TECHNICAL MEMORANDUM #2

DATE: October 17, 2019

Kittelson #: 20783
MDT #: 110591

TO: Wade Salyards, PE Montana Department of Transportation

FROM: Andy Daleiden, PE, Mark Heisinger, EIT, and Krista Purser, EIT – Kittelson & Associates, Inc.

PROJECT: Exposition Dr & 1st Ave N - Billings - NH 16-1(53)0, UPN 7908000

SUBJECT: Tier 1 Alternatives Evaluation and Screening

Introduction

This memorandum addresses the Tier 1 alternatives evaluation and screening for the Exposition Drive / 1st Avenue North intersection in Billings, MT. This report presents preliminary concept designs for the Tier 1 alternatives, discusses their evaluation, summarizes the PAC Meeting #2 results, and identifies which alternatives will be moved forward for the Tier 2 analysis.

PROJECT AREA

Located in Yellowstone County, within the Billings city limits, the Exposition Drive / 1st Avenue North intersection is located 1.3 miles northeast of downtown Billings and just southwest of MetraPark. This intersection resides on the Camino Real International Trade Corridor that connects Canada, United States, and Mexico, and is a critical junction that provides local and regional connectivity to downtown Billings, US 87, Highway 3, and Interstate 90. Figure 1 illustrates the project location within Billings and Yellowstone County. The eastern project limits end at the Dick Johnston Bridge which crosses the Yellowstone River and provides access to Interstate 90. A Montana Rail Link (MRL) railroad facility is located to the south of the study area and runs parallel to 1st Avenue North and US 87 over the Yellowstone River.

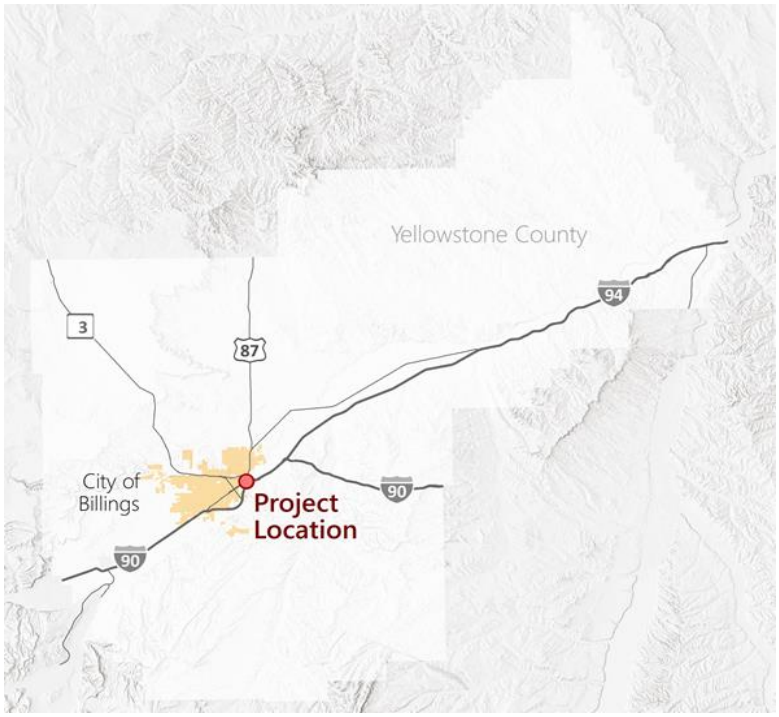


Figure 1 Project Vicinity Map

ALTERNATIVES DEVELOPMENT AND SCREENING PROCESS

The project team is applying a tiered process to developing and screening the intersection alternatives. The project team identified 16 initial options ranging from conventional intersection form to alternative intersections to grade-separated to system changes through new connections. The project team presented the 16 initial alternatives and evaluation results to the Project Advisory Committee (PAC), MDT, and Yellowstone County Commission in June, July, and August 2019. Through this discussion, the project team selected six alternatives to advance to Tier 1. Figure 2 illustrates the overall alternatives development and screening process for the project.

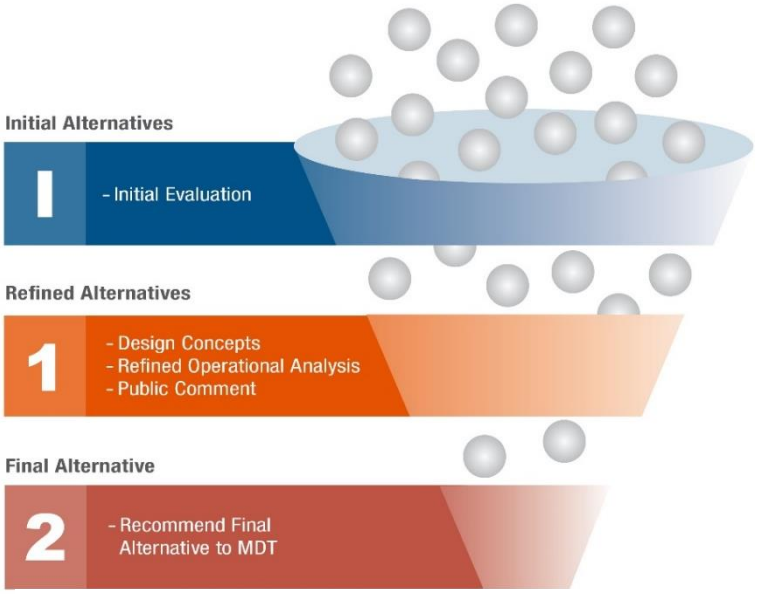


Figure 2 Alternatives Development and Screening Process

Tier 1 Alternatives and Evaluation

The Tier 1 analysis evaluates six alternatives, shown in Figures 3 through 8. As shown, the alternatives are:

- **Alternative 1 - No-Build**
  - Existing infrastructure remains in-place.
  - Potential signal timing adjustments, but no equipment changes
- **Alternative 2 - Westbound Shared Left/Right-Turn Lane**
  - Converts one of the existing westbound left-turn lanes into a shared left/right-turn lane and brings northbound right-turn lane through traffic signal at the Exposition Drive/1st Avenue N intersection
  - Adds pedestrian crossings to east and south legs of Exposition Drive/1st Avenue N
  - Realigns pedestrian crossing on the south leg of the Exposition Drive/4th Avenue N intersection to decrease crossing distance
  - Provides pathway on west side of Exposition Drive between 3rd Avenue N and 4th Avenue N and sidewalks elsewhere
- **Alternative 3 - Single Westbound Left-Turn Lane and Dual Westbound Right-Turn Lanes**
  - Converts one of the existing westbound left-turn lanes into a right-turn lane and brings northbound right-turn lane through traffic signal at the Exposition Drive/1st Avenue N intersection
  - Adds pedestrian crossings to east and north legs of Exposition Drive/1st Avenue N
  - Realigns pedestrian crossing on the south leg of the Exposition Drive/4th Avenue N intersection to decrease crossing distance
  - Provides pathway on west side of Exposition Drive between 3rd Avenue N and 4th Avenue N and sidewalks elsewhere

- **Alternative 4 - Free Westbound Right-Turn Lane**
  - Converts existing westbound right-turn lane into a free right-turn lane and brings northbound right-turn lane through traffic signal at the Exposition Drive/1st Avenue N intersection
  - Provides 4th northbound lane on Exposition Drive between 1st Avenue N and 4th Avenue N, which becomes the right-turn lane at 6th Avenue N
  - Adds pedestrian crossings to east and north legs of Exposition Drive/1st Avenue N
  - Realigns pedestrian crossing on the south leg of the Exposition Drive/4th Avenue N intersection to decrease crossing distance
  - Provides pathway on west side of Exposition Drive between 3rd Avenue N and 4th Avenue N and on the east side of Exposition Drive, provides sidewalks elsewhere
  - Provides pathway connection on north or south sides of 1st Avenue N from Exposition Drive to Jim Dutcher Trail
- **Alternative 5 - Dual Westbound Right-Turn Lanes**
  - Provides second westbound right-turn lane and brings northbound right-turn lane through traffic signal at the Exposition Drive/1st Avenue N intersection
  - Adds pedestrian crossings to east and north legs of Exposition Drive/1st Avenue N
  - Realigns pedestrian crossing on the south leg of the Exposition Drive/4th Avenue N intersection to decrease crossing distance
  - Provides pathway on west side of Exposition Drive between 1st Avenue N and 4th Avenue N and sidewalks elsewhere
  - Provides pathway connection on north or south sides of 1st Avenue N from Exposition Drive to Jim Dutcher Trail
- **Alternative 6 - Partial Displaced Left-Turn**
  - Provides partial displaced left-turn intersection, including a free westbound right-turn lane
  - Adds new signal at Exposition Drive/3rd Avenue N for cross-over
  - Brings Exposition Drive/1st Avenue N northbound right-turn lane through traffic signal
  - Adds pedestrian crossings to the south leg of Exposition Drive/1st Avenue N
  - Realigns Exposition Drive/4th Avenue N Intersection's south leg crossing to decrease crossing distance
  - Provides pathway on west side of Exposition Drive between 1st Avenue N and 4th Avenue N and sidewalks elsewhere
  - Provides pathway connection on south side of 1st Avenue N from Exposition Drive to Jim Dutcher Trail

EVALUATION RESULTS

The following describes the evaluation methodology implemented in the tiered approach. Each of the alternatives was evaluated based on the following criteria:

- **Safety Performance** – Is the alternative improving congested conditions? Are queues being reduced to reduce the potential for rear-end crashes?
- **Number of Free Right-Turns** – Are pedestrians required to cross a free right-turn lane? What's the potential for speed differentials or merging operations downstream?
- **Pedestrian Facility Quality** – What type of pedestrian facilities are provided? What's the quality of the pedestrian crossings at study area intersections?

- **Bicycle Facility Quality** – What type of bicycle facilities are provided? What's the quality of the bicycle crossings at study area intersections?
- **Traffic Operations (2040 AM/PM Peak Hour Level of Service)** – What level of service (LOS) will the intersection experience under 2040 conditions? Are queues reduced for the critical movements (e.g. westbound right-turn lane)?
    - *Future AM and PM peak hour operations worksheets are included in Appendix A and Appendix B, respectively*.
- Traffic Operations Lifespan (After 2040) – How long after 2040 will the intersection remain under capacity (intersection volume-to-capacity ratio of less than 1.0)?
- Right-Of-Way Impact – Relatively how much property is impacted?
- Number of Properties Impacted – How many properties are impacted?
- Design and Construction Cost Estimates – What's the relative cost between alternatives?

Table 1 (on the next page) compiles the evaluation results for each of the alternatives. Alternatives 2 and 3 remain mostly within existing right-of-way, resulting in lower property impacts and lower costs. However, these also provide the least operational improvement and over capacity operations in the year 2040. Alternatives 4 and 5 have moderate property impacts and costs and provide acceptable operations for another 8-12 years after 2040. Alternative 6 has the most property impacts and costs but provides acceptable operations for 16-20 years after 2040. Alternatives 4, 5, and 6 provide the most complete pedestrian and bicycle connectivity through pathways, detached sidewalks, and additional and/or enhanced pedestrian crossings at the signals. If desired, a phased approach could be considered for the intersection project, where Alternatives 4 or 5 could be implemented in the short-term followed by Alternative 6 in the long-term.

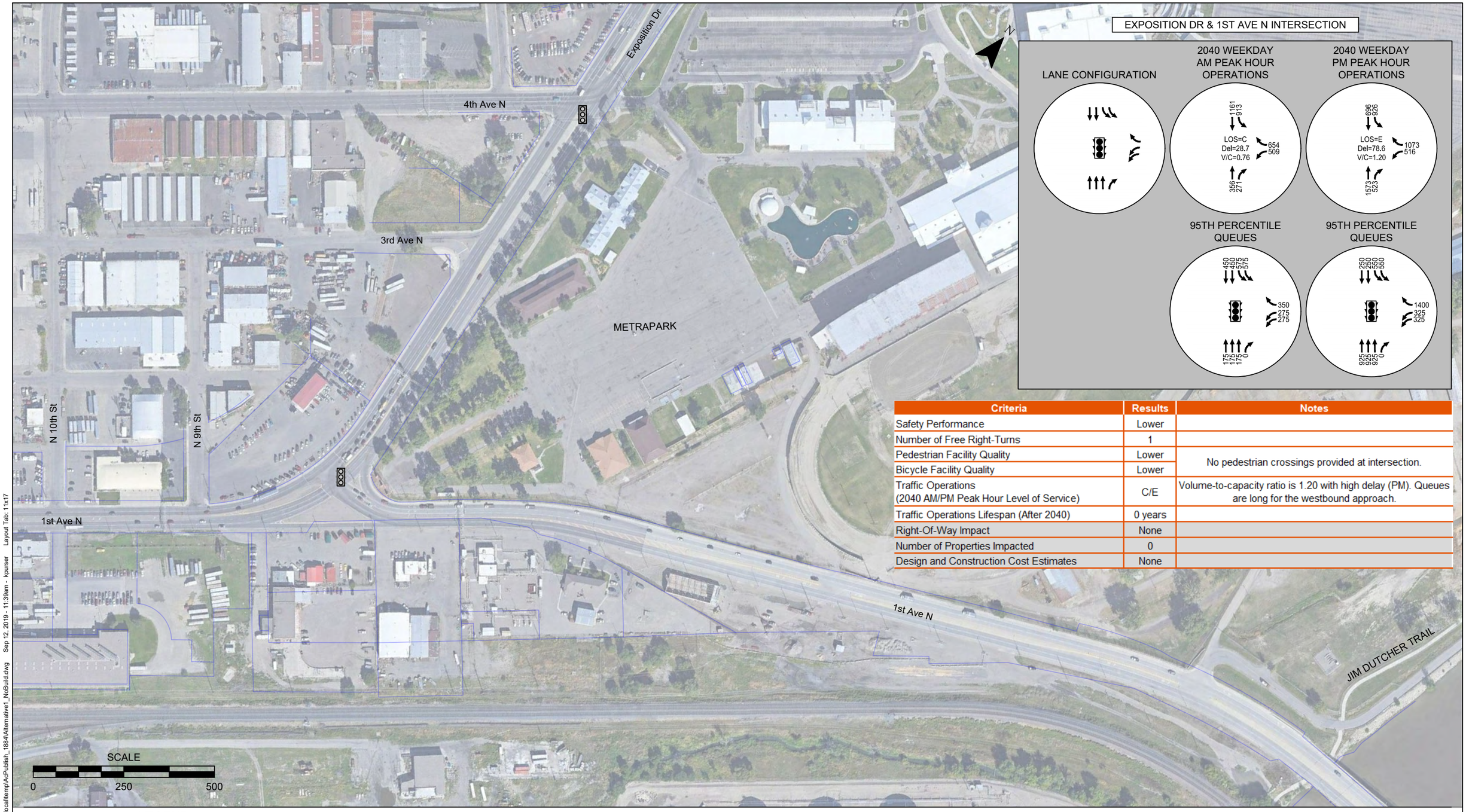
Based on this technical evaluation, the project team recommends that Alternatives 4 and 5 be advanced to Tier 2 given their good operations compared to all alternatives, higher quality pedestrian and bicycle facilities compared to all alternatives, and lower costs and property impacts than Alternative 6.

Table 1. Alternatives Evaluation

Criteria		Safety Performance	Number of Free Right-Turns	Pedestrian Facility Quality	Bicycle Facility Quality	Traffic Operations (2040 AM/PM Peak Hour LOS[1])	Traffic Operations Lifespan (After 2040)	Right-Of-Way Impact	Number of Properties Impacted	Design and Construction Cost Estimates
Alternative	1	Lower	1	Lower	Lower	C/High delay E	0 years	None	0	None
		No pedestrian or bicycle crossings provided at intersection. Volume-to-capacity ratio is 1.20 with high delay (PM). Queues are long for the westbound approach.								
	2	Medium	0	Medium	Medium	C/Low delay E	0 years	Lower	7	Lower
		South leg crossing requires two phases. Limited sidewalk/pathway improvements. Volume-to-capacity ratio is 1.06 with medium delay (PM). Queues are less for the westbound approach.								
	3	Medium	0	Medium	Medium	C/Low delay E	0 years	Lower-to-Medium	8	Lower
		Limited sidewalk/ pathway improvements. Volume-to-capacity ratio is 1.07 with medium delay (PM). Queues are longer for the westbound left-turn lane.								
	4	Medium	1	Higher	Higher	C/D	8-12 years	Medium-to-Higher	13	Medium
		Requires crossing at free right-turn. Provides pathway connection to Jim Dutcher Trail. Volume-to-capacity ratio is 0.90 (PM). Queues are less for the westbound approach.								
	5	Medium	0	Higher	Higher	C/D	8-12 years	Medium	13	Medium
		Provides crossings and several multi-use path options. Provides pathway connection to Jim Dutcher Trail. Volume-to-capacity ratio is 0.90 (PM). Queues are significantly less for the westbound approach.								
	6	Medium	1	Medium-to-Higher	Medium-to-Higher	B/B	16-20 years	Higher	13	Higher
		No crossing provided on east leg of intersection. Pedestrian and bicycle crossing on south leg potentially requires two phases. Provides pathway connection to Jim Dutcher Trail. Volume-to-capacity ratio is 0.82 (PM). Queues are significantly less for the westbound approach.								

[1]Level of Service – Indicates the average level of vehicle delay at an intersection. Calculated with HCM 6th Edition Methodology.

Orange shading represents the Tier 1 Alternatives selected for further analysis in Tier 2.



Criteria	Results	Notes
Safety Performance	Lower	
Number of Free Right-Turns	1	
Pedestrian Facility Quality	Lower	No pedestrian crossings provided at intersection.
Bicycle Facility Quality	Lower	
Traffic Operations (2040 AM/PM Peak Hour Level of Service)	C/E	Volume-to-capacity ratio is 1.20 with high delay (PM). Queues are long for the westbound approach.
Traffic Operations Lifespan (After 2040)	0 years	
Right-Of-Way Impact	None	
Number of Properties Impacted	0	
Design and Construction Cost Estimates	None	

LEGEND

EXISTING TRAFFIC SIGNAL

RIGHT-OF-WAY

EXPO&1ST

Alternative 1 - No-Build
Billings, Montana

Figure
3

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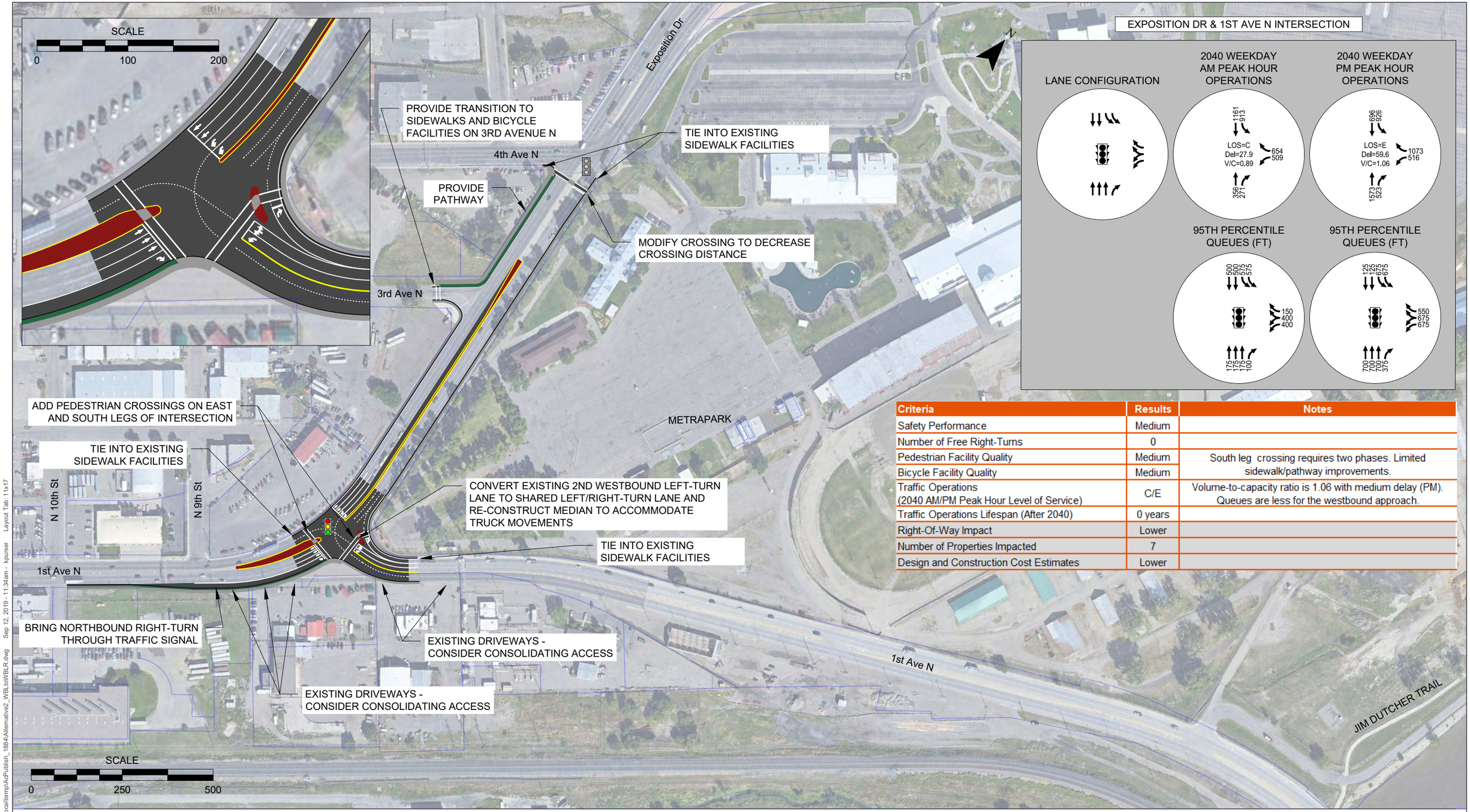

EXPOSITION DR & 1ST AVE N INTERSECTION

Criteria	Results	Notes
Safety Performance	Medium	
Number of Free Right-Turns	0	
Pedestrian Facility Quality	Medium	South leg crossing requires two phases. Limited sidewalk/pathway improvements.
Bicycle Facility Quality	Medium	
Traffic Operations (2040 AM/PM Peak Hour Level of Service)	C/E	Volume-to-capacity ratio is 1.06 with medium delay (PM). Queues are less for the westbound approach.
Traffic Operations Lifespan (After 2040)	0 years	
Right-Of-Way Impact	Lower	
Number of Properties Impacted	7	
Design and Construction Cost Estimates	Lower	

LEGEND

SIDEWALK OR PATHWAY | LANDSCAPING | EXISTING TRAFFIC SIGNAL | RIGHT-OF-WAY

ROADWAY | MEDIAN | NEW OR MODIFIED TRAFFIC SIGNAL

EXPO&1ST

Alternative 2 - Westbound Shared Left/Right-Turn Lane
Billings, Montana

Figure 4

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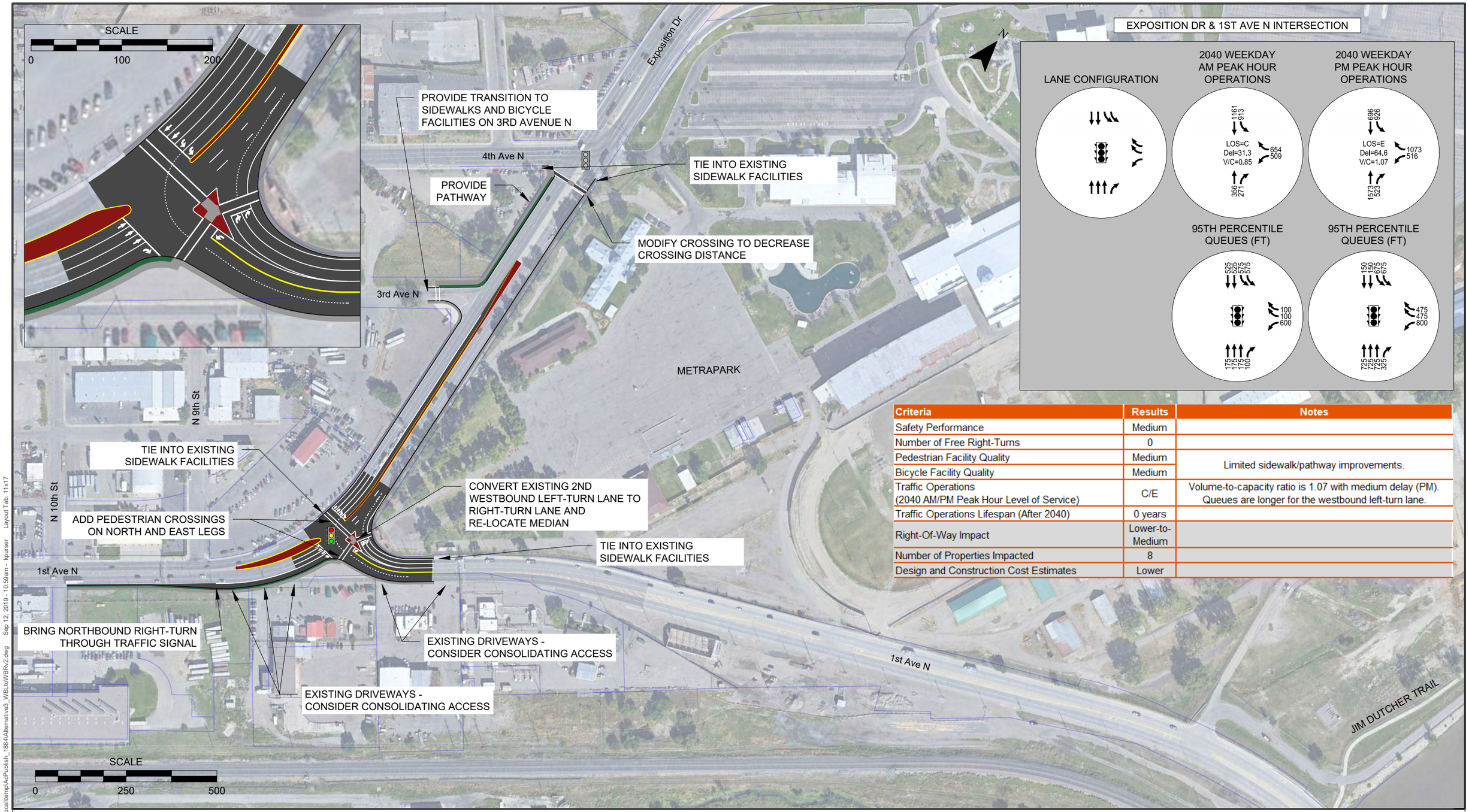

Criteria	Results	Notes
Safety Performance	Medium	
Number of Free Right-Turns	0	
Pedestrian Facility Quality	Medium	Limited sidewalk/pathway improvements.
Bicycle Facility Quality	Medium	
Traffic Operations (2040 AM/PM Peak Hour Level of Service)	C/E	Volume-to-capacity ratio is 1.07 with medium delay (PM). Queues are longer for the westbound left-turn lane.
Traffic Operations Lifespan (After 2040)	0 years	
Right-Of-Way Impact	Lower-to-Medium	
Number of Properties Impacted	8	
Design and Construction Cost Estimates	Lower	

LEGEND

SIDEWALK OR PATHWAY | LANDSCAPING | EXISTING TRAFFIC SIGNAL | RIGHT-OF-WAY

ROADWAY | MEDIAN | NEW OR MODIFIED TRAFFIC SIGNAL

EXPO&1ST

Alternative 3 - Single Westbound Left-Turn Lane and Dual Westbound Right-Turn Lanes
Billings, Montana

Figure 5

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SCALE
0 100 200

PROVIDE TRANSITION TO SIDEWALKS AND BICYCLE FACILITIES ON 3RD AVENUE N

Exposition Dr

TIE INTO EXISTING SIDEWALK FACILITIES

4th Ave N

PROVIDE PATHWAY

3rd Ave N

MODIFY CROSSING TO DECREASE CROSSING DISTANCE

PROVIDE PATHWAY

METRAPARK

TIE INTO EXISTING SIDEWALK FACILITIES

N 10th St

N 9th St

ADDITIONAL 4TH NORTHBOUND THROUGH LANE BECOMES RIGHT-TURN LANE AT 6TH AVENUE N

ADD PEDESTRIAN CROSSINGS ON NORTH AND EAST LEGS

1st Ave N

BRING NORTHBOUND RIGHT-TURN THROUGH TRAFFIC SIGNAL

EXISTING DRIVEWAYS - CONSIDER CONSOLIDATING ACCESS

EXISTING DRIVEWAYS - CONSIDER CONSOLIDATING ACCESS

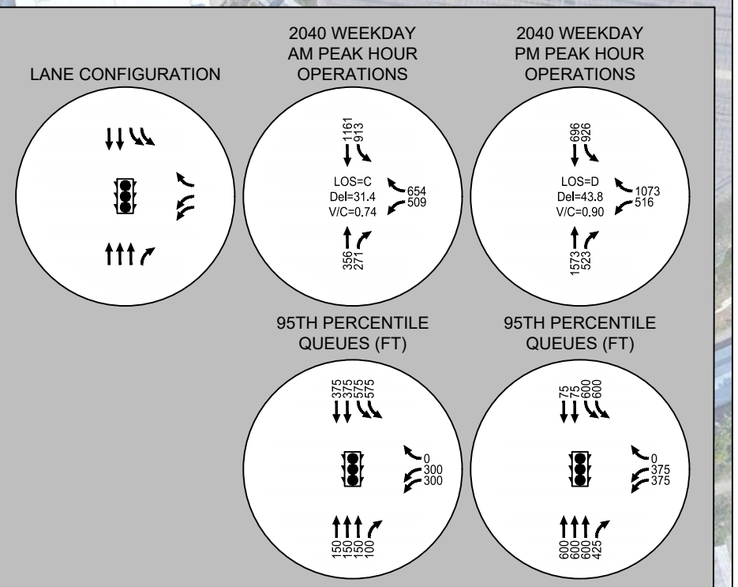
1st Ave N

JIM DUTCHER TRAIL

PROVIDE PATHWAY CONNECTION TO JIM DUTCHER TRAIL ON NORTH OR SOUTH SIDE OF 1ST AVE N (BOTH OPTIONS SHOWN)

SCALE
0 250 500

EXPOSITION DR & 1ST AVE N INTERSECTION



Criteria	Results	Notes
Safety Performance	Medium	
Number of Free Right-Turns	1	
Pedestrian Facility Quality	Higher	Requires crossing at free right-turn. Provides pathway connection to Jim Dutcher Trail.
Bicycle Facility Quality	Higher	
Traffic Operations (2040 AM/PM Peak Hour Level of Service)	C/D	Volume-to-capacity ratio is 0.90 (PM). Queues are less for the westbound approach.
Traffic Operations Lifespan (After 2040)	8-12 years	
Right-Of-Way Impact	Medium-to-Higher	
Number of Properties Impacted	13	
Design and Construction Cost Estimates	Medium	

LEGEND

SIDEWALK OR PATHWAY
ROADWAY
LANDSCAPING
MEDIAN
EXISTING TRAFFIC SIGNAL
NEW OR MODIFIED TRAFFIC SIGNAL
RIGHT-OF-WAY

EXPO&1ST

Alternative 4 - Free Westbound Right-Turn Lane
Billings, Montana

Figure 6

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SCALE
0
100
200

PROVIDE TRANSITION TO SIDEWALKS AND BICYCLE FACILITIES ON 3RD AVENUE N

Exposition Dr

TIE INTO EXISTING SIDEWALK FACILITIES

4th Ave N

PROVIDE PATHWAY

MODIFY CROSSING TO DECREASE CROSSING DISTANCE

3rd Ave N

METRAPARK

TIE INTO EXISTING SIDEWALK FACILITIES

PROVIDE PATHWAY

N 10th St

N 9th St

ADD PEDESTRIAN CROSSINGS ON NORTH AND EAST LEGS

ADD 2ND WESTBOUND RIGHT-TURN LANE

1st Ave N

BRING NORTHBOUND RIGHT-TURN THROUGH TRAFFIC SIGNAL

EXISTING DRIVEWAYS - CONSIDER CONSOLIDATING ACCESS

EXISTING DRIVEWAYS - CONSIDER CONSOLIDATING ACCESS

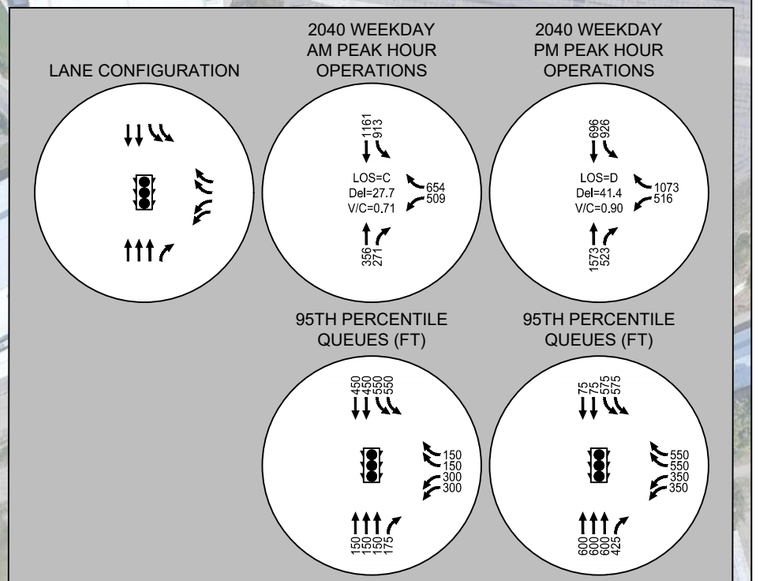
1st Ave N

JIM DUTCHER TRAIL

PROVIDE PATHWAY CONNECTION TO JIM DUTCHER TRAIL ON NORTH OR SOUTH SIDE OF 1ST AVE N (BOTH OPTIONS SHOWN)

SCALE
0
250
500

EXPOSITION DR & 1ST AVE N INTERSECTION



Criteria	Results	Notes
Safety Performance	Medium	
Number of Free Right-Turns	0	
Pedestrian Facility Quality	Higher	Provides crossings and several multi-use path options.
Bicycle Facility Quality	Higher	Provides pathway connection to Jim Dutcher Trail.
Traffic Operations (2040 AM/PM Peak Hour Level of Service)	C/D	Volume-to-capacity ratio is 0.90 (PM). Queues are significantly less for the westbound approach.
Traffic Operations Lifespan (After 2040)	8-12 years	
Right-Of-Way Impact	Medium	
Number of Properties Impacted	13	
Design and Construction Cost Estimates	Medium	

LEGEND

SIDEWALK OR PATHWAY
ROADWAY
LANDSCAPING
MEDIAN
EXISTING TRAFFIC SIGNAL
NEW OR MODIFIED TRAFFIC SIGNAL
RIGHT-OF-WAY

EXPO&1ST

Alternative 5 - Dual Westbound Right-Turn Lanes
Billings, Montana

Figure 7

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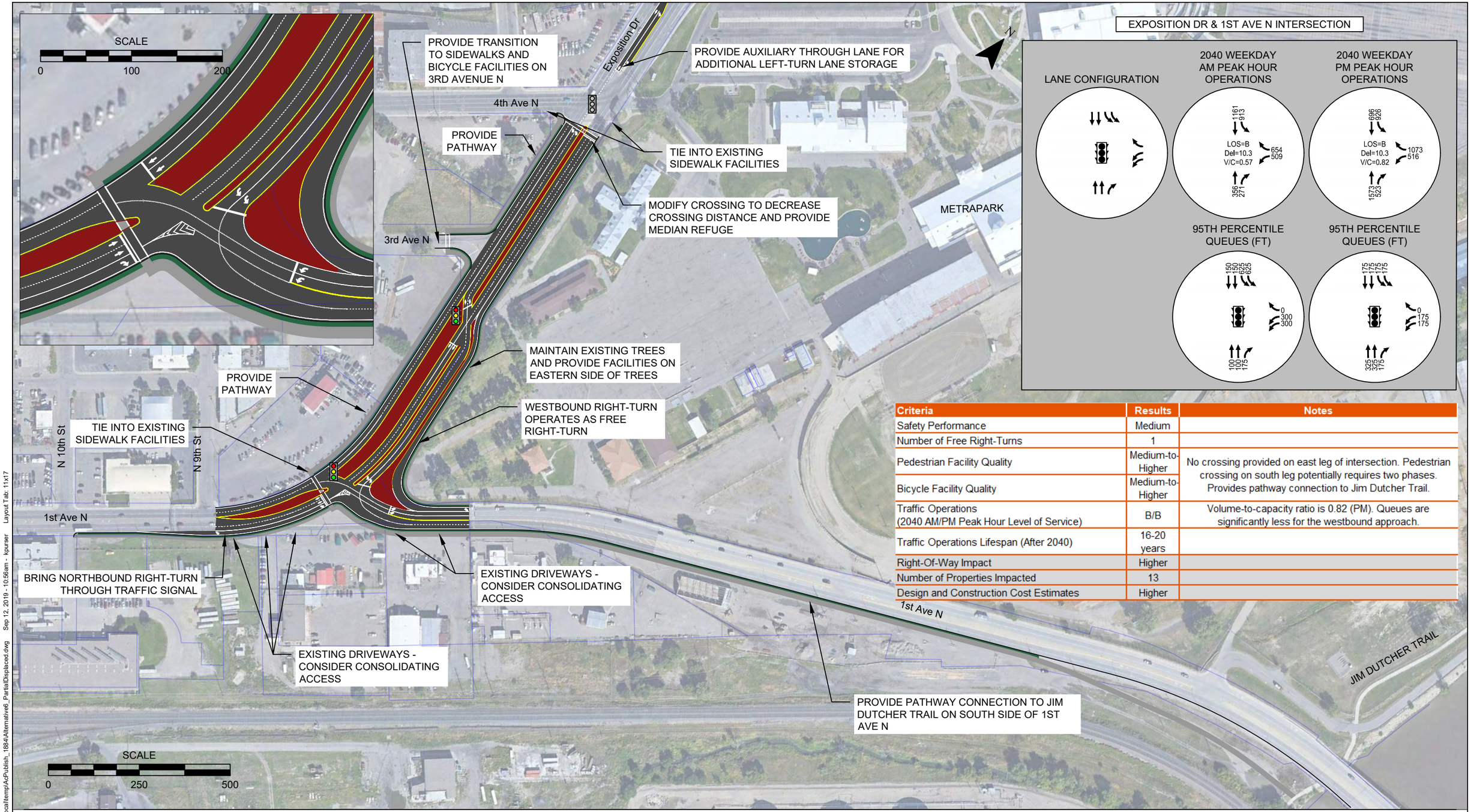

Criteria	Results	Notes
Safety Performance	Medium	
Number of Free Right-Turns	1	
Pedestrian Facility Quality	Medium-to-Higher	No crossing provided on east leg of intersection. Pedestrian crossing on south leg potentially requires two phases. Provides pathway connection to Jim Dutcher Trail.
Bicycle Facility Quality	Medium-to-Higher	
Traffic Operations (2040 AM/PM Peak Hour Level of Service)	B/B	Volume-to-capacity ratio is 0.82 (PM). Queues are significantly less for the westbound approach.
Traffic Operations Lifespan (After 2040)	16-20 years	
Right-Of-Way Impact	Higher	
Number of Properties Impacted	13	
Design and Construction Cost Estimates	Higher	

LEGEND

SIDEWALK OR PATHWAY
ROADWAY
LANDSCAPING
MEDIAN
EXISTING TRAFFIC SIGNAL
NEW OR MODIFIED TRAFFIC SIGNAL
RIGHT-OF-WAY

EXPO&1ST

Alternative 6 - Partial Displaced Left-Turn
Billings, Montana

Figure 8

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WEAVING ANALYSIS

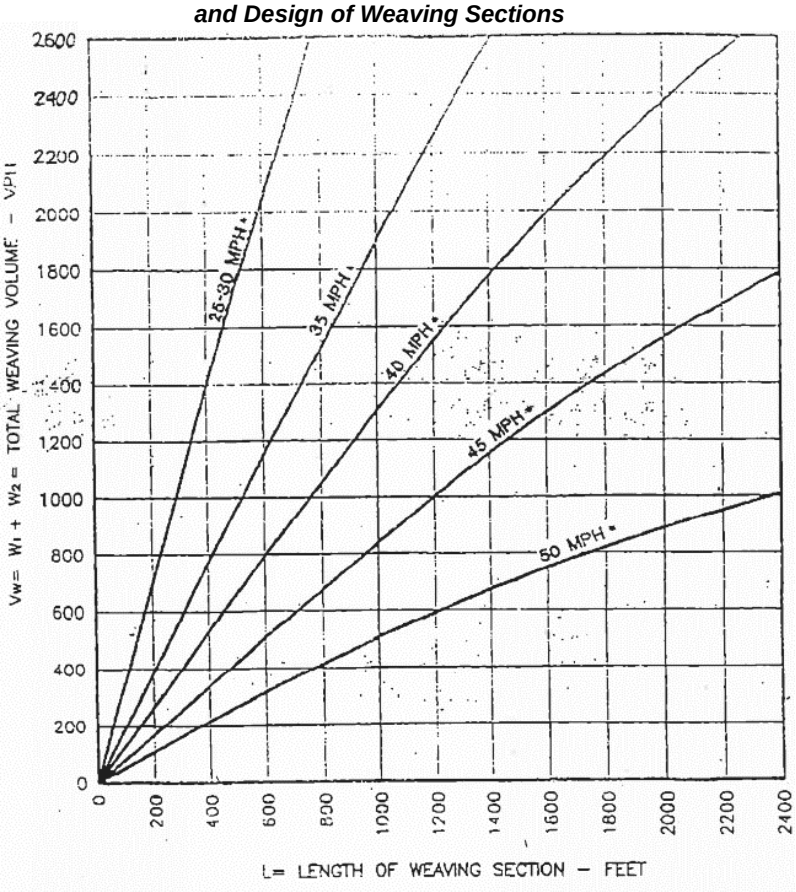
A weaving analysis was conducted on Exposition Drive between its intersections with 1st Avenue N and 6th Avenue N in the northbound direction for Alternatives 4, 5, and 6. This analysis was conducted using the *Procedure for Design Analysis of Frontage Road Weaving Sections* (Joel Leisch, 1996). This analysis is based on lane changing assumptions with no origin-destination data. This analysis does not capture the impacts of gaps due to upstream signal timing and ignores the impacts of the intermediate 4th Avenue N intersection.

The input parameters used in this analysis include:

- Total weaving volume, V_w
- Estimated queue length downstream, L_q
- Estimated stopping distance to the back of queue, L_s
- Estimated weave length prior to stopping at back of queue, L_w
- Total distance required to complete weave, $L_t = L_q + L_s + L_w$

Total weaving volumes for each alternative were developed based on their lane configurations and projected turning movements. The estimated weave length, L_w, is obtained using the nomograph shown in Exhibit 1. The nomograph is based on the average speed of weaving and the total weaving volume V_w. As the worst-case scenario, the L_w for each alternative is taken at the posted speed limit of 35 mph. In congested conditions, speeds are likely to be lower and require a shorter weaving distance.

Exhibit 1. Nomograph adopted from *Procedure for Analysis and Design of Weaving Sections*

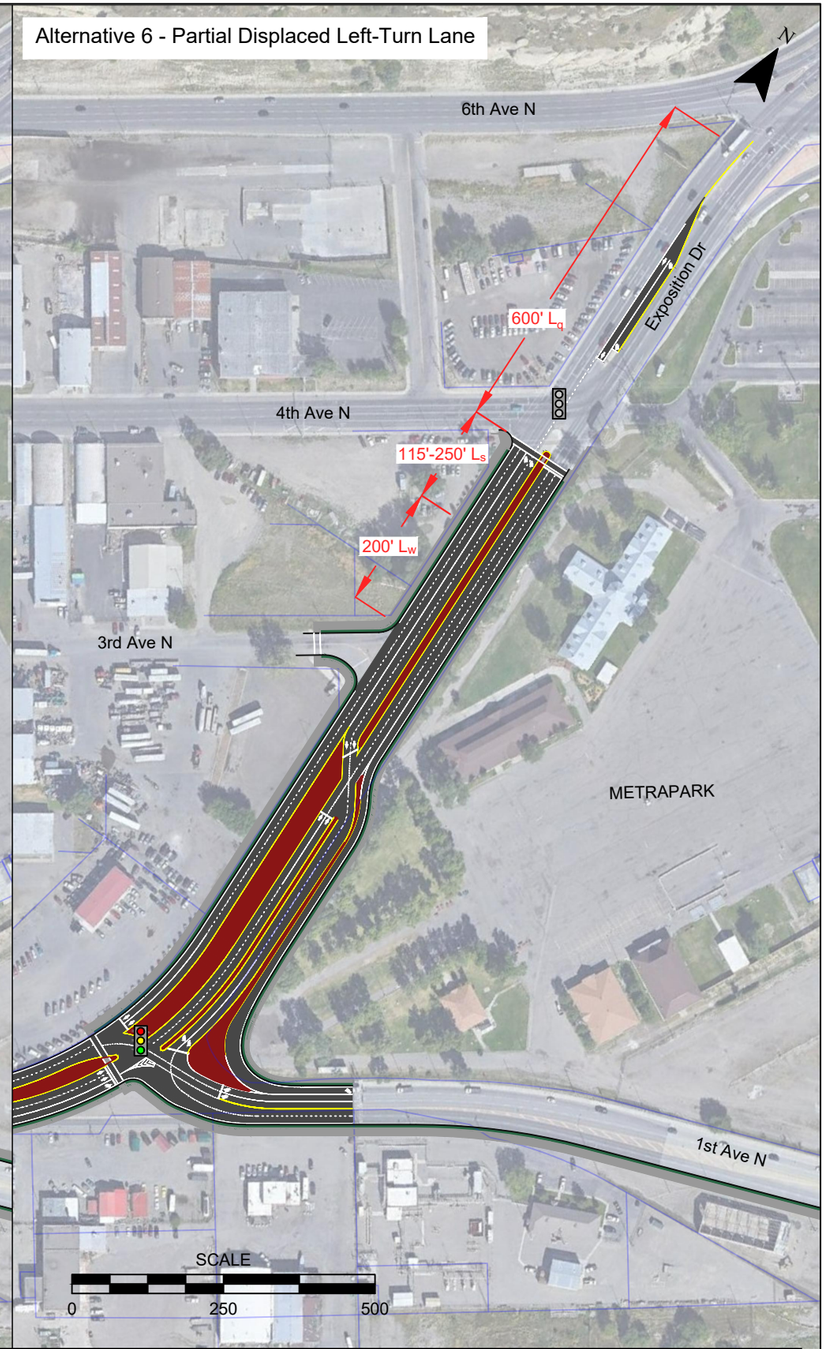


The stopping sight distance, L_s, is based on the 2018 AASHTO *A Policy on Geometric Design of Highways and Streets* at 25 mph at the end of the weave. The queue lengths are derived from Synchro's 95th percentile queue for the northbound through at Exposition Drive/6th Avenue N during the 2040 weekday PM peak hour, the worst movement and time period. Synchro captures some influences from signal coordination but may not fully capture the impacts of signal coordination on Exposition Drive.

The weaving calculations for the alternatives are summarized in Table 2 and shown in Figure 9. As shown, the total distance to complete a weave for Alternative 4 nears the design's provided length, primarily due to its higher weave volume as the westbound right-turn movement at Exposition Drive/1st Avenue N requires a lane change to the northbound-through movement at Exposition Drive/6th Avenue N. Alternative 5 provides sufficient space for weaving maneuvers given low weaving volumes and long weaving distance. The total distance to complete a weave for Alternative 6 also nears the design's provided length due to the shorter distance between Exposition Drive/crossover intersection near 3rd Avenue N and Exposition Drive/6th Avenue N. Given the worst-case scenario conditions and lack of origin-destination data, this analysis should be considered high-level and preliminary.

Table 2. Weaving Analysis Results

Alternative 4 – Free Westbound Right-Turn Lane							
Peak Hour	**V_w**	**L_w (ft)**	**L_s (ft)**	**L_q (ft)**	**L_t (ft)**	**Length Provided (ft)**	**Is L_t less than length provided? If Yes, there is sufficient space.**
2040 Weekday AM	597	300	155	250	705	1500	Yes
2040 Weekday PM	1,186	600	155	600	1355	1500	Yes
Alternative 5 – Dual Westbound Right-Turn Lanes							
Peak Hour	**V_w**	**L_w (ft)**	**L_s (ft)**	**L_q (ft)**	**L_t (ft)**	**Length Provided (ft)**	**Sufficient Space?**
2040 Weekday AM	144	100	155	250	505	1500	Yes
2040 Weekday PM	385	200	155	600	955	1500	Yes
Alternative 6 – Partial Displaced Left-Turn							
Peak Hour	**V_w**	**L_w (ft)**	**L_s (ft)**	**L_q (ft)**	**L_t (ft)**	**Length Provided (ft)**	**Sufficient Space?**
2040 Weekday AM	144	100	155	250	505	1000	Yes
2040 Weekday PM	385	200	155	600	955	1000	Yes



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LEGEND

L_W = WEAVE LENGTH
L_S = STOPPING SIGHT DISTANCE, RANGE IDENTIFIED FOR 20 MPH - 35 MPH. 25 MPH STOPPING SIGHT DISTANCE (155') SHOWN.
L_Q= DOWNSTREAM QUEUE LENGTH

Weaving Analysis
Billings, Montana

Figure
9

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PAC MEETING RESULTS

The Tier 1 alternatives were presented to MDT and the PAC on September 19th, 2019. Attendees were provided comment forms to give their feedback and recommendations for alternatives to advance to Tier 2. Table 3 summarizes the feedback.

Table 3. Comment Form Feedback from PAC

Alternative	Move Forward to Tier 2		Comments & Concerns
	Yes	No	
1	1	2	Used for comparison
2		5	**Pros:** No comments **Cons:** Doesn't solve operation issues for 2040
3		5	**Pros:** No comments **Cons:** Doesn't solve operation issues for 2040 Potential queuing problems for westbound left-turn
4	5		**Pros:** Good bicycle and pedestrian facilities Better safety for bicyclists and pedestrians with the larger median at the intersection Simple design for user expectancy (driver, bicyclist, pedestrian) Relieves queuing on westbound right-turn movement Good free-flow movement for vehicles heading west-to-north for most times of day, especially as crossing is only activated when pedestrian is present **Cons:** No comments
5	3	2	**Pros:** Good bicyclist and pedestrian facilities **Cons:** Potential queueing on westbound right-turn if no right-turns-on-red are allowed
6	3	2	**Pros:** Longer life expectancy, fewer construction periods for the same lifespan Relieves queuing on westbound right-turn **Cons:** Higher right-of-way and cost Worse bicycle and pedestrian facilities compared to Alternatives 4 and 5 Potential northbound left-turn weaving issues between 1st Avenue N and 6th Avenue N

Note: Some comment sheets did not circle yes or no for an alternative, which is why the total votes do not sum to six for each alternative. Orange shading represents the alternatives that received the most support from the PAC.

Tier 1 Alternatives Selected for Tier 2

Based on the feedback received from the PAC meeting, as well as input from the Yellowstone County Policy Coordinating Committee (PCC) and MDT, **Alternatives 1, 4, and 5 were selected for further evaluation in Tier 2**. This decision was confirmed during a meeting with MDT on October 15, 2019.

Alternative 6 was considered for Tier 2 evaluation based on the feedback from the PAC and anticipated longer life-span, but was ultimately removed because of the deficient bicycle and pedestrian facilities, higher right-of-way impacts and costs, and the close signal spacing that could result in long-term queuing and weaving conflicts. Alternatives 2 and 3 were removed from further evaluation in Tier 2 because they were not projected to solve the operation issues in year 2040 and still had significant costs to implement the changes.

Appendix A Future Year 2040 AM Traffic Operations Worksheets

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	509	654	356	271	913	1161
v/c Ratio	0.49	0.69	0.37	0.19	0.88	0.61
Control Delay	40.9	14.1	52.4	0.3	65.1	18.6
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	40.9	14.1	52.4	0.3	65.1	18.6
Queue Length 50th (ft)	203	288	110	0	451	357
Queue Length 95th (ft)	259	339	154	0	556	449
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	1034	1019	957	1417	1195	1907
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.49	0.64	0.37	0.19	0.76	0.61

Intersection Summary

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	509	654	356	271	913	1161
Future Volume (veh/h)	509	654	356	271	913	1161
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1654	1559	1614	1682	1654	1695
Adj Flow Rate, veh/h	509	654	356	0	913	1161
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	7	14	10	5	7	4
Cap, veh/h	1049	867	1110		956	1916
Arrive On Green	0.34	0.34	0.25	0.00	0.47	0.89
Sat Flow, veh/h	3057	1321	4550	1425	3057	3306
Grp Volume(v), veh/h	509	654	356	0	913	1161
Grp Sat Flow(s),veh/h/ln	1528	1321	1468	1425	1528	1611
Q Serve(g_s), s	19.7	50.6	9.9	0.0	43.1	12.7
Cycle Q Clear(g_c), s	19.7	50.6	9.9	0.0	43.1	12.7
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	1049	867	1110		956	1916
V/C Ratio(X)	0.48	0.75	0.32		0.96	0.61
Avail Cap(c_a), veh/h	1049	867	1110		1213	1922
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	1.00	1.00	0.00	1.00	1.00
Uniform Delay (d), s/veh	38.8	17.6	45.6	0.0	38.8	4.0
Incr Delay (d2), s/veh	0.3	3.8	0.8	0.0	13.2	0.4
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	11.8	21.2	6.7	0.0	22.8	4.4
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	39.2	21.4	46.4	0.0	52.1	4.4
LnGrp LOS	D	C	D		D	A
Approach Vol, veh/h	1163		356	A		2074
Approach Delay, s/veh	29.2		46.4			25.4
Approach LOS	C		D			C

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	51.4	42.6			94.0	56.0
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	59.5	* 25			* 90	51.5
Max Q Clear Time (g_c+I1), s	45.1	11.9			14.7	52.6
Green Ext Time (p_c), s	1.8	0.4			6.7	0.0

Intersection Summary	
HCM 6th Ctrl Delay	28.7
HCM 6th LOS	C

Notes

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Unsignalized Delay for [NBR] is excluded from calculations of the approach delay and intersection delay.

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	797	366	356	271	913	1161
v/c Ratio	0.87	0.45	0.31	0.47	0.88	0.57
Control Delay	54.5	10.7	48.3	8.8	64.5	14.7
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	54.5	10.7	48.3	8.8	64.5	14.7
Queue Length 50th (ft)	343	145	104	0	478	352
Queue Length 95th (ft)	398	135	157	91	556	478
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	1069	882	1141	572	1215	2041
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.75	0.41	0.31	0.47	0.75	0.57

Intersection Summary

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	509	654	356	271	913	1161
Future Volume (veh/h)	509	654	356	271	913	1161
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1654	1559	1614	1682	1654	1695
Adj Flow Rate, veh/h	388	784	356	0	913	1161
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	7	14	10	5	7	4
Cap, veh/h	438	1562	1396		956	2125
Arrive On Green	0.28	0.28	0.32	0.00	0.47	0.99
Sat Flow, veh/h	1576	2642	4550	1425	3057	3306
Grp Volume(v), veh/h	388	784	356	0	913	1161
Grp Sat Flow(s),veh/h/ln	1576	1321	1468	1425	1528	1611
Q Serve(g_s), s	35.4	25.9	9.0	0.0	43.1	1.2
Cycle Q Clear(g_c), s	35.4	25.9	9.0	0.0	43.1	1.2
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	438	1562	1396		956	2125
V/C Ratio(X)	0.88	0.50	0.25		0.96	0.55
Avail Cap(c_a), veh/h	562	1769	1396		1233	2125
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	1.00	1.00	0.00	1.00	1.00
Uniform Delay (d), s/veh	51.8	17.8	38.1	0.0	38.8	0.3
Incr Delay (d2), s/veh	13.0	0.3	0.4	0.0	12.8	0.2
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	21.6	12.1	6.0	0.0	22.7	0.4
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	64.8	18.1	38.5	0.0	51.6	0.4
LnGrp LOS	E	B	D		D	A
Approach Vol, veh/h	1172		356	A		2074
Approach Delay, s/veh	33.6		38.5			23.0
Approach LOS	C		D			C

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	51.4	52.3			103.8	46.2
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	60.5	* 22			* 88	53.5
Max Q Clear Time (g_c+I1), s	45.1	11.0			3.2	37.4
Green Ext Time (p_c), s	1.8	0.4			6.7	4.4

Intersection Summary	
HCM 6th Ctrl Delay	27.9
HCM 6th LOS	C

Notes

User approved volume balancing among the lanes for turning movement.

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Unsignalized Delay for [NBR] is excluded from calculations of the approach delay and intersection delay.

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	509	654	356	271	913	1161
v/c Ratio	0.89	0.39	0.40	0.19	0.90	0.63
Control Delay	63.6	7.4	56.0	0.3	67.4	20.7
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	63.6	7.4	56.0	0.3	67.4	20.7
Queue Length 50th (ft)	458	105	114	0	468	362
Queue Length 95th (ft)	587	93	163	0	557	525
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	647	1758	895	1417	1115	1834
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.79	0.37	0.40	0.19	0.82	0.63

Intersection Summary

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	509	654	356	271	913	1161
Future Volume (veh/h)	509	654	356	271	913	1161
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1654	1559	1614	1682	1654	1695
Adj Flow Rate, veh/h	509	654	356	0	913	1161
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	7	14	10	5	7	4
Cap, veh/h	552	1540	1083		954	1894
Arrive On Green	0.35	0.35	0.25	0.00	0.47	0.88
Sat Flow, veh/h	1576	2325	4550	1425	3057	3306
Grp Volume(v), veh/h	509	654	356	0	913	1161
Grp Sat Flow(s),veh/h/ln	1576	1163	1468	1425	1528	1611
Q Serve(g_s), s	46.5	19.8	9.9	0.0	43.2	13.9
Cycle Q Clear(g_c), s	46.5	19.8	9.9	0.0	43.2	13.9
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	552	1540	1083		954	1894
V/C Ratio(X)	0.92	0.42	0.33		0.96	0.61
Avail Cap(c_a), veh/h	657	1694	1083		1131	1894
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	1.00	1.00	0.00	1.00	1.00
Uniform Delay (d), s/veh	46.8	11.9	46.4	0.0	38.9	4.5
Incr Delay (d2), s/veh	17.0	0.2	0.8	0.0	15.2	0.4
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	27.7	8.4	6.7	0.0	23.1	4.9
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	63.7	12.1	47.2	0.0	54.1	4.9
LnGrp LOS	E	B	D		D	A
Approach Vol, veh/h	1163		356	A		2074
Approach Delay, s/veh	34.7		47.2			26.6
Approach LOS	C		D			C

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	51.3	41.7			93.0	57.0
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	55.5	* 18			* 79	62.5
Max Q Clear Time (g_c+I1), s	45.2	11.9			15.9	48.5
Green Ext Time (p_c), s	1.6	0.3			6.7	4.0

Intersection Summary	
HCM 6th Ctrl Delay	31.3
HCM 6th LOS	C

Notes

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Unsignalized Delay for [NBR] is excluded from calculations of the approach delay and intersection delay.

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	509	654	356	271	913	1161
v/c Ratio	0.83	0.50	0.23	0.40	0.88	0.49
Control Delay	69.1	1.4	36.5	6.4	60.4	8.7
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	69.1	1.4	36.5	6.4	60.4	8.7
Queue Length 50th (ft)	248	0	89	0	469	327
Queue Length 95th (ft)	299	0	137	77	555	358
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	773	1305	1555	681	1296	2354
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.66	0.50	0.23	0.40	0.70	0.49

Intersection Summary

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	509	654	356	271	913	1161
Future Volume (veh/h)	509	654	356	271	913	1161
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1654	1559	1614	1682	1654	1695
Adj Flow Rate, veh/h	509	0	356	271	913	1161
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	7	14	10	5	7	4
Cap, veh/h	568		1802	583	957	2423
Arrive On Green	0.19	0.00	0.41	0.41	0.47	1.00
Sat Flow, veh/h	3057	1321	4550	1425	3057	3306
Grp Volume(v), veh/h	509	0	356	271	913	1161
Grp Sat Flow(s),veh/h/ln	1528	1321	1468	1425	1528	1611
Q Serve(g_s), s	24.4	0.0	7.8	20.8	43.1	0.0
Cycle Q Clear(g_c), s	24.4	0.0	7.8	20.8	43.1	0.0
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	568		1802	583	957	2423
V/C Ratio(X)	0.90		0.20	0.46	0.95	0.48
Avail Cap(c_a), veh/h	785		1802	583	1314	2423
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	0.00	1.00	1.00	1.00	1.00
Uniform Delay (d), s/veh	59.6	0.0	28.5	32.3	38.8	0.0
Incr Delay (d2), s/veh	10.1	0.0	0.2	2.7	11.2	0.1
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	15.3	0.0	5.1	12.0	22.4	0.0
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	69.7	0.0	28.7	35.0	49.9	0.1
LnGrp LOS	E		C	C	D	A
Approach Vol, veh/h	509	A	627			2074
Approach Delay, s/veh	69.7		31.4			22.0
Approach LOS	E		C			C

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	51.4	66.2			117.6	32.4
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	64.5	* 33			* 1E2	38.5
Max Q Clear Time (g_c+I1), s	45.1	22.8			2.0	26.4
Green Ext Time (p_c), s	1.9	0.4			6.7	1.5

Intersection Summary	
HCM 6th Ctrl Delay	31.4
HCM 6th LOS	C

Notes

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Unsignalized Delay for [WBR] is excluded from calculations of the approach delay and intersection delay.

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	509	654	356	271	913	1161
v/c Ratio	0.77	0.46	0.25	0.19	0.84	0.50
Control Delay	63.3	13.5	39.7	0.3	52.9	7.7
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	63.3	13.5	39.7	0.3	52.9	7.7
Queue Length 50th (ft)	244	158	93	0	468	255
Queue Length 95th (ft)	292	141	144	0	544	438
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	853	1657	1436	1417	1396	2306
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.60	0.39	0.25	0.19	0.65	0.50

Intersection Summary

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	509	654	356	271	913	1161
Future Volume (veh/h)	509	654	356	271	913	1161
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1654	1559	1614	1682	1654	1695
Adj Flow Rate, veh/h	509	654	356	0	913	1161
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	7	14	10	5	7	4
Cap, veh/h	679	1245	1641		957	2305
Arrive On Green	0.22	0.22	0.37	0.00	0.47	1.00
Sat Flow, veh/h	3057	2325	4550	1425	3057	3306
Grp Volume(v), veh/h	509	654	356	0	913	1161
Grp Sat Flow(s),veh/h/ln	1528	1163	1468	1425	1528	1611
Q Serve(g_s), s	23.3	27.3	8.3	0.0	43.0	0.0
Cycle Q Clear(g_c), s	23.3	27.3	8.3	0.0	43.0	0.0
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	679	1245	1641		957	2305
V/C Ratio(X)	0.75	0.53	0.22		0.95	0.50
Avail Cap(c_a), veh/h	866	1387	1641		1416	2305
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	1.00	1.00	0.00	1.00	1.00
Uniform Delay (d), s/veh	54.4	22.5	32.1	0.0	38.7	0.0
Incr Delay (d2), s/veh	2.7	0.3	0.3	0.0	9.3	0.1
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	14.0	11.7	5.4	0.0	22.1	0.0
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	57.2	22.9	32.4	0.0	48.0	0.1
LnGrp LOS	E	C	C		D	A
Approach Vol, veh/h	1163		356	A		2074
Approach Delay, s/veh	37.9		32.4			21.2
Approach LOS	D		C			C

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	51.5	60.7			112.2	37.8
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	69.5	* 24			* 99	42.5
Max Q Clear Time (g_c+I1), s	45.0	10.3			2.0	29.3
Green Ext Time (p_c), s	1.9	0.5			6.7	4.1

Intersection Summary	
HCM 6th Ctrl Delay	27.7
HCM 6th LOS	C

Notes

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Unsignalized Delay for [NBR] is excluded from calculations of the approach delay and intersection delay.

Lane Group	WBL	NBT	NBR	SBT
Lane Group Flow (vph)	509	356	271	1161
v/c Ratio	0.78	0.16	0.25	0.50
Control Delay	9.8	7.0	1.4	7.4
Queue Delay	0.0	0.0	1.7	0.1
Total Delay	9.8	7.0	3.1	7.5
Queue Length 50th (ft)	6	51	0	137
Queue Length 95th (ft)	5	84	30	126
Internal Link Dist (ft)	69	243		715
Turn Bay Length (ft)			255	
Base Capacity (vph)	964	2203	1106	2330
Starvation Cap Reductn	0	0	0	254
Spillback Cap Reductn	0	0	663	0
Storage Cap Reductn	0	0	0	0
Reduced v/c Ratio	0.53	0.16	0.61	0.56

Intersection Summary

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (vph)	509	0	356	271	0	1161
Future Volume (vph)	509	0	356	271	0	1161
Ideal Flow (vphpl)	1750	1750	1750	1750	1750	1750
Total Lost time (s)	4.0		4.0	4.0		4.0
Lane Util. Factor	0.97		0.95	1.00		0.95
Frt	1.00		1.00	0.85		1.00
Flt Protected	0.95		1.00	1.00		1.00
Satd. Flow (prot)	3014		3023	1417		3197
Flt Permitted	0.95		1.00	1.00		1.00
Satd. Flow (perm)	3014		3023	1417		3197
Peak-hour factor, PHF	1.00	1.00	1.00	1.00	1.00	1.00
Adj. Flow (vph)	509	0	356	271	0	1161
RTOR Reduction (vph)	0	0	0	74	0	0
Lane Group Flow (vph)	509	0	356	197	0	1161
Heavy Vehicles (%)	7%	14%	10%	5%	0%	4%
Turn Type	Prot		NA	Perm		NA
Protected Phases	8		2			2
Permitted Phases				2		
Actuated Green, G (s)	32.7		109.3	109.3		109.3
Effective Green, g (s)	32.7		109.3	109.3		109.3
Actuated g/C Ratio	0.22		0.73	0.73		0.73
Clearance Time (s)	4.0		4.0	4.0		4.0
Vehicle Extension (s)	3.0		3.0	3.0		3.0
Lane Grp Cap (vph)	657		2202	1032		2329
v/s Ratio Prot	c0.17		0.12			c0.36
v/s Ratio Perm				0.14		
v/c Ratio	0.77		0.16	0.19		0.50
Uniform Delay, d1	55.2		6.3	6.4		8.7
Progression Factor	0.04		1.00	1.00		0.71
Incremental Delay, d2	5.0		0.2	0.4		0.7
Delay (s)	7.2		6.4	6.8		6.9
Level of Service	A		A	A		A
Approach Delay (s)	7.2		6.6			6.9
Approach LOS	A		A			A

Intersection Summary			
HCM 2000 Control Delay	6.9	HCM 2000 Level of Service	A
HCM 2000 Volume to Capacity ratio	0.56		
Actuated Cycle Length (s)	150.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	57.3%	ICU Level of Service	B
Analysis Period (min)	15		
c Critical Lane Group			

Lane Group	WBR	NBT	SBL	SBT	NER2
Lane Group Flow (vph)	654	356	913	1219	5
v/c Ratio	0.49	0.21	0.76	0.38	0.00
Control Delay	1.1	15.6	31.4	0.3	0.0
Queue Delay	0.0	0.0	0.2	0.0	0.0
Total Delay	1.1	15.6	31.5	0.3	0.0
Queue Length 50th (ft)	0	100	236	0	0
Queue Length 95th (ft)	0	157	198	0	0
Internal Link Dist (ft)		715		374	
Turn Bay Length (ft)					
Base Capacity (vph)	1328	1664	1748	3181	1514
Starvation Cap Reductn	0	0	205	0	0
Spillback Cap Reductn	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0
Reduced v/c Ratio	0.49	0.21	0.59	0.38	0.00

Intersection Summary

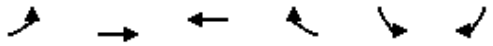
Movement	WBL	WBR	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NER	NER2
Lane Configurations											
Traffic Volume (vph)	0	654	0	356	0	913	1161	58	0	0	5
Future Volume (vph)	0	654	0	356	0	913	1161	58	0	0	5
Ideal Flow (vphpl)	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750
Total Lost time (s)		4.0		4.0		4.0	4.0				4.0
Lane Util. Factor		1.00		0.95		0.97	0.95				1.00
Frt		0.86		1.00		1.00	0.99				0.86
Flt Protected		1.00		1.00		0.95	1.00				1.00
Satd. Flow (prot)		1328		3023		3014	3180				1514
Flt Permitted		1.00		1.00		0.95	1.00				1.00
Satd. Flow (perm)		1328		3023		3014	3180				1514
Peak-hour factor, PHF	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Adj. Flow (vph)	0	654	0	356	0	913	1161	58	0	0	5
RTOR Reduction (vph)	0	0	0	0	0	0	0	0	0	0	0
Lane Group Flow (vph)	0	654	0	356	0	913	1219	0	0	0	5
Heavy Vehicles (%)	2%	14%	0%	10%	0%	7%	4%	0%	0%	0%	0%
Turn Type		pt+ov		NA		Prot	NA				Perm
Protected Phases		2 1!		2!		1	6				
Permitted Phases											6
Actuated Green, G (s)		150.0		82.6		59.4	150.0				150.0
Effective Green, g (s)		150.0		82.6		59.4	150.0				150.0
Actuated g/C Ratio		1.00		0.55		0.40	1.00				1.00
Clearance Time (s)				4.0		4.0	4.0				4.0
Vehicle Extension (s)				3.0		3.0	3.0				3.0
Lane Grp Cap (vph)		1328		1664		1193	3180				1514
v/s Ratio Prot		c0.49		0.12		c0.30	0.38				
v/s Ratio Perm											0.00
v/c Ratio		0.49		0.21		0.77	0.38				0.00
Uniform Delay, d1		0.0		17.2		39.3	0.0				0.0
Progression Factor		1.00		0.82		0.71	1.00				1.00
Incremental Delay, d2		0.3		0.3		2.5	0.3				0.0
Delay (s)		0.3		14.4		30.4	0.3				0.0
Level of Service		A		B		C	A				A
Approach Delay (s)	0.3			14.4			13.2		0.0		
Approach LOS	A			B			B		A		

Intersection Summary			
HCM 2000 Control Delay	10.6	HCM 2000 Level of Service	B
HCM 2000 Volume to Capacity ratio	0.62		
Actuated Cycle Length (s)	150.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	61.3%	ICU Level of Service	B
Analysis Period (min)	15		

! Phase conflict between lane groups.
c Critical Lane Group

Lane Group	EBT	WBT	WBR	SBL
Lane Group Flow (vph)	271	509	654	913
v/c Ratio	0.39	0.75	0.50	0.42
Control Delay	54.2	61.9	1.4	1.4
Queue Delay	2.9	0.0	0.0	0.0
Total Delay	57.1	61.9	1.4	1.4
Queue Length 50th (ft)	120	247	0	0
Queue Length 95th (ft)	168	293	0	47
Internal Link Dist (ft)	69	647		615
Turn Bay Length (ft)				
Base Capacity (vph)	1013	994	1305	2196
Starvation Cap Reductn	624	0	0	0
Spillback Cap Reductn	0	0	0	0
Storage Cap Reductn	0	0	0	0
Reduced v/c Ratio	0.70	0.51	0.50	0.42

Intersection Summary



Movement	EBL	EBT	WBT	WBR	SBL	SBR
Lane Configurations						
Traffic Volume (vph)	0	271	509	654	913	0
Future Volume (vph)	0	271	509	654	913	0
Ideal Flow (vphpl)	1750	1750	1750	1750	1750	1750
Total Lost time (s)		4.0	4.0	4.0	4.0	
Lane Util. Factor		0.95	0.95	1.00	0.97	
Frt		1.00	1.00	0.85	1.00	
Flt Protected		1.00	1.00	1.00	0.95	
Satd. Flow (prot)		3167	3107	1305	3014	
Flt Permitted		1.00	1.00	1.00	0.95	
Satd. Flow (perm)		3167	3107	1305	3014	
Peak-hour factor, PHF	1.00	1.00	1.00	1.00	1.00	1.00
Adj. Flow (vph)	0	271	509	654	913	0
RTOR Reduction (vph)	0	0	0	0	0	0
Lane Group Flow (vph)	0	271	509	654	913	0
Heavy Vehicles (%)	0%	5%	7%	14%	7%	0%
Turn Type		NA	NA	Free	Prot	
Protected Phases		8	4		2	
Permitted Phases				Free		
Actuated Green, G (s)		32.7	32.7	150.0	109.3	
Effective Green, g (s)		32.7	32.7	150.0	109.3	
Actuated g/C Ratio		0.22	0.22	1.00	0.73	
Clearance Time (s)		4.0	4.0		4.0	
Vehicle Extension (s)		3.0	3.0		3.0	
Lane Grp Cap (vph)		690	677	1305	2196	
v/s Ratio Prot		0.09	c0.16		0.30	
v/s Ratio Perm				c0.50		
v/c Ratio		0.39	0.75	0.50	0.42	
Uniform Delay, d1		50.2	54.9	0.0	7.9	
Progression Factor		1.07	1.00	1.00	0.11	
Incremental Delay, d2		0.4	4.7	1.4	0.5	
Delay (s)		53.8	59.6	1.4	1.3	
Level of Service		D	E	A	A	
Approach Delay (s)		53.8	26.8		1.3	
Approach LOS		D	C		A	

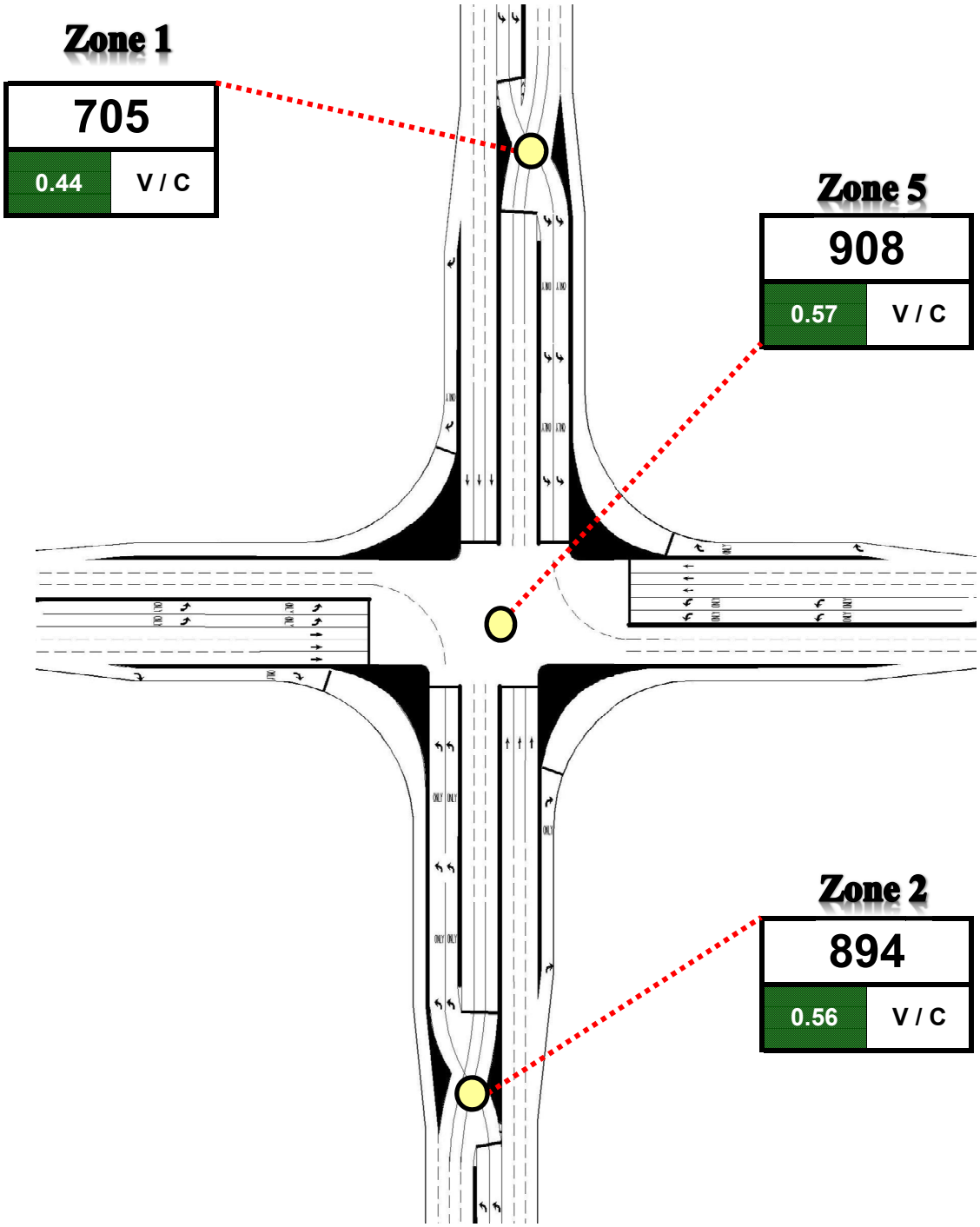
Intersection Summary			
HCM 2000 Control Delay	20.0	HCM 2000 Level of Service	C
HCM 2000 Volume to Capacity ratio	0.57		
Actuated Cycle Length (s)	150.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	50.2%	ICU Level of Service	A
Analysis Period (min)	15		
c Critical Lane Group			

Partial Displaced Left Turn Intersection (N-S)

Design and Results

Project Name:	*Exposition Drive & 1st Avenue N*
Project Number:	*20783_112*
Location	*Billings, MT*
Date	May 28, 2019

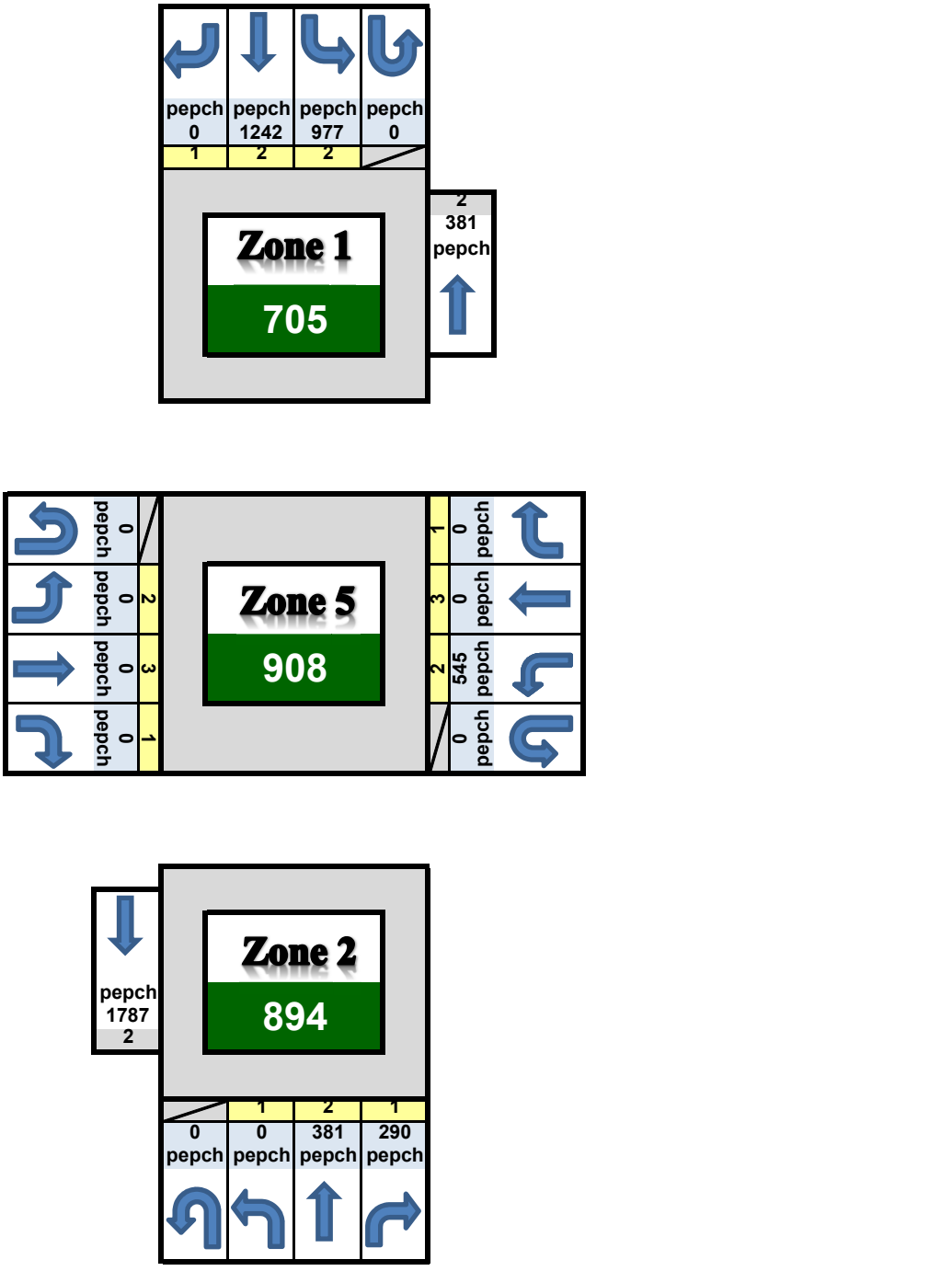
Critical Lane Volume Sum			
< 1200	1200 - 1399	1400 - 1599	≥ 1600
VOLUME / CAPACITY RATIO:	**0.57**		



Note: This diagram does not reflect the actual lane configuration of the Intersection

Partial Displaced Left Turn Intersection (N-S)

Data Input and Configuration



Back to Results

Appendix B Future Year 2040 PM Traffic Operations Worksheets

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	516	1073	1573	523	926	696
v/c Ratio	0.69	1.03	1.61	0.36	0.68	0.31
Control Delay	57.2	56.4	318.4	0.7	55.0	16.5
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	57.2	56.4	318.4	0.7	55.0	16.5
Queue Length 50th (ft)	238	~1118	~806	0	458	174
Queue Length 95th (ft)	304	#1381	#904	0	529	239
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	747	1043	974	1444	1363	2227
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.69	1.03	1.61	0.36	0.68	0.31

Intersection Summary

~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.

95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	516	1073	1573	523	926	696
Future Volume (veh/h)	516	1073	1573	523	926	696
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1682	1695	1723	1709	1641	1695
Adj Flow Rate, veh/h	516	1073	1573	0	926	696
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	5	4	2	3	8	4
Cap, veh/h	756	809	1622		969	2238
Arrive On Green	0.24	0.24	0.34	0.00	0.48	1.00
Sat Flow, veh/h	3107	1437	4858	1448	3032	3306
Grp Volume(v), veh/h	516	1073	1573	0	926	696
Grp Sat Flow(s),veh/h/ln	1554	1437	1568	1448	1516	1611
Q Serve(g_s), s	22.6	36.5	49.4	0.0	44.0	0.0
Cycle Q Clear(g_c), s	22.6	36.5	49.4	0.0	44.0	0.0
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	756	809	1622		969	2238
V/C Ratio(X)	0.68	1.33	0.97		0.96	0.31
Avail Cap(c_a), veh/h	756	809	1622		1384	2244
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	1.00	1.00	0.00	1.00	1.00
Uniform Delay (d), s/veh	51.5	32.8	48.4	0.0	38.0	0.0
Incr Delay (d2), s/veh	2.5	155.4	16.2	0.0	10.3	0.0
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	13.8	87.6	29.1	0.0	22.5	0.0
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	54.0	188.2	64.6	0.0	48.3	0.0
LnGrp LOS	D	F	E		D	A
Approach Vol, veh/h	1589		1573	A		1622
Approach Delay, s/veh	144.6		64.6			27.6
Approach LOS	F		E			C

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	52.5	56.5			109.0	41.0
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	68.5	* 31			* 1E2	36.5
Max Q Clear Time (g_c+I1), s	46.0	51.4			2.0	38.5
Green Ext Time (p_c), s	1.9	0.0			3.4	0.0

Intersection Summary	
HCM 6th Ctrl Delay	78.6
HCM 6th LOS	E

Notes

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Unsignalized Delay for [NBR] is excluded from calculations of the approach delay and intersection delay.

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	1053	536	1573	523	926	696
v/c Ratio	1.10	0.68	1.00	0.55	1.07	0.33
Control Delay	102.4	25.6	72.9	16.7	117.1	7.6
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	102.4	25.6	72.9	16.7	117.1	7.6
Queue Length 50th (ft)	~535	371	~568	257	~527	76
Queue Length 95th (ft)	#674	530	#683	358	#659	116
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	955	785	1567	943	865	2099
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	1.10	0.68	1.00	0.55	1.07	0.33

Intersection Summary

~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.

95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	516	1073	1573	523	926	696
Future Volume (veh/h)	516	1073	1573	523	926	696
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1682	1695	1723	1709	1641	1695
Adj Flow Rate, veh/h	516	1073	1573	523	926	696
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	5	4	2	3	8	4
Cap, veh/h	454	1648	1574	895	879	2109
Arrive On Green	0.28	0.28	0.33	0.33	0.44	0.98
Sat Flow, veh/h	1602	2874	4858	1448	3032	3306
Grp Volume(v), veh/h	516	1073	1573	523	926	696
Grp Sat Flow(s),veh/h/ln	1602	1437	1568	1448	1516	1611
Q Serve(g_s), s	42.5	38.1	50.2	32.4	43.5	0.9
Cycle Q Clear(g_c), s	42.5	38.1	50.2	32.4	43.5	0.9
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	454	1648	1574	895	879	2109
V/C Ratio(X)	1.14	0.65	1.00	0.58	1.05	0.33
Avail Cap(c_a), veh/h	454	1648	1574	895	879	2115
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	1.00	1.00	1.00	1.00	1.00
Uniform Delay (d), s/veh	53.8	21.8	49.9	17.1	42.4	0.5
Incr Delay (d2), s/veh	85.4	0.9	22.5	2.8	45.4	0.0
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	38.9	18.2	30.5	16.2	28.5	0.4
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	139.2	22.7	72.4	19.9	87.7	0.5
LnGrp LOS	F	C	E	B	F	A
Approach Vol, veh/h	1589		2096			1622
Approach Delay, s/veh	60.5		59.3			50.3
Approach LOS	E		E			D

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	48.0	55.0			103.0	47.0
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	43.5	* 50			* 99	42.5
Max Q Clear Time (g_c+I1), s	45.5	52.2			2.9	44.5
Green Ext Time (p_c), s	0.0	0.0			3.4	0.0

Intersection Summary	
HCM 6th Ctrl Delay	56.9
HCM 6th LOS	E

Notes

User approved volume balancing among the lanes for turning movement.

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	516	1073	1573	523	926	696
v/c Ratio	1.07	0.69	1.05	0.74	1.09	0.34
Control Delay	111.3	21.8	87.7	20.9	121.9	9.2
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	111.3	21.8	87.7	20.9	121.9	9.2
Queue Length 50th (ft)	~560	376	~614	150	~534	82
Queue Length 95th (ft)	#789	464	#711	305	#665	136
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	480	1559	1492	704	853	2035
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	1.07	0.69	1.05	0.74	1.09	0.34

Intersection Summary

~ Volume exceeds capacity, queue is theoretically infinite.
Queue shown is maximum after two cycles.

95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	516	1073	1573	523	926	696
Future Volume (veh/h)	516	1073	1573	523	926	696
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1682	1695	1723	1709	1641	1695
Adj Flow Rate, veh/h	516	1073	1573	523	926	696
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	5	4	2	3	8	4
Cap, veh/h	486	1490	1499	462	867	2044
Arrive On Green	0.30	0.30	0.32	0.32	0.43	0.95
Sat Flow, veh/h	1602	2529	4858	1448	3032	3306
Grp Volume(v), veh/h	516	1073	1573	523	926	696
Grp Sat Flow(s),veh/h/ln	1602	1264	1568	1448	1516	1611
Q Serve(g_s), s	45.5	45.4	47.8	47.8	42.9	2.3
Cycle Q Clear(g_c), s	45.5	45.4	47.8	47.8	42.9	2.3
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	486	1490	1499	462	867	2044
V/C Ratio(X)	1.06	0.72	1.05	1.13	1.07	0.34
Avail Cap(c_a), veh/h	486	1490	1499	462	867	2051
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	1.00	1.00	1.00	1.00	1.00
Uniform Delay (d), s/veh	52.3	22.0	51.1	51.1	42.8	1.4
Incr Delay (d2), s/veh	58.3	1.7	37.5	83.7	50.4	0.0
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	35.3	18.9	32.7	39.1	29.2	1.0
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	110.6	23.7	88.6	134.8	93.2	1.4
LnGrp LOS	F	C	F	F	F	A
Approach Vol, veh/h	1589		2096			1622
Approach Delay, s/veh	51.9		100.1			53.8
Approach LOS	D		F			D

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	47.4	52.6			100.0	50.0
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	42.9	* 48			* 96	45.5
Max Q Clear Time (g_c+I1), s	44.9	49.8			4.3	47.5
Green Ext Time (p_c), s	0.0	0.0			3.4	0.0

Intersection Summary	
HCM 6th Ctrl Delay	71.5
HCM 6th LOS	E

Notes

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	516	1073	1573	523	926	696
v/c Ratio	0.91	0.75	0.85	0.58	0.95	0.29
Control Delay	80.0	3.7	46.8	20.0	86.4	3.7
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	80.0	3.7	46.8	20.0	86.4	3.7
Queue Length 50th (ft)	256	0	523	288	490	61
Queue Length 95th (ft)	#352	0	591	403	#585	71
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	583	1430	1860	904	1005	2411
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.89	0.75	0.85	0.58	0.92	0.29

Intersection Summary

95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	516	1073	1573	523	926	696
Future Volume (veh/h)	516	1073	1573	523	926	696
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1682	1695	1723	1709	1641	1695
Adj Flow Rate, veh/h	516	0	1573	523	926	696
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	5	4	2	3	8	4
Cap, veh/h	558		1938	857	959	2443
Arrive On Green	0.18	0.00	0.41	0.41	0.47	1.00
Sat Flow, veh/h	3107	1437	4858	1448	3032	3306
Grp Volume(v), veh/h	516	0	1573	523	926	696
Grp Sat Flow(s),veh/h/ln	1554	1437	1568	1448	1516	1611
Q Serve(g_s), s	24.5	0.0	44.3	34.6	44.4	0.0
Cycle Q Clear(g_c), s	24.5	0.0	44.3	34.6	44.4	0.0
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	558		1938	857	959	2443
V/C Ratio(X)	0.92		0.81	0.61	0.97	0.28
Avail Cap(c_a), veh/h	590		1938	857	1021	2443
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	0.00	1.00	1.00	1.00	1.00
Uniform Delay (d), s/veh	60.5	0.0	39.0	19.6	38.6	0.0
Incr Delay (d2), s/veh	20.0	0.0	3.8	3.2	19.4	0.0
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	16.5	0.0	24.4	17.4	24.1	0.0
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	80.5	0.0	42.8	22.8	58.0	0.0
LnGrp LOS	F		D	C	E	A
Approach Vol, veh/h	516	A	2096			1622
Approach Delay, s/veh	80.5		37.8			33.1
Approach LOS	F		D			C

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	52.0	66.6			118.6	31.4
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	50.5	* 57			* 1.1E2	28.5
Max Q Clear Time (g_c+I1), s	46.4	46.3			2.0	26.5
Green Ext Time (p_c), s	1.0	2.2			3.4	0.4

Intersection Summary	
HCM 6th Ctrl Delay	41.2
HCM 6th LOS	D

Notes

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Unsignalized Delay for [WBR] is excluded from calculations of the approach delay and intersection delay.

Lane Group	WBL	WBR	NBT	NBR	SBL	SBT
Lane Group Flow (vph)	516	1073	1573	523	926	696
v/c Ratio	0.89	0.77	0.87	0.66	0.94	0.29
Control Delay	76.8	30.6	49.0	13.6	83.3	3.8
Queue Delay	0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	76.8	30.6	49.0	13.6	83.3	3.8
Queue Length 50th (ft)	256	436	529	102	488	61
Queue Length 95th (ft)	#352	539	598	239	#574	73
Internal Link Dist (ft)	796		243			715
Turn Bay Length (ft)		775		255	575	
Base Capacity (vph)	583	1420	1811	797	1025	2397
Starvation Cap Reductn	0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0	0
Reduced v/c Ratio	0.89	0.76	0.87	0.66	0.90	0.29

Intersection Summary

95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (veh/h)	516	1073	1573	523	926	696
Future Volume (veh/h)	516	1073	1573	523	926	696
Initial Q (Qb), veh	0	0	0	0	0	0
Ped-Bike Adj(A_pbT)	1.00	1.00		1.00	1.00	
Parking Bus, Adj	1.00	1.00	1.00	1.00	1.00	1.00
Work Zone On Approach	No		No			No
Adj Sat Flow, veh/h/ln	1682	1695	1723	1709	1641	1695
Adj Flow Rate, veh/h	516	1073	1573	523	926	696
Peak Hour Factor	1.00	1.00	1.00	1.00	1.00	1.00
Percent Heavy Veh, %	5	4	2	3	8	4
Cap, veh/h	590	1282	1886	581	961	2410
Arrive On Green	0.19	0.19	0.40	0.40	0.48	1.00
Sat Flow, veh/h	3107	2529	4858	1448	3032	3306
Grp Volume(v), veh/h	516	1073	1573	523	926	696
Grp Sat Flow(s),veh/h/ln	1554	1264	1568	1448	1516	1611
Q Serve(g_s), s	24.2	28.5	45.2	50.8	44.4	0.0
Cycle Q Clear(g_c), s	24.2	28.5	45.2	50.8	44.4	0.0
Prop In Lane	1.00	1.00		1.00	1.00	
Lane Grp Cap(c), veh/h	590	1282	1886	581	961	2410
V/C Ratio(X)	0.87	0.84	0.83	0.90	0.96	0.29
Avail Cap(c_a), veh/h	590	1282	1886	581	1041	2416
HCM Platoon Ratio	1.00	1.00	1.00	1.00	1.50	1.50
Upstream Filter(I)	1.00	1.00	1.00	1.00	1.00	1.00
Uniform Delay (d), s/veh	59.0	31.7	40.4	42.1	38.5	0.0
Incr Delay (d2), s/veh	13.7	5.0	4.5	19.5	18.6	0.0
Initial Q Delay(d3),s/veh	0.0	0.0	0.0	0.0	0.0	0.0
%ile BackOfQ(95%),veh/ln	15.8	23.4	25.0	28.1	24.0	0.0
Unsig. Movement Delay, s/veh						
LnGrp Delay(d),s/veh	72.7	36.7	44.9	61.6	57.1	0.0
LnGrp LOS	E	D	D	E	E	A
Approach Vol, veh/h	1589		2096			1622
Approach Delay, s/veh	48.4		49.1			32.6
Approach LOS	D		D			C

Timer - Assigned Phs	1	2			6	8
Phs Duration (G+Y+Rc), s	52.0	65.0			117.0	33.0
Change Period (Y+Rc), s	4.5	* 4.8			* 4.8	4.5
Max Green Setting (Gmax), s	51.5	* 56			* 1.1E2	28.5
Max Q Clear Time (g_c+I1), s	46.4	52.8			2.0	30.5
Green Ext Time (p_c), s	1.2	1.3			3.4	0.0

Intersection Summary	
HCM 6th Ctrl Delay	43.8
HCM 6th LOS	D

Notes

* HCM 6th computational engine requires equal clearance times for the phases crossing the barrier.

Lane Group	WBL	NBT	NBR	SBT
Lane Group Flow (vph)	516	1573	523	696
v/c Ratio	0.62	0.71	0.89	0.32
Control Delay	5.1	19.7	42.3	9.8
Queue Delay	0.0	0.0	4.8	0.0
Total Delay	5.1	19.7	47.1	9.8
Queue Length 50th (ft)	5	476	269	97
Queue Length 95th (ft)	5	744	387	176
Internal Link Dist (ft)	69	243		715
Turn Bay Length (ft)			255	
Base Capacity (vph)	1126	2201	699	2158
Starvation Cap Reductn	29	0	0	0
Spillback Cap Reductn	0	0	116	0
Storage Cap Reductn	0	0	0	0
Reduced v/c Ratio	0.47	0.71	0.90	0.32

Intersection Summary

Movement	WBL	WBR	NBT	NBR	SBL	SBT
Lane Configurations						
Traffic Volume (vph)	516	0	1573	523	0	696
Future Volume (vph)	516	0	1573	523	0	696
Ideal Flow (vphpl)	1750	1750	1750	1750	1750	1750
Total Lost time (s)	4.0		4.0	4.0		4.0
Lane Util. Factor	0.97		0.95	1.00		0.95
Frt	1.00		1.00	0.85		1.00
Flt Protected	0.95		1.00	1.00		1.00
Satd. Flow (prot)	3072		3260	1444		3197
Flt Permitted	0.95		1.00	1.00		1.00
Satd. Flow (perm)	3072		3260	1444		3197
Peak-hour factor, PHF	1.00	1.00	1.00	1.00	1.00	1.00
Adj. Flow (vph)	516	0	1573	523	0	696
RTOR Reduction (vph)	0	0	0	195	0	0
Lane Group Flow (vph)	516	0	1573	328	0	696
Heavy Vehicles (%)	5%	0%	2%	3%	0%	4%
Turn Type	Prot		NA	custom		NA
Protected Phases	8		2	4		2
Permitted Phases						
Actuated Green, G (s)	40.7		101.3	40.7		101.3
Effective Green, g (s)	40.7		101.3	40.7		101.3
Actuated g/C Ratio	0.27		0.68	0.27		0.68
Clearance Time (s)	4.0		4.0	4.0		4.0
Vehicle Extension (s)	3.0		3.0	3.0		3.0
Lane Grp Cap (vph)	833		2201	391		2159
v/s Ratio Prot	0.17		c0.48	c0.23		0.22
v/s Ratio Perm						
v/c Ratio	0.62		0.71	0.84		0.32
Uniform Delay, d1	47.9		15.3	51.5		10.1
Progression Factor	0.04		1.00	1.00		0.81
Incremental Delay, d2	1.3		2.0	14.5		0.3
Delay (s)	3.3		17.3	66.0		8.6
Level of Service	A		B	E		A
Approach Delay (s)	3.3		29.5			8.6
Approach LOS	A		C			A

Intersection Summary			
HCM 2000 Control Delay	21.0	HCM 2000 Level of Service	C
HCM 2000 Volume to Capacity ratio	0.75		
Actuated Cycle Length (s)	150.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	69.9%	ICU Level of Service	C
Analysis Period (min)	15		
c Critical Lane Group			

Lane Group	WBR	NBT	SBL	SBT	NER2
Lane Group Flow (vph)	1073	1573	926	1608	30
v/c Ratio	0.74	0.57	0.85	0.50	0.02
Control Delay	2.2	5.3	61.6	1.2	0.0
Queue Delay	0.4	0.1	49.8	0.0	0.0
Total Delay	2.6	5.5	111.4	1.2	0.0
Queue Length 50th (ft)	0	221	452	15	0
Queue Length 95th (ft)	0	15	531	12	0
Internal Link Dist (ft)		715		374	
Turn Bay Length (ft)					
Base Capacity (vph)	1452	2772	1174	3195	1484
Starvation Cap Reductn	0	0	376	0	0
Spillback Cap Reductn	85	282	0	0	0
Storage Cap Reductn	0	0	0	0	0
Reduced v/c Ratio	0.78	0.63	1.16	0.50	0.02

Intersection Summary

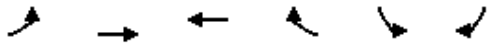
Movement	WBL	WBR	NBL	NBT	NBR	SBL	SBT	SBR	NEL	NER	NER2
Lane Configurations											
Traffic Volume (vph)	0	1073	0	1573	0	926	1596	12	0	0	30
Future Volume (vph)	0	1073	0	1573	0	926	1596	12	0	0	30
Ideal Flow (vphpl)	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750
Total Lost time (s)		4.0		4.0		4.0	4.0				4.0
Lane Util. Factor		1.00		0.91		0.97	0.95				1.00
Frt		0.86		1.00		1.00	1.00				0.86
Flt Protected		1.00		1.00		0.95	1.00				1.00
Satd. Flow (prot)		1456		4778		2986	3194				1484
Flt Permitted		1.00		1.00		0.95	1.00				1.00
Satd. Flow (perm)		1456		4778		2986	3194				1484
Peak-hour factor, PHF	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Adj. Flow (vph)	0	1073	0	1573	0	926	1596	12	0	0	30
RTOR Reduction (vph)	0	0	0	0	0	0	0	0	0	0	0
Lane Group Flow (vph)	0	1073	0	1573	0	926	1608	0	0	0	30
Heavy Vehicles (%)	2%	4%	0%	0%	0%	8%	4%	0%	2%	2%	2%
Turn Type		pt+ov		NA		Prot	NA				Perm
Protected Phases		2 1!		2!		1	6				
Permitted Phases											6
Actuated Green, G (s)		150.0		87.1		54.9	150.0				150.0
Effective Green, g (s)		150.0		87.1		54.9	150.0				150.0
Actuated g/C Ratio		1.00		0.58		0.37	1.00				1.00
Clearance Time (s)				4.0		4.0	4.0				4.0
Vehicle Extension (s)				3.0		3.0	3.0				3.0
Lane Grp Cap (vph)		1456		2774		1092	3194				1484
v/s Ratio Prot		c0.74		0.33		c0.31	0.50				
v/s Ratio Perm											0.02
v/c Ratio		0.74		0.57		0.85	0.50				0.02
Uniform Delay, d1		0.0		19.7		43.7	0.0				0.0
Progression Factor		1.00		0.23		1.24	1.00				1.00
Incremental Delay, d2		1.3		0.6		6.0	0.5				0.0
Delay (s)		1.3		5.2		60.1	0.5				0.0
Level of Service		A		A		E	A				A
Approach Delay (s)	1.3			5.2			22.3		0.0		
Approach LOS	A			A			C		A		

Intersection Summary			
HCM 2000 Control Delay	12.7	HCM 2000 Level of Service	B
HCM 2000 Volume to Capacity ratio	0.80		
Actuated Cycle Length (s)	150.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	111.8%	ICU Level of Service	H
Analysis Period (min)	15		

! Phase conflict between lane groups.
c Critical Lane Group

Lane Group	EBT	WBT	WBR	SBL
Lane Group Flow (vph)	523	516	1073	926
v/c Ratio	0.60	0.60	0.75	0.46
Control Delay	26.2	49.4	3.7	15.7
Queue Delay	2.0	0.0	0.0	0.0
Total Delay	28.1	49.4	3.7	15.7
Queue Length 50th (ft)	119	232	0	490
Queue Length 95th (ft)	94	255	0	566
Internal Link Dist (ft)	69	647		615
Turn Bay Length (ft)				
Base Capacity (vph)	1183	1161	1430	2016
Starvation Cap Reductn	488	0	0	0
Spillback Cap Reductn	0	0	0	0
Storage Cap Reductn	0	0	0	0
Reduced v/c Ratio	0.75	0.44	0.75	0.46

Intersection Summary



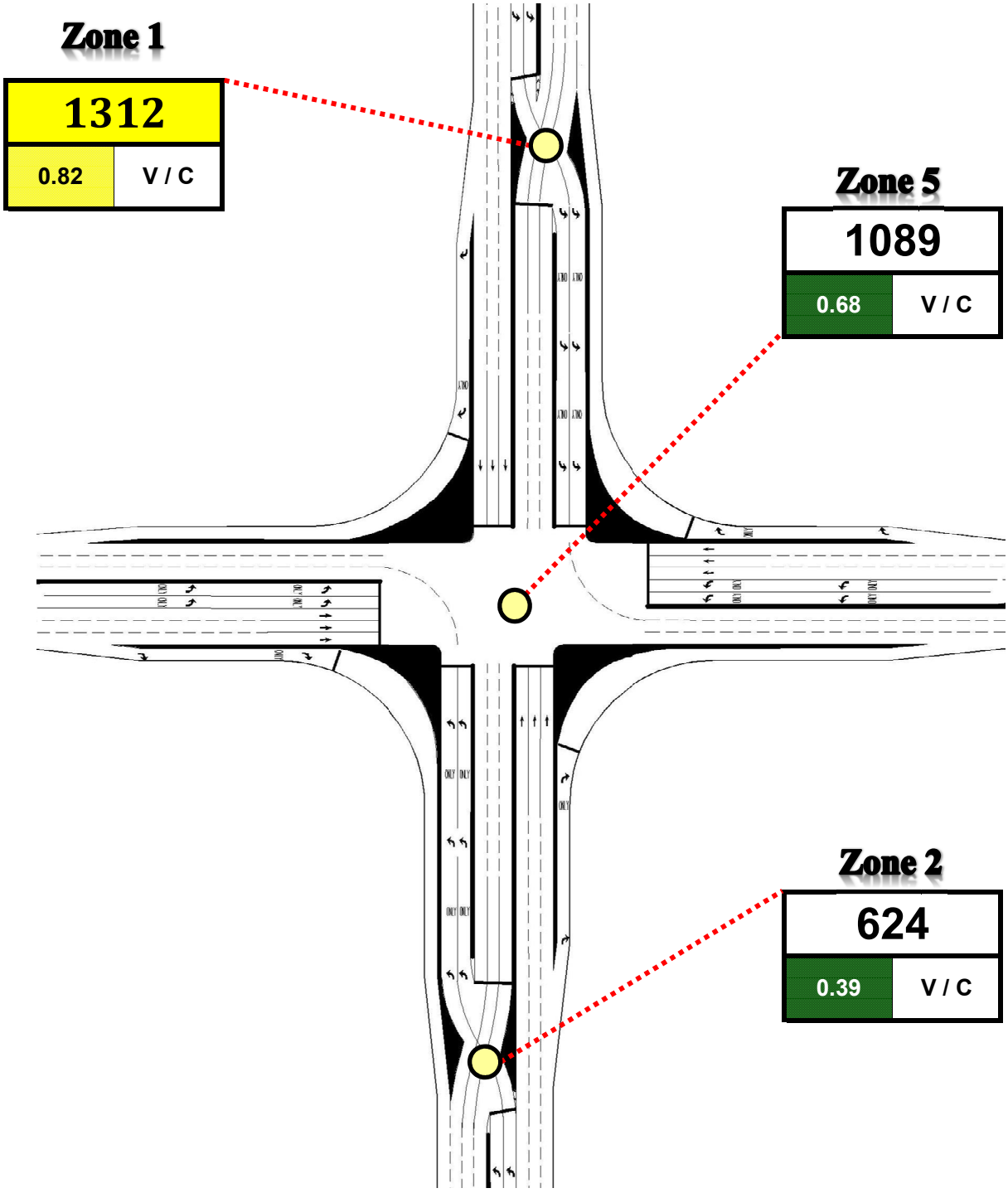
Movement	EBL	EBT	WBT	WBR	SBL	SBR
Lane Configurations						
Traffic Volume (vph)	0	523	516	1073	926	0
Future Volume (vph)	0	523	516	1073	926	0
Ideal Flow (vphpl)	1750	1750	1750	1750	1750	1750
Total Lost time (s)		4.0	4.0	4.0	4.0	
Lane Util. Factor		0.95	0.95	1.00	0.97	
Frt		1.00	1.00	0.85	1.00	
Flt Protected		1.00	1.00	1.00	0.95	
Satd. Flow (prot)		3228	3167	1430	2986	
Flt Permitted		1.00	1.00	1.00	0.95	
Satd. Flow (perm)		3228	3167	1430	2986	
Peak-hour factor, PHF	1.00	1.00	1.00	1.00	1.00	1.00
Adj. Flow (vph)	0	523	516	1073	926	0
RTOR Reduction (vph)	0	0	0	0	0	0
Lane Group Flow (vph)	0	523	516	1073	926	0
Heavy Vehicles (%)	2%	3%	5%	4%	8%	2%
Turn Type		NA	NA	Free	Prot	
Protected Phases		8	4		2	
Permitted Phases				Free		
Actuated Green, G (s)		40.7	40.7	150.0	101.3	
Effective Green, g (s)		40.7	40.7	150.0	101.3	
Actuated g/C Ratio		0.27	0.27	1.00	0.68	
Clearance Time (s)		4.0	4.0		4.0	
Vehicle Extension (s)		3.0	3.0		3.0	
Lane Grp Cap (vph)		875	859	1430	2016	
v/s Ratio Prot		0.16	0.16		0.31	
v/s Ratio Perm				c0.75		
v/c Ratio		0.60	0.60	0.75	0.46	
Uniform Delay, d1		47.5	47.6	0.0	11.5	
Progression Factor		0.52	1.00	1.00	1.16	
Incremental Delay, d2		0.7	1.2	3.7	0.4	
Delay (s)		25.6	48.8	3.7	13.8	
Level of Service		C	D	A	B	
Approach Delay (s)		25.6	18.3		13.8	
Approach LOS		C	B		B	

Intersection Summary			
HCM 2000 Control Delay	18.2	HCM 2000 Level of Service	B
HCM 2000 Volume to Capacity ratio	0.79		
Actuated Cycle Length (s)	150.0	Sum of lost time (s)	8.0
Intersection Capacity Utilization	51.0%	ICU Level of Service	A
Analysis Period (min)	15		
c Critical Lane Group			

Partial Displaced Left Turn Intersection (N-S)

Design and Results

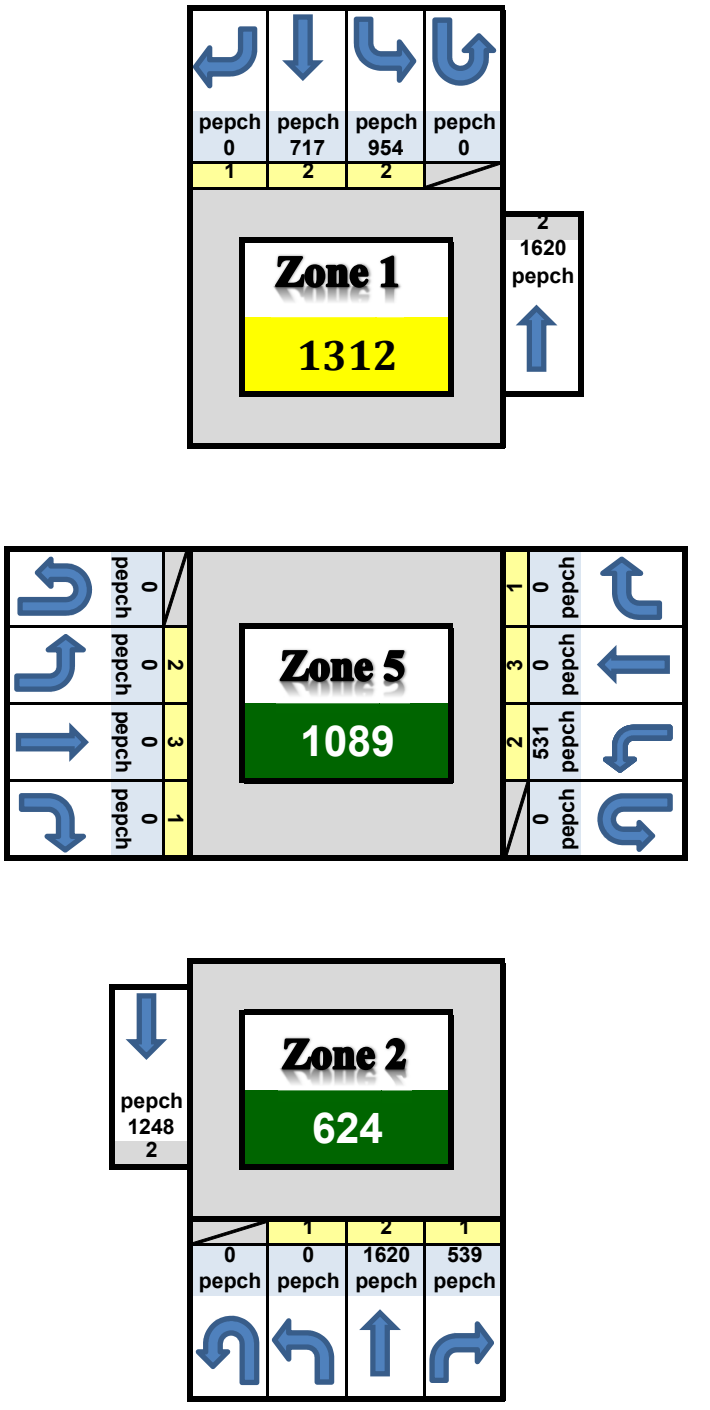
		Critical Lane Volume Sum			
Project Name:	*Exposition Drive & 1st Avenue N*	< 1200	1200 - 1399	1400 - 1599	≥ 1600
Project Number:	*20783_112*	VOLUME / CAPACITY RATIO:		0.82	
Location	*Billings, MT*				
Date	May 28, 2019				



Note: This diagram does not reflect the actual lane configuration of the Intersection

Partial Displaced Left Turn Intersection (N-S)

Data Input and Configuration



Back to Results