400
3RD LANE DEPRESSED MEDIAN SUBTOTAL				$26,019.27		$28,000
RAMPS - SINGLE 12' LANE						
CRUSHED AGGREGATE COURSE	77.80	CUYD	$17.33	$1,348.27		$1,300
TOP SURF 3/4 IN GR 3B	6.70	CUYD	$27.90	$186.93		$200
COVER - TYPE 2	133.00	SQYD	$0.52	$69.16		$100
DUST PALLIATIVE	0.22	TON		$0.00	$115.00	$0
PLANT MIX BIT SURF GR S-3/4 IN	34.30	TON	$24.40	$836.92		$800
ASPHALT CEMENT PG 64 64-28	1.85	TON	$614.80	$1,137.38		$1,100
EMULS ASPHALT CRS-2P	0.23	TON	$512.76	$117.93		$100
STRIPING-WHITE EPOXY	1.00	GAL	$54.71	$54.71		$100
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
RAMPS - SINGLE 12' LANE SUBTOTAL				$3,806.99		$3,800

CATEGORY	LENGTH (STA)	COST PER STATION	SUBTOTAL
3RD LANE DEPRESSED MEDIAN	83.07	$28,000.00	$2,300,000
RAMPS - SINGLE 12' LANE LENGTH			
LOCKWOOD EB OFF-RAMP	4.50		
SOUTH 27TH STREET WB OFF-RAMP	3.00		
TOTAL RAMP LENGTH	7.50	$3,800.00	$28,500

BRIDGE	LENGTH (FT.)	WIDTH (FT.)	COST PER SQUARE FOOT [4]	SUBTOTAL
MT POWER RR SPUR				
EB STRUCTURE	148.00	56.00	$150.00	$1,200,000
WB STRUCTURE	148.00	56.00	$150.00	$1,200,000
SUBTOTAL BRIDGE COST				$2,400,000

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION M-6
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
SUBTOTAL 1					$4,700,000	
ADDITIONAL COSTS						
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [5]					20%	$900,000
MOBILIZATION @ 10% OF SUBTOTAL 1 [6]					10%	$470,000
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1					10%	$470,000
SUBTOTAL 2						$6,500,000
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [7]					9.64%	$626,600
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [8]					20%	$1,300,000
					30%	$2,000,000
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [9]					**$8,400,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [9]					**$9,100,000**	

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[2] Average MDT bid prices provided for the period November 2010 to July 2011.
[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.

[4] Planning level costs for simple bridge structures range on average between $110 and $150 per square foot. A conservative estimate of $150 per square foot was utilized for this structure.
[5] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[6] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[7] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[8] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[9] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION B-6
Planning Level Estimate of Costs

Bridge	Length (Ft.)	Width (Ft.)	Cost Per Square Foot [1]	Amount [2]	
YELLOWSTONE RIVER					
EB STRUCTURE	945.00	56.00	$200.00	$10,600,000	
WB STRUCTURE	930.25	56.00	$200.00	$10,400,000	
SUBTOTAL 1				$21,000,000	
ADDITIONAL COSTS					
MISCELLANEOUS @ 0% OF SUBTOTAL 1 [3]				0%	$0
MOBILIZATION @ 10% OF SUBTOTAL 1 [4]				10%	$2,100,000
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1				10%	$2,100,000
SUBTOTAL 2				$25,200,000	
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [5]				9.64%	$2,400,000
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [6]				20%	$5,000,000
				30%	$7,600,000
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [7]				**$32,600,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [7]				**$35,200,000**	

[1] Due to the complexity of constructing a multi-span structure over the Yellowstone River, to be conservative an estimate of $200 per square foot was utilized. This cost does not include enhanced design or aesthetic features associated with a signature bridge structure.

[2] Planning level costs may range between $150 and $200 per square foot. Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.

[3] Miscellaneous costs are assumed to be included within the per square foot cost.

[4] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.

[5] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.

[6] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.

[7] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION U-7
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
3RD LANE DEPRESSED MEDIAN						
EXCAVATION-UNCLASSIFIED	341.00	CUYD	$4.07	$1,387.87		$1,400
CRUSHED AGGREGATE COURSE	417.70	CUYD	$17.33	$7,238.74		$7,200
TOP SURF 3/4 IN GR 3B	32.60	CUYD	$27.90	$909.54		$900
COVER - TYPE 2	1,373.00	SQYD	$0.52	$713.96		$700
DUST PALLIATIVE	2.22	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	168.30	TON	$24.40	$4,106.52		$4,100
ASPHALT CEMENT PG 64-28	9.09	TON	$614.80	$5,588.53		$5,600
EMULS ASPHALT CRS-2P	2.33	TON	$512.76	$1,194.73		$1,200
GUTTER-CONC VALLEY	66.67	SQYD	$69.89	$4,659.57		$4,700
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
STORM DRAINAGE PER STATION	1.00	LS		$0.00	$200.00	$200
GUARD RAIL-CABLE	100.00	LNFT		$0.00	$14.00	$1,400
3RD LANE DEPRESSED MEDIAN SUBTOTAL						$28,000
ADDITIONAL EMBANKMENT	6,000.00	CUYD	$6.60	$39,600.00		$39,600

CATEGORY	LENGTH (STA.)	COST PER STATION	SUBTOTAL
3RD LANE DEPRESSED MEDIAN	35.00	$28,000.00	$980,000
		SUBTOTAL 1	$1,019,600

ADDITIONAL COSTS		
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [5]	20%	$203,900
MOBILIZATION @ 10% OF SUBTOTAL 1 [6]	10%	$102,000
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1	10%	$102,000
SUBTOTAL 2		$1,400,000
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [7]	9.64%	$135,000
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [8]	20%	$300,000
	30%	$400,000
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [9]	**$1,800,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [9]	**$1,900,000**	

[1] One station is equal to 100 feet.
[2] Average MDT bid prices provided for the period November 2010 to July 2011.
[3] Cost estimates are provided in 2011 dollars. All dollar amounts are rounded for planning purposes.

[4] Planning level costs for simple bridge structures range on average between $110 and $150 per square foot. A conservative estimate of $150 per square foot was utilized for this structure.
[5] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[6] The Mobilization category includes all costs incurred in assembling and transporting materials to the work site.
[7] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[8] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[9] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.

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BILLINGS AREA I-90 CORRIDOR PLANNING STUDY - OPTION M-7
Planning Level Estimate of Costs

Item Description	Approx. Quantity (Per Station) [1]	Unit	Average Bid Prices [2]		Adjusted Unit Prices	
			Unit Price	Amount	Unit Price	Amount [3]
			Dollars	Dollars	Dollars	Dollars
3RD LANE DEPRESSED MEDIAN						
EXCAVATION-UNCLASSIFIED	341.00	CUYD	$4.07	$1,387.87		$1,400
CRUSHED AGGREGATE COURSE	417.70	CUYD	$17.33	$7,238.74		$7,200
TOP SURF 3/4 IN GR 3B	32.60	CUYD	$27.90	$909.54		$900
COVER - TYPE 2	1,373.00	SQYD	$0.52	$713.96		$700
DUST PALLIATIVE	2.22	TON		$0.00	$115.00	$300
PLANT MIX BIT SURF GR S-3/4 IN	168.30	TON	$24.40	$4,106.52		$4,100
ASPHALT CEMENT PG 64-28	9.09	TON	$614.80	$5,588.53		$5,600
EMULS ASPHALT CRS-2P	2.33	TON	$512.76	$1,194.73		$1,200
GUTTER-CONC VALLEY	66.67	SQYD	$69.89	$4,659.57		$4,700
STRIPING-WHITE EPOXY	3.00	GAL	$54.71	$164.13		$200
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
STORM DRAINAGE PER STATION	1.00	LS		$0.00	$200.00	$200
GUARD RAIL-CABLE	100.00	LNFT		$0.00	$14.00	$1,400
3RD LANE DEPRESSED MEDIAN SUBTOTAL				$26,019.27		$28,000
RAMPS - SINGLE 12' LANE						
CRUSHED AGGREGATE COURSE	77.80	CUYD	$17.33	$1,348.27		$1,300
TOP SURF 3/4 IN GR 3B	6.70	CUYD	$27.90	$186.93		$200
COVER - TYPE 2	133.00	SQYD	$0.52	$69.16		$100
DUST PALLIATIVE	0.22	TON		$0.00	$115.00	$0
PLANT MIX BIT SURF GR S-3/4 IN	34.30	TON	$24.40	$836.92		$800
ASPHALT CEMENT PG 64 64-28	1.85	TON	$614.80	$1,137.38		$1,100
EMULS ASPHALT CRS-2P	0.23	TON	$512.76	$117.93		$100
STRIPING-WHITE EPOXY	1.00	GAL	$54.71	$54.71		$100
STRIPING-YELLOW EPOXY	1.00	GAL	$55.68	$55.68		$100
RAMPS - SINGLE 12' LANE SUBTOTAL				$3,806.99		$3,800

CATEGORY	LENGTH (STA.)	COST PER STATION	SUBTOTAL
3RD LANE DEPRESSED MEDIAN	111.00	$28,000.00	$3,100,000
RAMPS - SINGLE 12' LANE LENGTH			
JOHNSON LANE EB OFF-RAMP	4.75		
LOCKWOOD WB OFF-RAMP	3.00		
TOTAL RAMP LENGTH	7.75	$3,800.00	$29,500
		SUBTOTAL 1	$3,100,000

ADDITIONAL COSTS		
MISCELLANEOUS @ 20% OF SUBTOTAL 1 [4]	20%	$620,000
MOBILIZATION @ 10% OF SUBTOTAL 1 [5]	10%	$310,000
CONSTRUCTION ENGINEERING @ 10% OF SUBTOTAL 1	10%	$310,000
SUBTOTAL 2		$4,300,000
INDIRECT COST (IDC) - CONSTRUCTION @ 9.64% OF SUBTOTAL 2 [6]	9.64%	$414,500
CONTINGENCY @ 20% & 30% OF SUBTOTAL 2 [7]	20%	$900,000
	30%	$1,300,000
TOTAL IMPROVEMENT OPTION COST @ 20% CONTINGENCY [8]	**$5,600,000**	
TOTAL IMPROVEMENT OPTION COST @ 30% CONTINGENCY [8]	**$6,000,000**	

[1] One station is equal to 100 feet.
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[4] The Miscellaneous category is estimated at 20 percent due to unknown factors including but not limited to excavation, embankment, topsoil, guardrail, BMPs, utilities, lighting, traffic control, noxious weeds, slope treatments, ditch or channel excavation, incidental pavement transitional areas, temporary striping, temporary water pollution/erosion control measures and public relations.
[5] The Mobilization category includes all costs incurred in assembling and tranportating materials to the work site.
[6] Indirect costs are costs not directly associated with the construction of a project, but incurred during the construction processes. IDC percentage is subject to change.
[7] A contingency range of 20 to 30 percent was used due to the high degree of unknown factors over the planning horizon, as well as the substantial amount of items not accounted for in this planning level cost estimate.
[8] The Total Improvement Option Cost reflects an estimate of potential construction costs based on planning level estimates, and should not be considered an actual cost or encompassing all scenarios and circumstances.