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MEMORANDUM

Date:	**December 28, 2012**
To:	**Matt Wessell, Atkins**
cc:	**Long Nguyen, Mark Connelly, Sharlene Shadowen, James Flohr - CDOT**
From:	**David Woolfall, P.E., P.T.O.E.**
Project:	**North I-25, Crossroads to SH 14 Design**
Subject:	Updated **Double Crossover Diamond Evaluation at SH 14 and Prospect Interchanges**

Introduction

This technical memorandum provides an analysis of the Double-Crossover-Diamond (DCD) concept at the Mulberry (SH 14) and Prospect interchanges on I-25. The interchanges were identified for reconstruction as part of the North I-25 EIS, both as Standard Diamond Interchanges (SDI).

This memorandum has been updated from the October 29, 2012 version to include more information on pedestrian accommodations and more information about potential cost differences.

The Atkins/TSH team has begun preliminary design to implement the EIS concepts. During the preliminary design the required laneage, traffic forecasts, and traffic operations of the SDI at each location was evaluated. The traffic characteristics at these interchanges confirmed that DCDs may be well suited for these two interchanges. In general, the following characteristics of the two locations may make the DCD design a good alternative to the SDI:

- Both interchanges will be completely reconstructed in the future
- Traffic flow served by each interchange is primarily northbound-to-westbound (NB to WB) or eastbound-to-southbound (EB to SB). The greatest proportion of traffic at each interchange is turning, not through traffic, which is well suited to the DCD.
- The DCD design fits within the diamond interchange envelope evaluated and cleared by the EIS.
- The DCD design fits within the planned adjacent intersections on each crossroad.
- The DCD designs can achieve the same or better LOS as regular diamonds but with 15%-20% less bridge area at each location.

If the SDI concept advances to the Value Engineering stage near FIR, or if public/private partnership delivery is pursued in the project, the DCD will undoubtedly be brought forward as an alternative due to potentially lower costs. This analysis provides an opportunity for CDOT and the local jurisdictions to review the DCD concept prior to VE and possibly approve the DCD design as the primary alternative for the FIR plans.

A summary matrix that compares the attributes of the SDI and DCD concepts at both Mulberry and Prospect locations is shown in Table 1. The analysis categories where one interchange type is clearly superior to the other are highlighted in green.

Table 1 - Comparison Summary - SDI vs. DCD

	Standard Diamond Interchange (SDI)	Double-Crossover Diamond (DCD)
Total lanes on structure	**SH 14 / Mulberry = 10 lanes** **Prospect = 7 lanes**	**SH 14 / Mulberry = 8 lanes (3+5)** **Prospect = 6 lanes (3+3)**
Structure - other	Likely a single structure but could be done with two structures. Single structure needs to be done with phased construction. **Mulberry = 49,350 sf , Prospect = 40,950 sf**	Likely two structures – so phasing is simpler, some extra cost for double shoulders and double bridge rails. North structure can be at higher elevation to facilitate I-25 profile **Mulbry= 45,500 sf (-8%), Prospect= 37,100 sf (- 9.5%)**
Vertical Profile	Per Nov. 15th meeting, posted speed limit for overpasses will be 40mph, design speed for vertical crest will be 50mph. Longer crest vertical requires more earthwork, more ROW, more work on connecting local access ramps at Mulberry	DCD horizontal design requires 30 to 35mph curves at crossovers, vertical design can be lowered to 40 or 45mph crest vertical. Smaller vertical crest requires less earthwork, ties into existing sooner.
Signal Phasing	Standard 3-phase signals, protected lefts for all movements. Min. cycle length = about 80 sec. Prospect, 90 sec. Mulberry	2-phase signals, some lower volume left turn movements could be free-lefts . Min. cycle length = about 40 sec. Prospect, 50 sec. Mulberry
Signal Coordination	Likely full cycle lengths (100-120 seconds) needed during peak periods due to adjacent frontage road phasing	Interchange signals could half-cycle (50-60 seconds) even during peak periods, reducing queuing at interchange
Left turn geometry	Triple-lefts radius range from 80' to 120', which constrains left turning vehicles, especially trucks	Triple-lefts radius range from 155' to 200', less constrained so turning traffic moves at more constant speed, less path overlap for large trucks
Ramp geometrics	Desirable to bring ramp to intersection with crossroad at or near perpendicular. Requires more area/ROW for ramps	More flexibility with angle of ramp approaching crossroad, since all traffic turns the angle of ramp approach is more flexible. Reduces land area needed for interchange
Vehicle Queues	Peak hour left and right turn queues are longer since full signal cycles are used	Peak hour left and right turn queues are shorter at full cycle lengths due to two signal phases, and substantially shorter if half-cycles are used in signal timing
Transit	If transit stops are along the ramps, buses continue thru using standard signal phasing. EIS shows transit stops are away from interchange	If bus stops are on the ramps, special lane and signal phase required for thru bus movement. EIS shows transit stops are away from interchange
Maintenance	Snowplows often continue straight from ramp-to-ramp, which is accommodated at SDI	DCD would not allow a snowplow to continue straight from ramp-to-ramp. Special lane or drive-over island would need to be constructed, or plowing procedures revised
Bicycles	Right-hand lane adjacent to travel lanes per Ft. Collins preference	Right-hand lane adjacent to travel lanes per Ft. Collins preference. Should provide good striping thru wide intersct.
Pedestrians	Per Ft. Collins, 6 ft. sidewalks on eachside of the bridge with6 ft. separation from driving lane (bike lane). Decision for 40mph speed limit allows no barrier between walk & lanes	Option for single sidewalk (assume 8 ft.) along inside of one of the two bridges – between opposing traffic flows. Same separation of peds to traffic as SDI. More difficult to convey proper travel direction to visually impaired pedestrians due to angled/non-intuitive travel paths.
Safety - General	6 approach conflicts per intersection. More potential for higher-speed angled collisions. More potential for wrong-way turn onto freeway off-ramp.	4 approach conflicts per intersection at lower speeds due to geometry. Main intersection is skewed, but all traffic goes straight at skewed crossing. Wrong way turn onto freeway ramp virtually impossible.
Construction Phasing	Standard method, SDI with reduced lanes during construction.	Standard method, SDI with reduced lanes during construction, temporary paving thru gaps in arterial curves until DCD traffic control is ready to implement

The descriptions in Table 1 show that both interchange types will work at both locations. The comparison categories show that the DCD does have some clear and quantifiable advantages in several areas, including:

- Less bridge structure at each location, accounting for about $0.5 Million in savings at each location
- The DCD has an opportunity for reduced overall earthwork due to the potential lower design speed of the crest vertical curve. Reduction of about 60,000 cy at each interchange, savings of $300,000 to $500,000 per location.
- Better traffic operations in LOS, but greatly improved flexibility for traffic operations in both peak and off-peak by allowing half-cycling of signals, reducing overall delay and pedestrian delay.
- Better geometric characteristics and flexibility for accommodating the high turning volumes at each interchange.
- Improved safety for the DCD due to lower speeds, fewer conflict points, and reduced potential for wrong-way movements entering the freeway.

The primary issues noted with the DCD are in the areas of pedestrian accommodation and in snow removal maintenance. Final design for each of these issues could likely mitigate the concerns noted.

Traffic Analysis

The 2035 travel forecasts from the EIS (updated 2011 FEIS numbers) were used for the evaluation of the DCD concept and comparison to the SDI at each location. The 2035 peak hour traffic forecasts for each location are shown in **Figure 1**. Although the forecasts will likely be updated in the future, the existing traffic volumes and traffic forecasts show the traffic split approaching each interchange have predominant traffic flow serving a Fort Collins to South I-25 connection.

The EIS traffic analysis focused on the SDI at each location and showed that each SDI would achieve good LOS. The Mulberry interchange needs triple-lefts from NB to WB, and both Mulberry and Prospect have high EB to SB right turning traffic at the west ramp intersection, to the point where a 2nd right turn lane should be incorporated at each location.

The traffic volume figure shows 2035 traffic forecasts for the southern ramps at each interchange exceeding 2,000 vph per direction. For a comparison, the existing volumes at 120th and I-25 - a very busy interchange at the north end of Denver suburbs - do not exceed 1,500 vph for any ramp.

The laneage for each SDI and potential laneage for each DCD is shown in **Figure 2** for the SH 14/Mulberry interchange and **Figure 3** for the Prospect interchange. This is the laneage used to provide a comparison of intersection LOS and preliminary design geometrics at each ramp intersection with the crossroad. The intersection comparison LOS is shown in **Table 2**. This table also shows a comparison of vehicle queues at the two heaviest traffic movements at each interchange, which are the NB lefts and the EB rights. The traffic operations interaction along the arterial corridor is evaluated later in this memo.

As shown in the individual intersection results, the LOS results for the SDI and DCD are similar in most cases. The notable aspect is that the DCD achieves the same result with fewer lanes. In addition, the shorter intersection crossings for the DCD allow the DCD to use half-cycle phasing (50 or 60 seconds vs. 100 or 120 seconds). The half cycle phasing is particularly advantageous to reduce delay in the off-peak times. For the vehicle queues on the key movements, the DCD queuing is shorter in all scenarios, and substantially shorter when half-cycles are used for the signals.

Figure 1 - 2035 Peak Hour Traffic Forecasts

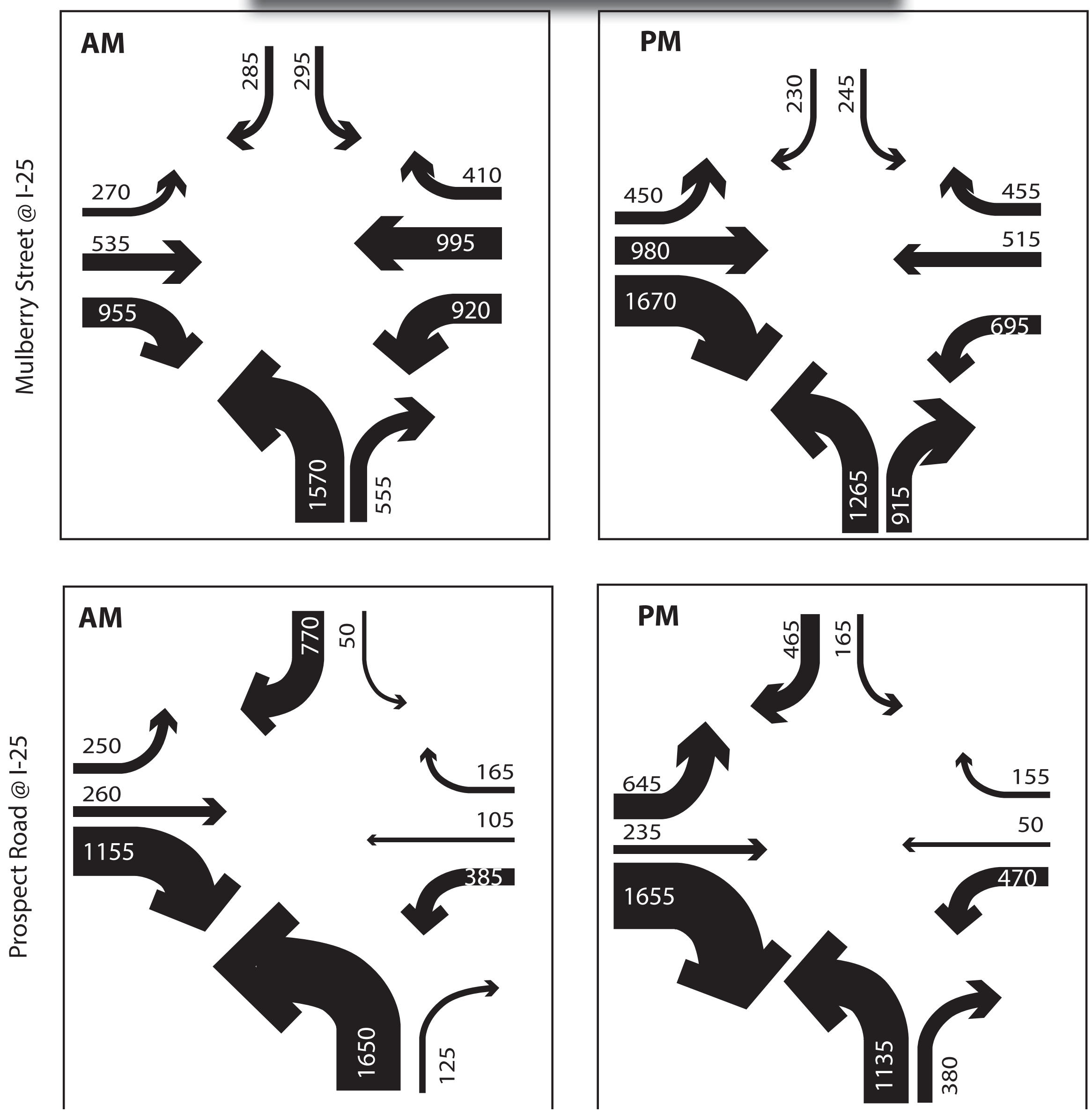

Figure 2 - 2035 Laneage - SH 14 / Mulberry

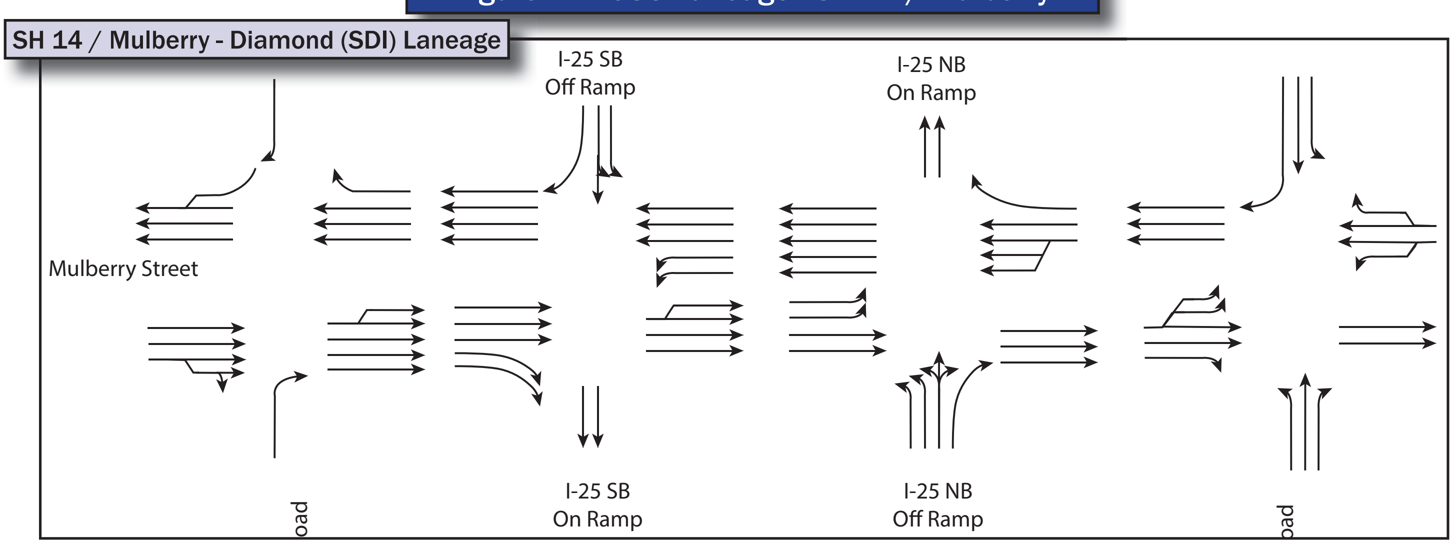

Figure 2 (continued) - 2035 Laneage - SH 14 / Mulberry

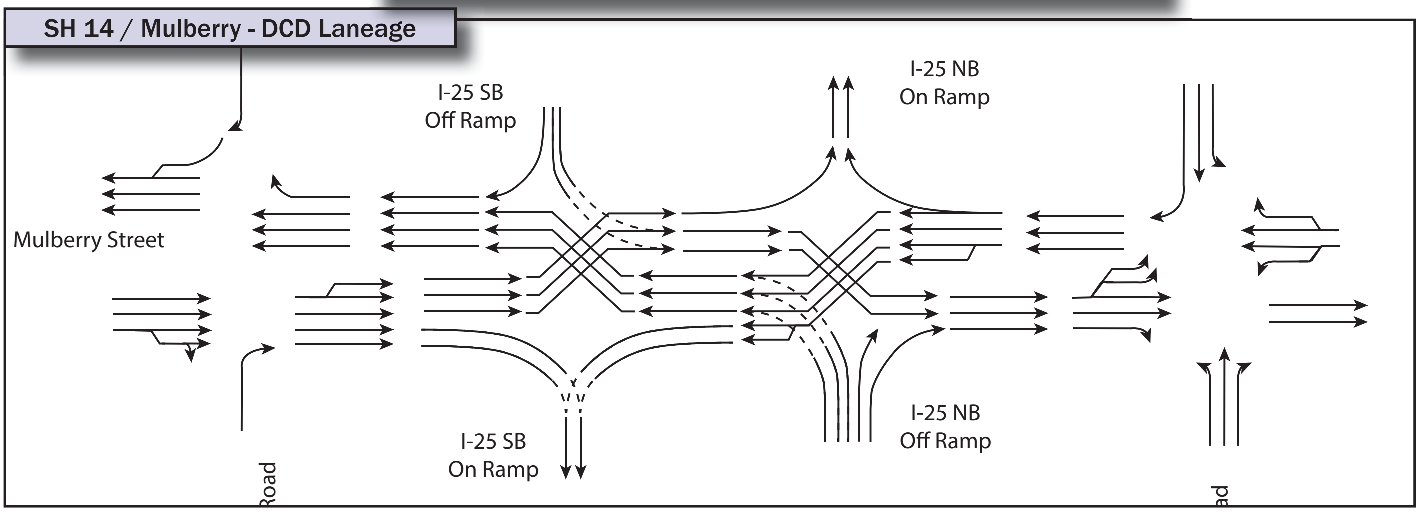

Figure 3 - 2035 Laneage - Prospect

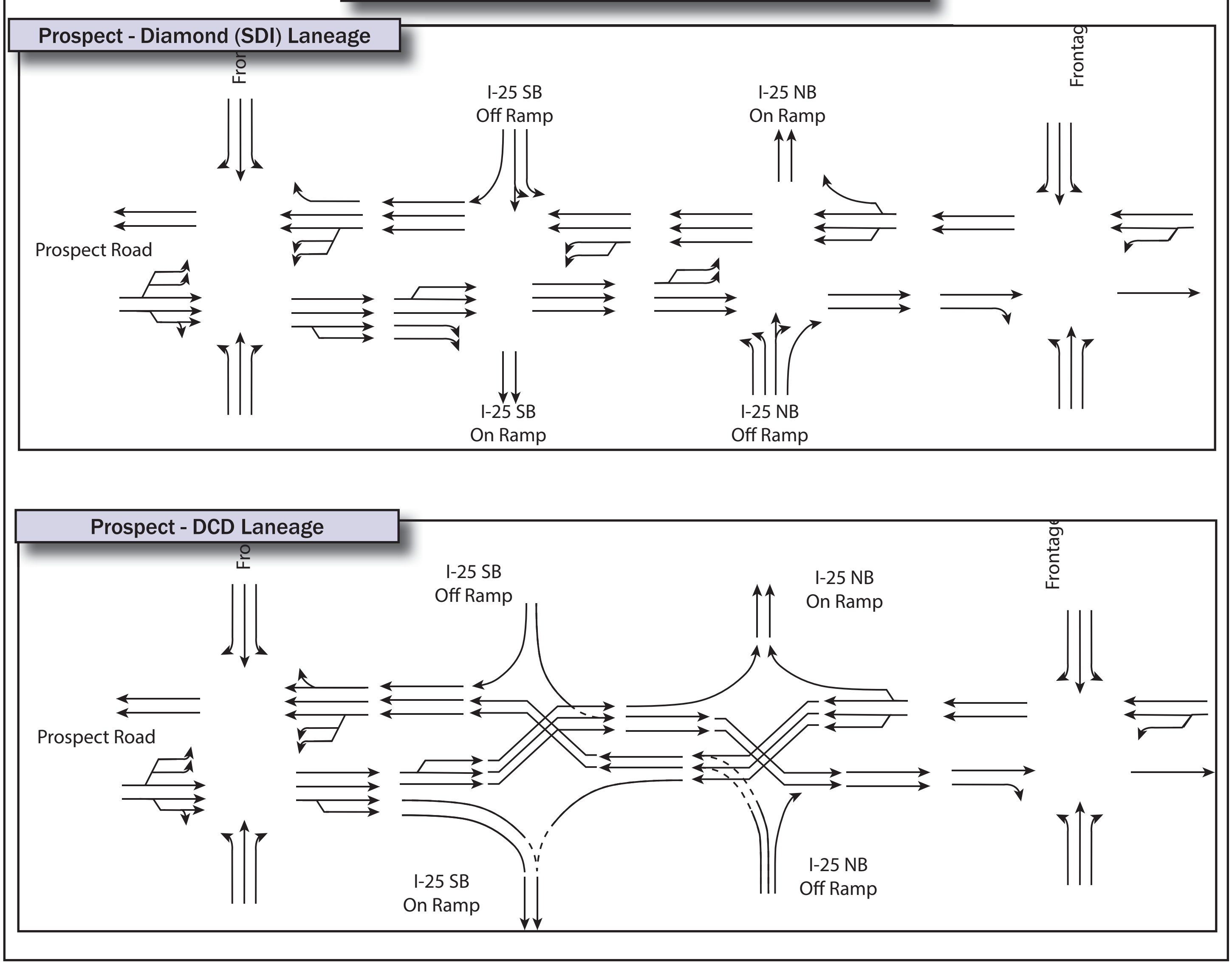

Table 2 - 2035 Level of Service Comparison

AM Peak, 2035

	SDI (120) [2] 95th % Queue. (ft)	SDI (120) [2] LOS (delay)	DCD (120) [2] 95th % Queue. (ft)	DCD (120) [2] LOS (delay)	DCD (60) [2] 95th % Queue. (ft)	DCD (60) [2] LOS (delay)
Mulberry Street/I-25						
East	NBL - 518	C (27.6) (1)	NBL - 427	B (14.2) (1)	NBL - 243	B (13.7) (1)
West	EBR - 456	C (24.5)	EBR - 290	C (20.5) (1)	EBR - 248	B (11.2) (1)
Prospect Road/I-25						
East	NBL - 754	C (32.4) (1)	NBL - 675	B (15.1) (1)	NBL - 507	B (14.9) (1)
West	EBR - 130	A (7.0)	EBR - 512	B (10.1) (1)	EBR - 303	A (7.1) (1)

FOOTNOTE:
(1) HCS 2000 LOS reported.
(2) Cycle Length (seconds)

PM Peak, 2035

	SDI (120) [2] 95th % Queue. (ft)	SDI (120) [2] LOS (delay)	DCD (120) [2] 95th % Queue. (ft)	DCD (120) [2] LOS (delay)	DCD (60) [2] 95th % Queue. (ft)	DCD (60) [2] LOS (delay)
Mulberry Street/I-25						
East	NBL - 383	C (20.5) (1)	NBL - 264	A (9.5) (1)	NBL - 150	A (8.7) (1)
West	EBR - 1056	D (40.8)	EBR - 728	B (17.5) (1)	EBR - 501	B (19.5) (1)
Prospect Road/I-25						
East	NBL - 573	C (34.7) (1)	NBL - 223	A (6.7) (1)	NBL - 223	A (7.1) (1)
West	EBR - 778	C (21.6)	EBR - 951	C (22.4) (1)	EBR - 599	D (37.8) (1)

FOOTNOTE:
(1) HCS 2000 LOS reported.
(2) Cycle Length (seconds)

Corridor operations and signal progression need to be considered with both the SDI and DCD designs. Synchro was used to provide initial optimization of system operations, which was then translated to progression diagrams to compare the operations of the SDI and the DCD. These preliminary time-space diagrams are shown in the appendix. The signal phasing with each DCD concept is shown on the time-space diagram. Time space diagrams were prepared for SDI with 120 second cycles, DCD with 120 second cycles, and DCD with 60 second cycles. In general, the progression band for the key traffic movements is the same for the SDI and the DCD when measured as a percentage of total cycle length.

Table 3 below shows a comparison of system operations on each arterial as calculated by a Simtraffic simulation. The signal timing parameters were optimized by the computer to attempt to show an unbiased comparison of performance measures. Preliminary time-space progression diagrams based on the simulations are contained in the Appendix. The results are similar to the LOS results in that performance measures are nearly the same or better for most scenarios with the DCD, and the opportunity for shorter cycle lengths with the DCD offers the best operations in all cases.

Table 3 - 2035 Measures of Effectiveness Comparison

North I-25 Interchange Alternatives under Evaluation at Mulberry

	AM Peak			PM Peak		
Measure of Effectiveness	SDI [1]	DCD (120) [1]	DCD (60) [1]	SDI [1]	DCD (120) [1]	DCD (60) [1]
Total Delay (hr)	36.9	31.5	26	35.6	23.8	17.3
Total Delay/Veh (S)	392.8	347.5	336.6	406.7	388.7	325.4
Total Stops	2352	1752	1981	2647	1537	1699
Travel Time (hr)	51.6	44.2	38.6	49.7	45.6	44.6
Fuel Used (gal)	25	23	21.8	25.5	23.2	23.5

North I-25 Interchange Alternatives under Evaluation at Prospect

	AM Peak			PM Peak		
Measure of Effectiveness	SDI [1]	DCD (120) [1]	DCD (60) [1]	SDI [1]	DCD (120) [1]	DCD (60) [1]
Total Delay (hr)	16.2	16.6	15.5	19	21.2	17
Total Delay/Veh (S)	360.2	335.2	299.4	385.6	286.7	334
Total Stops	1067	1125	1016	1735	1776	1483
Travel Time (hr)	26.9	28.7	28.6	33	36.4	28.9
Fuel Used (gal)	14.7	16.4	14.8	17.1	19.2	16.9

FOOTNOTE:

(1) Cycle Length (seconds)

Pedestrians and Bicycles

Pedestrian and bicycle accommodations at a DCD are not very different than at an SDI. Based on the November 15, 2012 meeting with the City of Ft. Collins, on-street bike lanes are preferred on each arterial and carrying through the interchange. At an SDI, the bicycle lanes are essentially straight and remain alongside the right-hand through lane through the interchange. The same is true for a DCD, the on-street bike lane continues alongside the right-hand through lane as the through lanes criss-cross at each side of the interchange. For this reason, there are no notable differences to document for bicycle lanes for either the SDI or the DCD.

The pedestrian accommodation at an SDI was assumed to be 6 ft. attached sidewalks along each side of the bridge over I-25. The route for pedestrians is generally straight with the exception of crossing the right turn lanes at about 45 degree angles. At a DCD the pedestrian route over I-25 can be similar except that there would be twice as many angled crossings (4 per direction) due to the geometrics of the ramp intersections.

The DCD offers the opportunity to install a single sidewalk across I-25, between the opposing lanes of traffic (see the bridge cross section options). This option for pedestrian accommodation still results in the same exposure to adjacent traffic as the SDI, but may increase the amount of traffic volume a pedestrian must cross since all pedestrians would cross the through lanes. Careful design and possibly signing to delineate the intended pedestrian path would also be required since this pedestrian route may not be intuitive to all users.

Pedestrian route options at the DCD are shown in the preliminary interchange layouts.

Preliminary Interchange Geometry

The DCD design requires the arterial lanes to "criss-cross" each other at approximately the ramp intersection location. This generally requires a lower design speed for the arterial, in the range of 30 to 35mph, which results in a similar footprint as an SDI. Using higher design speeds is possible but may widen the earthwork and ROW footprint, and may require the arterial curves to extend onto the bridge.

DCDs for the Mulberry and Prospect interchanges were preliminarily designed for DCDs using 35mph crossroad design speeds. This is an early iteration of design intended to bring forth discussion of the concept and questions. The design will evolve after determining details such as arterial lane balance, phased implementation potential, and location and width of bicycle and pedestrian facilities.

One important modification shown for both SDIs and the DCDs is the need for a 2nd EB to SB right turn lane at each interchange due to extremely high right turn volume. The right turn volumes exceeding 1,500 vph are similar to those at Lincoln and I-25 in south Denver (1,800 vph AM, 1,600 vph PM) and several other locations in Denver including:

- Arapahoe Road and I-25.
- Park Avenue West/Fox St. to I-25
- 20th Street to I-25
- Wadsworth to I-70/I-76

The double right turn lanes should be planned to have signal control to facilitate pedestrian crossings and to meter the conflict between the EB to SB double-rights and the WB to SB double lefts. This approach has the advantage of keeping the on-ramp a maximum of two lanes, which makes the merge prior to the mainline easier to accomplish.

The preliminary layouts for both the DCDs and SDIs are shown in the attached figures, with notes added for particular items of interest for each interchange.

Phased Implementation

The 2035 traffic forecasts in most cases represent a doubling of the traffic volume from existing conditions. The 2035 forecasts require items such as signalized double-rights at each interchange or triple-lefts at the SH 14 interchange. There are opportunities at both interchanges and with either the SDI or DCD concept to design for phased implementation of these higher number of turn lanes. Triple left turns do not need to be implemented immediately, double left turns probably work for up to 20 years of the design life. Similarly, the double-rights are not needed immediately, single rights (free-flow) also probably work for 10-15 years of the project design life.

At this current level of design it is important that the maximum interchange template is designed so that appropriate right-of-way can be acquired. Phased implementation of laneage can be considered post-FIR as more information is learned and in anticipation of updated travel forecasts.

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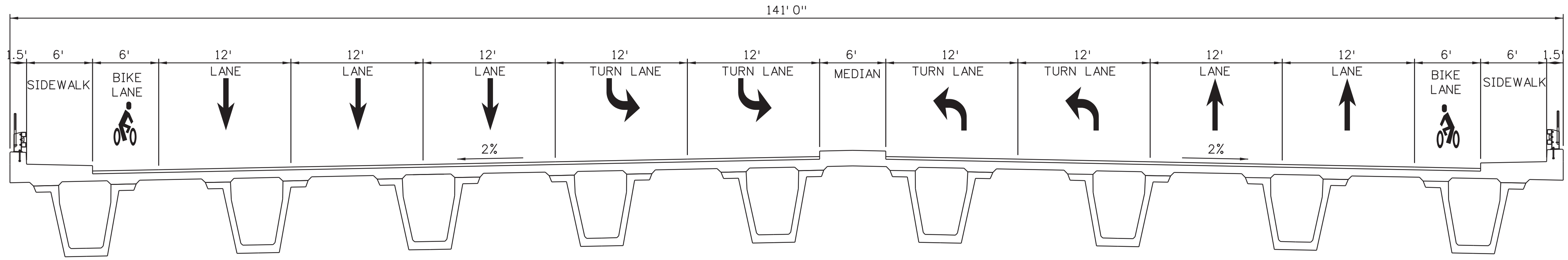
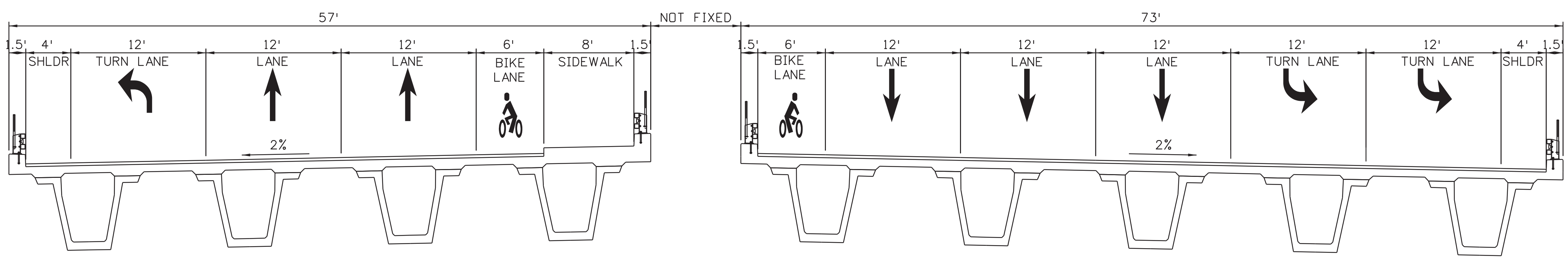
Cross Section Comparisons - Mulberry Interchange

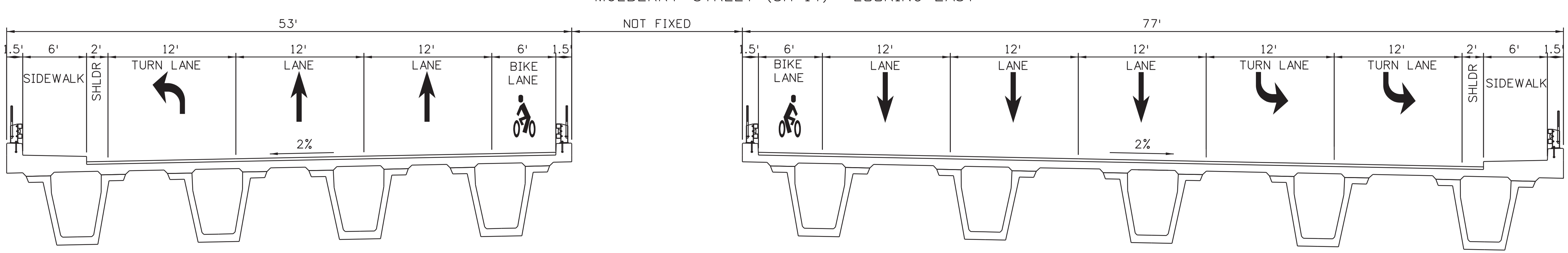
DIAMOND INTERCHANGE TYPICAL SECTION
PER FT. COLLINS MEETING 11/15/2012
BIKE LANES AND ATTACHED SIDEWALK
MULBERRY STREET (SH 14) - LOOKING EAST



DIVERGING DIAMOND INTERCHANGE TYPICAL SECTION
MULBERRY STREET (SH 14) - LOOKING EAST



DIVERGING DIAMOND INTERCHANGE TYPICAL SECTION
MULBERRY STREET (SH 14) - LOOKING EAST



Preliminary Layout - Standard Diamond at I-25 and SH 14

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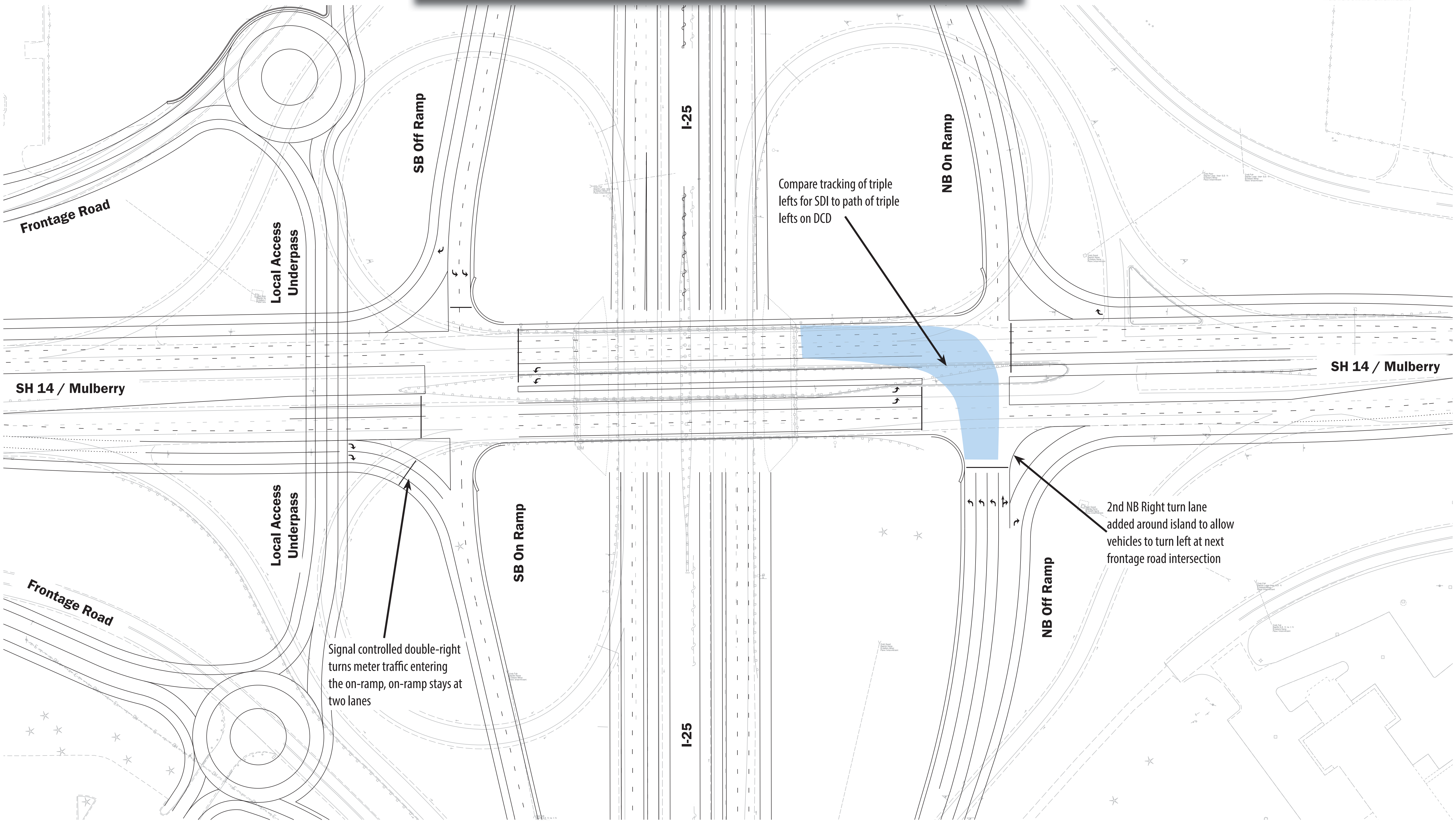
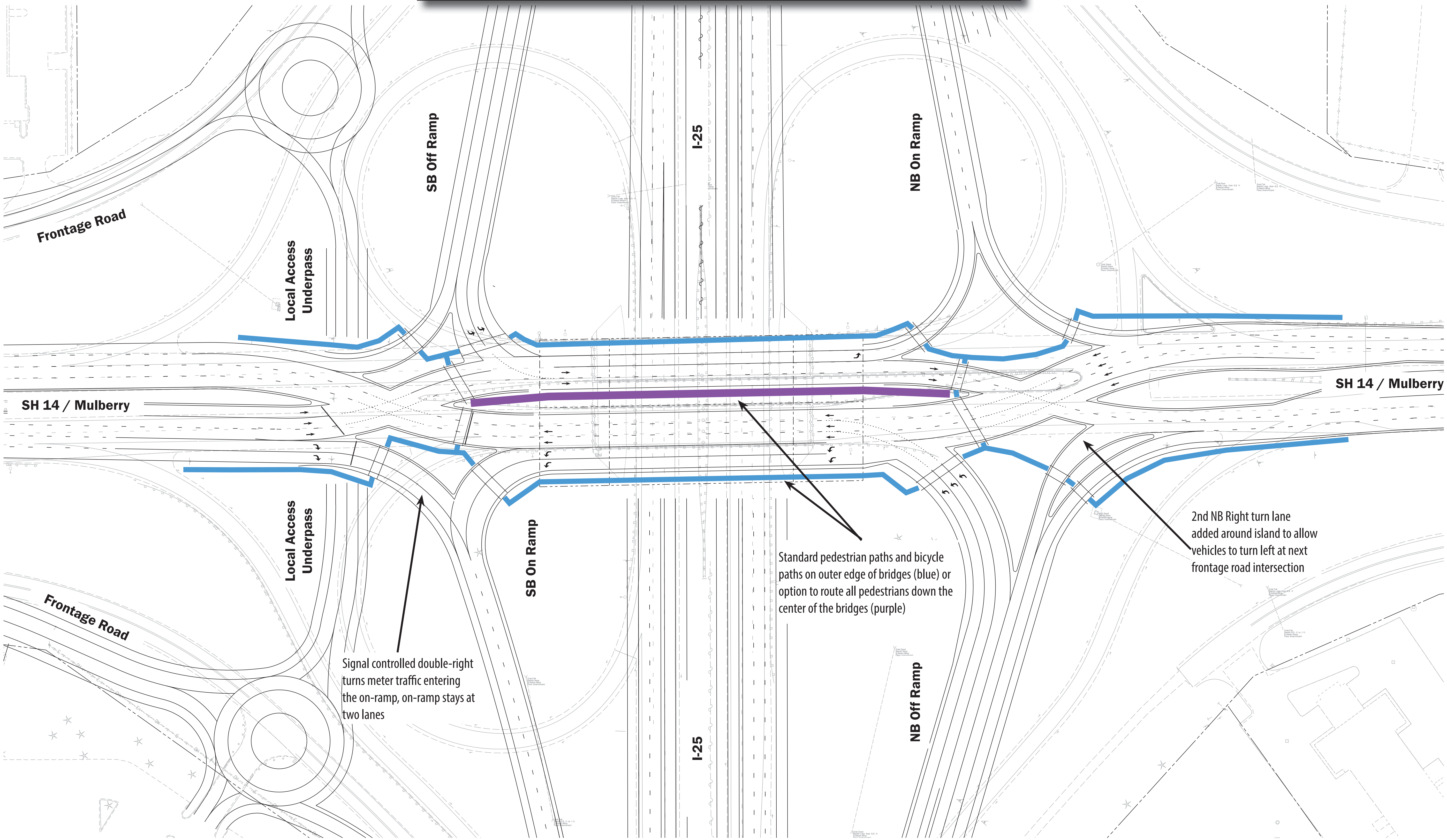


Preliminary Layout - Double Crossover Diamond at I-25 and SH 14



Cross Section Comparisons - Prospect Interchange

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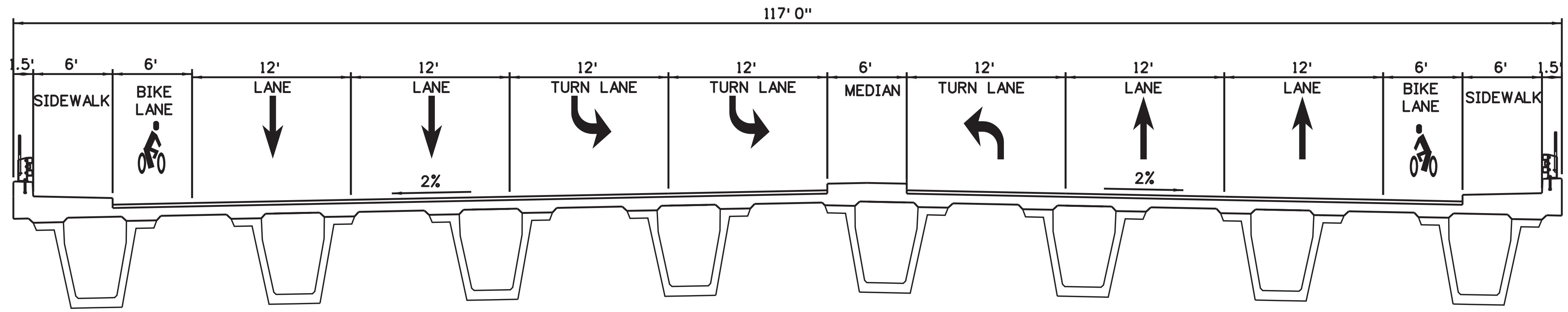
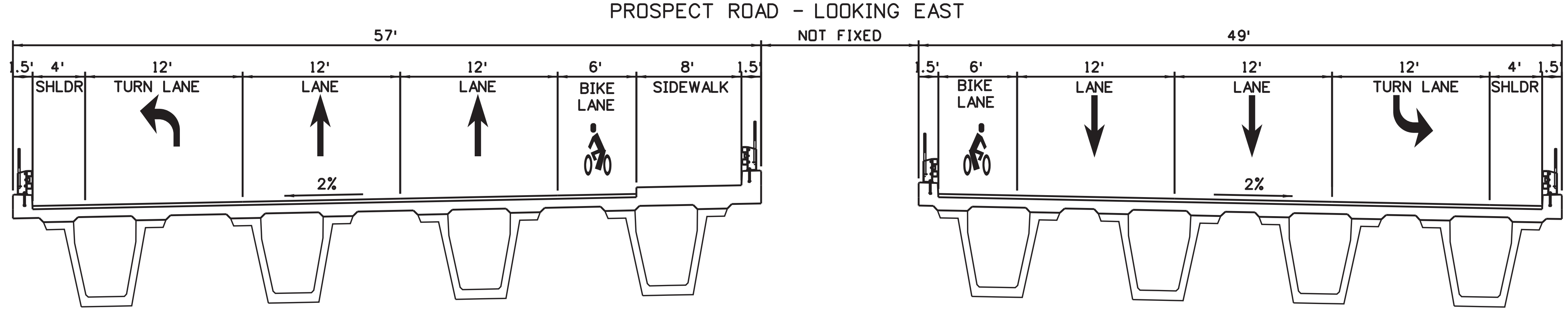
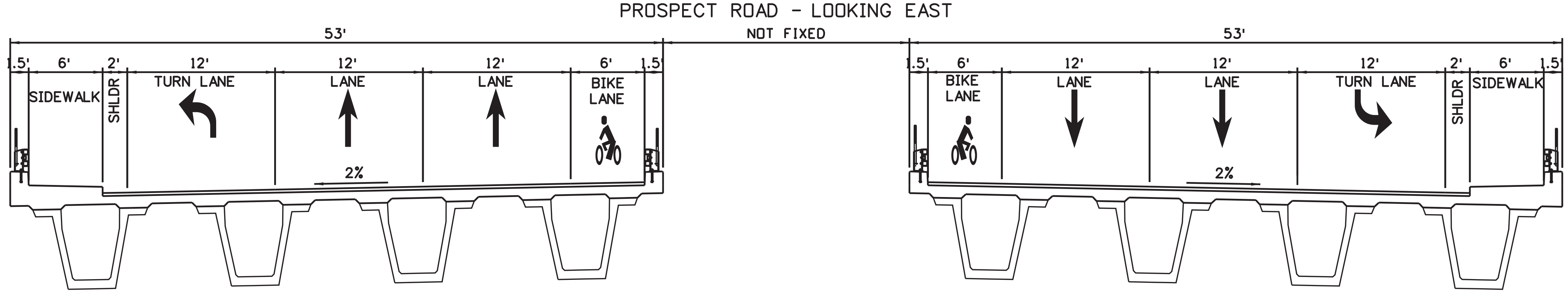
DIAMOND INTERCHANGE TYPICAL SECTION
PER FT. COLLINS MEETING 11/15/2012
BIKE LANES AND ATTACHED SIDEWALK
PROSPECT ROAD - LOOKING EAST



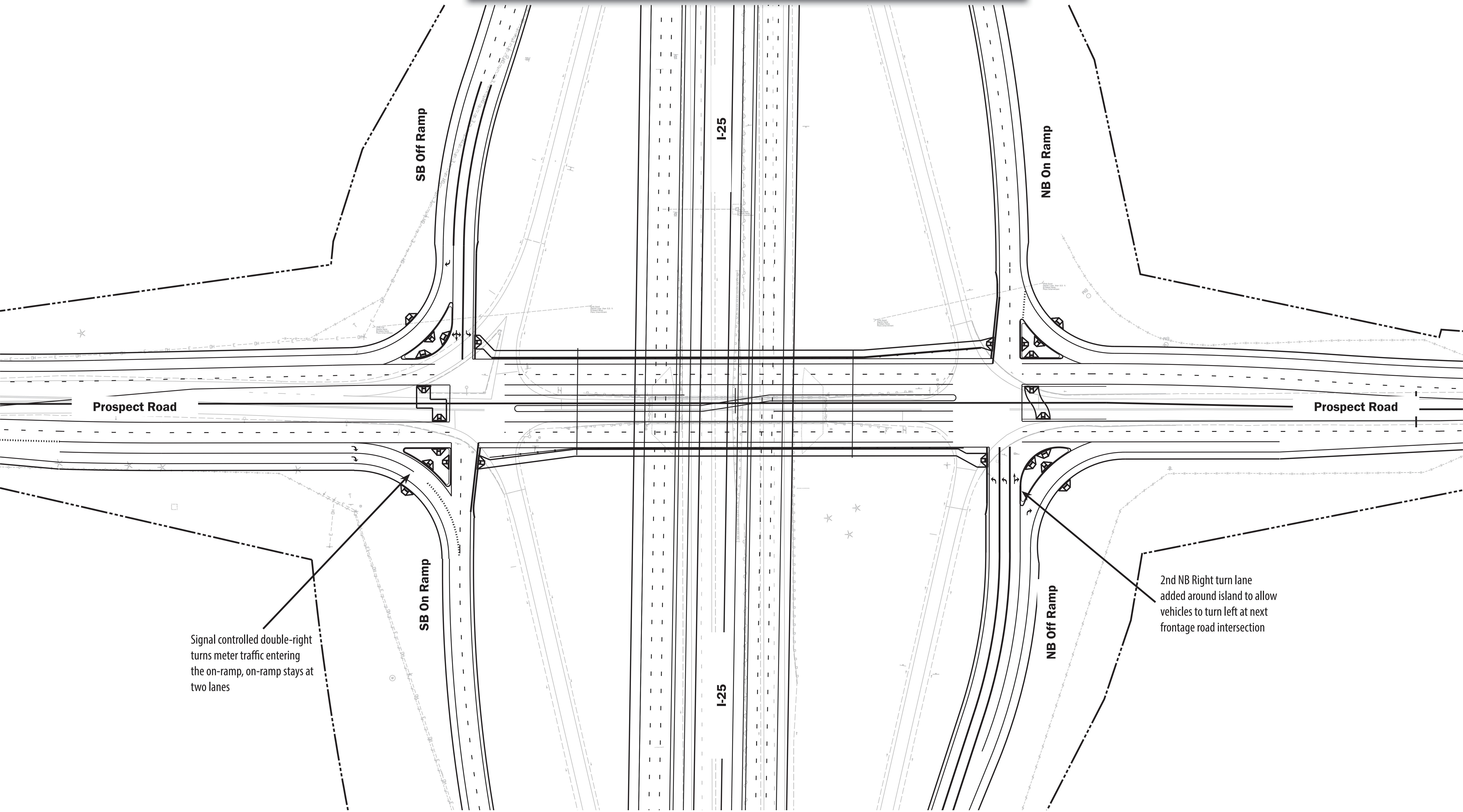
DIVERGING DIAMOND INTERCHANGE TYPICAL SECTION
SIDEWALK INSIDE
PROSPECT ROAD - LOOKING EAST



DIVERGING DIAMOND INTERCHANGE TYPICAL SECTION
SIDEWALK OUTSIDE
PROSPECT ROAD - LOOKING EAST



Preliminary Layout - Standard Diamond at I-25 and Prospect



Preliminary Layout - Double Crossover Diamond at I-25 and Prospect

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