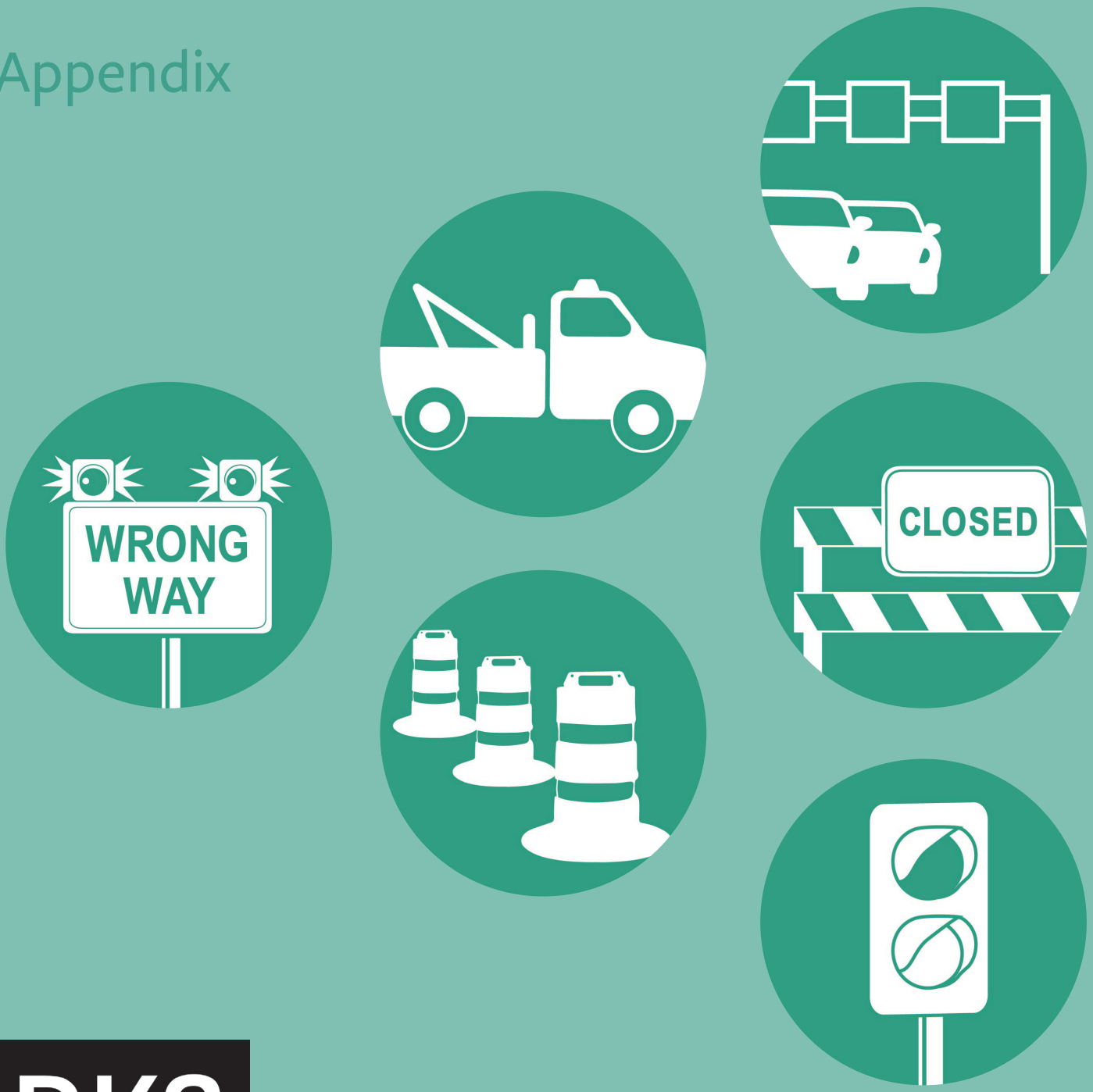
FINAL REPORT

I-90 Operations Study

May 2018

Appendix



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FINAL REPORT

I-90 Operations Study

May 2018

Appendix A

Existing Conditions Report

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I-90: Four Lakes to Idaho Stateline

Operations Study

EXISTING CONDITIONS FINAL REPORT

March 2017

Document Description

Client	WSDOT Eastern Region
Contract Number	
Project / Proposal Name	I-90: Four Lakes to Idaho Stateline Operations Study
Related Task	
Prepared By	DKS Associates
Document Name	Existing Conditions Report
Date Document Approved	

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2	2/2/2017	Revised Draft	DKS
3	3/10/2017	Final Report	DKS
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INTRODUCTION

Interstate 90 (I-90) through the Spokane region was completed in 1974, and since that time, the region has come to rely upon the interstate as an essential transportation corridor for the regional and interstate movement of people and goods. As the region's population grew, traffic volumes increased on I-90. Higher traffic volumes, combined with crashes, construction work zones and other incidents have increased the operational strain on I-90.

The I-90: Four Lakes to Idaho Stateline Operations Study details current issues and needs and develops an operations strategy for improving safety and managing traffic flow within the I-90 corridor over the next ten years. In this study, practical solutions that maximize benefits for travelers without adding new lanes to I-90 will be examined. This report describes the existing corridor conditions including corridor travel characteristics, crashes and incidents, transportation system management and operations activities, and planned/funded projects.

KEY FINDINGS

The existing conditions analysis identified both safety and travel time reliability as the primary concerns for the I-90 corridor through the Spokane metropolitan region.

Safety Findings

- **Crashes on I-90 have steadily increased over the past five years.** Crashes increased 22 percent between 2011 and 2015 in the study corridor. Crashes contribute significantly to non-recurring traffic congestion on I-90.
- **Crashes occur almost daily on I-90.** Between 2011 and 2015, the I-90 corridor experienced 3,600 crashes. The increasing number of crashes create unpredictable travel times for autos, transit and freight.
- **I-90 on- and off-ramp traffic regularly queues onto the mainline at some interchanges.** As traffic volumes continue to increase, queues form on the off-ramps with vehicles backing onto I-90. The ramp queues create a safety hazard by increasing the likelihood of rear-end crashes. Locations where queuing has been observed include:
    - Eastbound off-ramp at Division
    - Westbound off-ramp at Maple/Walnut
    - Eastbound off-ramp at Maple/Walnut
    - Westbound Lincoln off-ramp
- **Many I-90 on- and off-ramps experience a higher than expected number of crashes**. Closely spaced interchanges along with short weave and merge areas on the mainline, particularly through downtown Spokane, contribute to the higher than expected volume of crashes. The following locations are crash hotspots:
    - Eastbound on-ramp from US 195 (short acceleration and merge area)
    - Eastbound and westbound on-ramps at the Hamilton interchange (short weave area)

  - Eastbound on-ramp from Freya (short acceleration and merge area)
  - Interchange at Exit 280: Maple/4th/Walnut/Division including on-ramps, off-ramps and terminals intersections (short spacing between on- and off-ramps)
  - Interchange at Exit 281: Division/Browne Street including on-ramps, off-ramps and terminals intersections (observed queueing spilling onto mainline)

- **Weather and poor driving behavior contribute to the majority of I-90 crashes.** Inclement weather, exceeding a reasonably safe speed, and following too closely represent 84 percent of the contributing factors to crashes.
- **Rear-end, sideswipe and fixed object crashes occur most frequently on I-90**. Rear-end and sideswipe crashes make up 59 percent of total crashes between 2011 and 2015. Crashes with a fixed object are the third most common crash type accounting for 30 percent of the total.
- **Driving under the influence (DUI) is the leading cause of high severity crashes on I-90.** Close to 25 percent of all high severity crashes are DUI-related.

Travel Reliability Findings

- **Traffic volumes are steadily increasing on I-90**. Between 2012 and 2015 traffic volumes rose by an average of 10 percent in the corridor.
- **Traffic patterns have a distinctive peak travel direction**. Westbound traffic volumes rise during the morning rush hour and eastbound volumes rise in the evening rush hour. Congestion and reliability issues are more likely to occur westbound in the mornings and eastbound in the evenings.
- **Incidents are a growing cause of unreliable travel times on I-90.** Over the last five years, unplanned incidents along the corridor increased by 40 percent. Incidents includes crashes along with other reported events such as disabled vehicles, debris on the roadway, and construction or maintenance events that disrupt the normal flow of traffic.

CORRIDOR CHARACTERISTICS

The project study corridor comprises a 30-mile corridor of I-90 through the Spokane metropolitan area, from the southwest where it connects to SR 904, through the cities of Spokane, Spokane Valley, and Liberty Lake to the east where it meets the Idaho border. For analysis of the corridor operations, four distinct segments, labeled segments A through D, are used because they reflect different land use (urban/rural) and traffic volume characteristics. Figure 1 illustrates the project limits from Four Lakes, west of Spokane, to the Washington/Idaho state line, and distinguishes the analysis segments.

This section presents the corridor characteristics organized by the four segments, including roadway characteristics, traffic volumes, travel time reliability, and a summary of WSDOT's most recent Corridor Capacity Report.

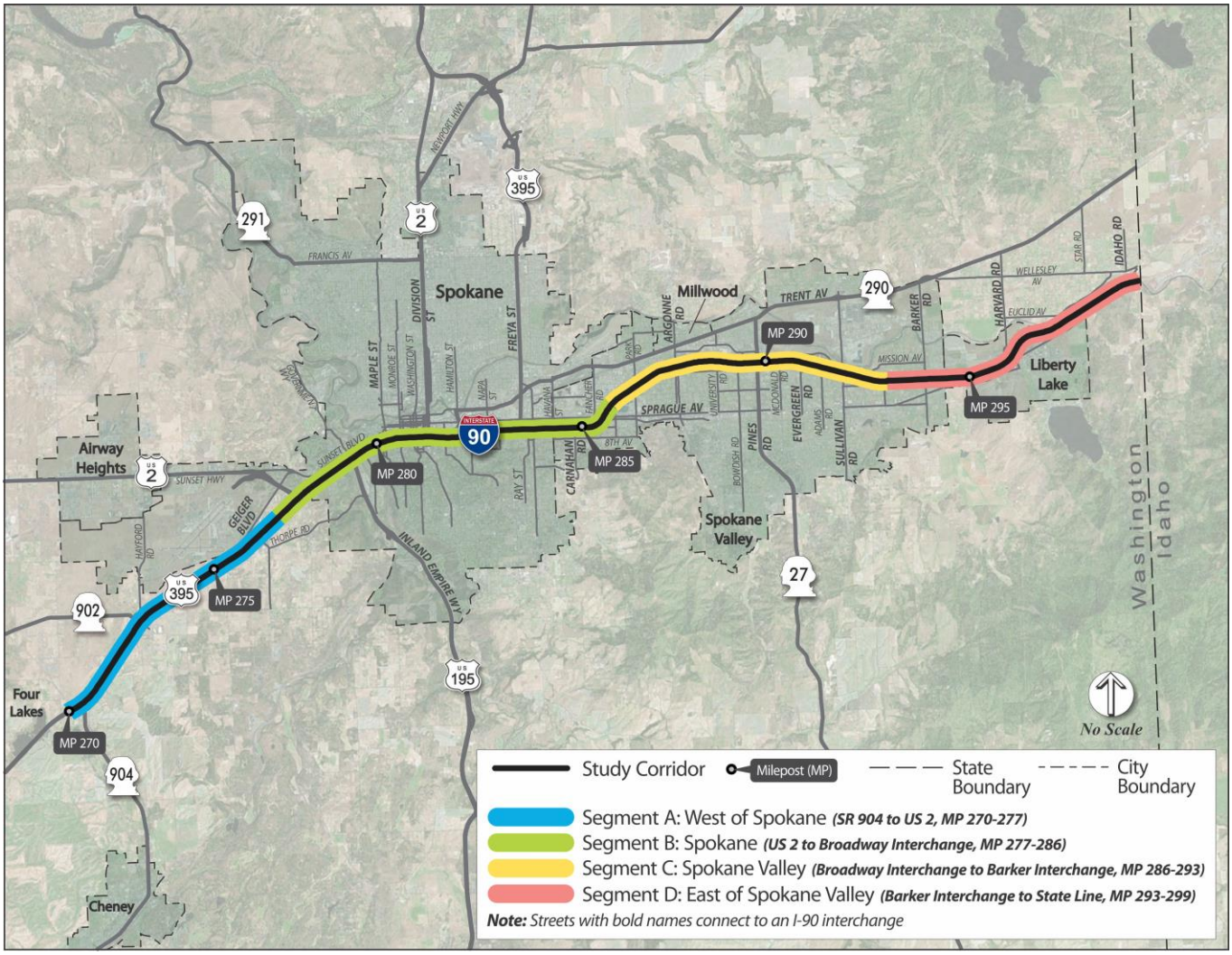

Figure 1. I-90 Corridor Study Area

Roadway Characteristics

Table 1 shows some of the typical roadway characteristics for each study segment including length, posted speed, lanes, shoulders, ramps, interchange spacing, type of median, and any other unique characteristics.

Along segments A and D, most of I-90 has shoulders available for disabled vehicles, appropriate spacing between interchanges[1], and grassy medians. In segments B and C, the interchanges are closely spaced with short weave and merge areas, there are limited or no shoulders through some areas, and the median is a concrete barrier which limits emergency vehicle access and inside shoulder width.

Table 1: Corridor Segment Roadway Characteristics

	Segment A: West of Spokane (MP 270-277)	Segment B: Spokane (MP 277- 286)	Segment C: Spokane Valley (MP 286-293)	Segment D: E. of Spokane Valley (MP 293-299)
Segment Length*	6.8 miles	8.6 miles	7.8 miles	5.8 miles
Posted Speed	70 mph (60 mph for trucks)	60 mph	60 mph	70 mph (60 mph for trucks)
Lanes (per direction)	2-3	3-5	3-4	2
Shoulders	Yes (inside and outside)	Some outside shoulders. No parking, tow away zone.	Yes (outside)	Yes (outside mainly)
Number of Entrance Ramps	Eastbound - 4 Westbound - 4	Eastbound - 9 Westbound - 9	Eastbound - 4 Westbound - 6	Eastbound – 4 Westbound – 3
Interchange Spacing	1 to 4 miles	< 1 to 2 miles	< 1 to 2 miles	2 to 3 miles
Median Barrier	Concrete or grassy median	Concrete	Concrete	Cable barrier or grassy median
Unique Characteristics	N/A	5% downgrade eastbound (approx. MP 277 to 279)	N/A	N/A

*The milepost range used for each segment is rounded and the segment length represents the mileage of the segment.

Figure 2 (2a and 2b) displays the lane geometry and interchange spacing for the I-90 corridor. WSDOT design manual requirements between on-off ramps for weaving is a minimum of 1,000 feet, and 800 feet between two

[1] The WSDOT design manual defines standard interchange spacing as one-mile minimum spacing between interchanges in urban areas, and three mile spacing in rural areas. (WSDOT Design Manual. M22-01.12. Section 1360.02. November 2015.)

off-ramps or two on-ramps. Eleven merge and weave areas along the corridor do not meet current performance expectations due to short spacing. Table 2 lists the eleven areas by segment.

Table 2: Merge and Weave Areas Not Meeting Performance Expectations

Segment A: West of Spokane (MP 270-277)	
Location	**Lane Geometry and/or Spacing Issues**
Westbound between the Grove Rd on-ramp and Geiger Blvd on-ramp	Short merge area
Segment B: Spokane (MP 277- 286)	
Location	**Lane Geometry and/or Spacing Issues**
Eastbound on-ramp from I-195	Short acceleration and merge area
Eastbound on-ramp from Maple/Walnut	Short distance between the on-ramp from Maple/Walnut and from Lincoln/Monroe
Eastbound between Hamilton on-ramp and Altamont off-ramp (Exit 283A)	Short weave area
Eastbound between Altamont on-ramp and Freya off-ramp (Exit 283B)	Short weave area
Eastbound on-ramp from Freya	Short acceleration/merge area
Westbound between Freya on-ramp and Altamont off-ramp (Exit 283A)	Short weave area
Westbound between Altamont on-ramp and Hamilton off-ramp (Exit 282B)	Short weave area
Westbound between Exit 282B off-ramp and Exit 282A off-ramp	Short spacing between off-ramps
Westbound between Division Street on Exit 280B	Short weave area
Westbound between Exit 280B and Exit 280A	Short spacing between off-ramps

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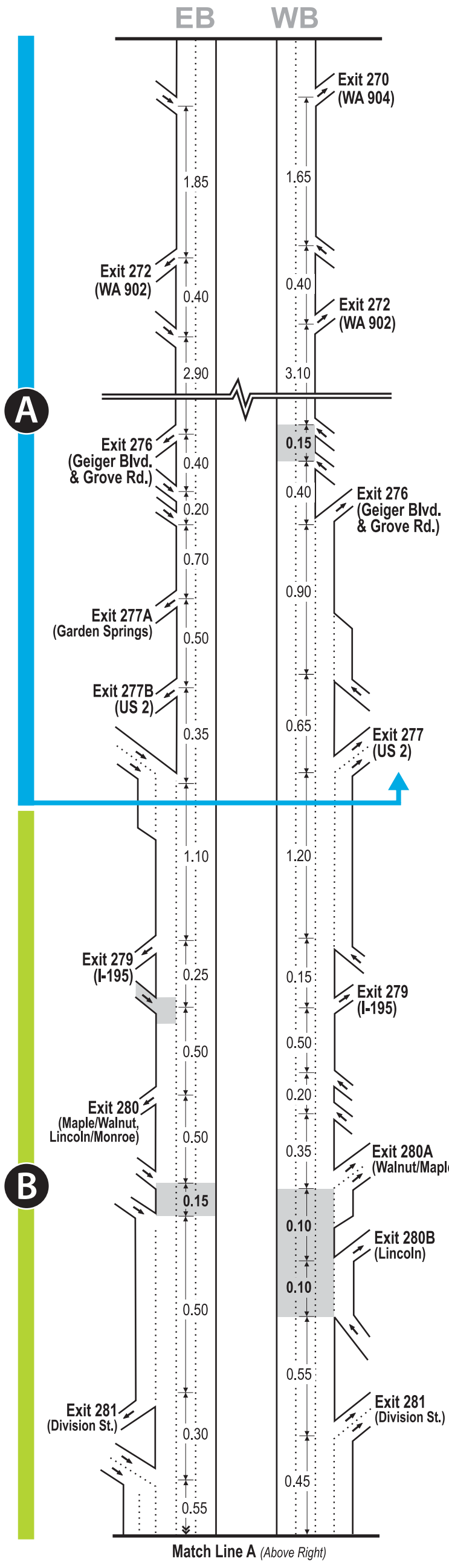

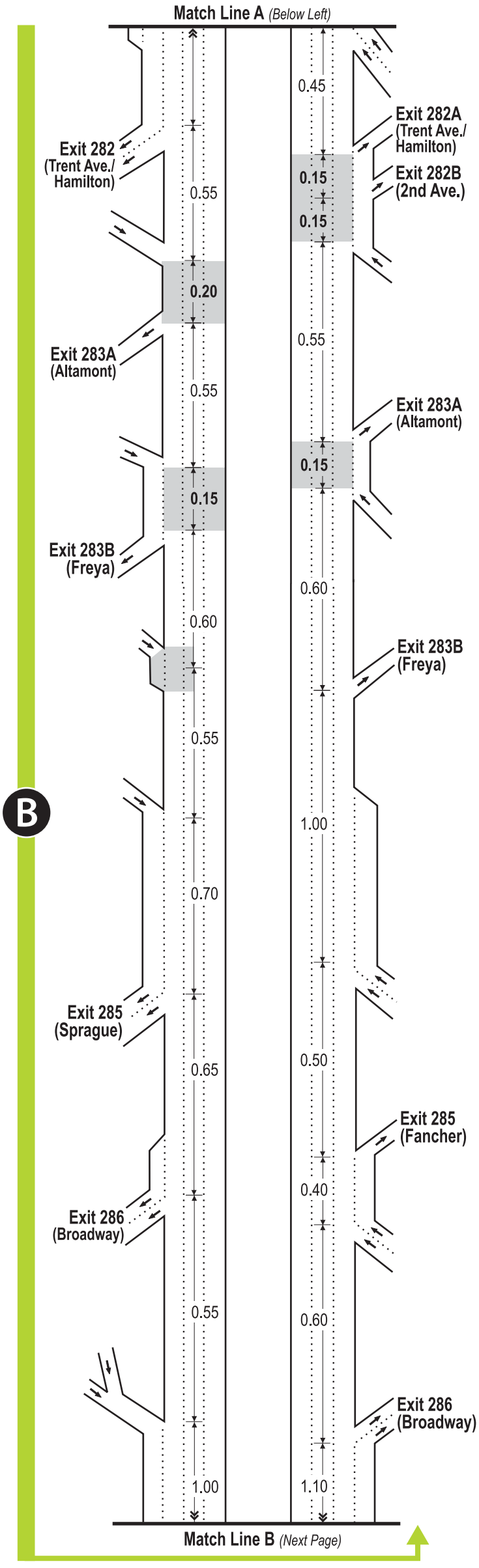

NOT TO SCALE

LEGEND

X - Segment (Color Coded)

0.00 - Distance In Miles Between Interchange Gore Areas (Rounded to Nearest 0.05)

0.00 - Merge or Weave Areas That Do Not Meet Current Performance Expectations or Have Observed Safety Problems

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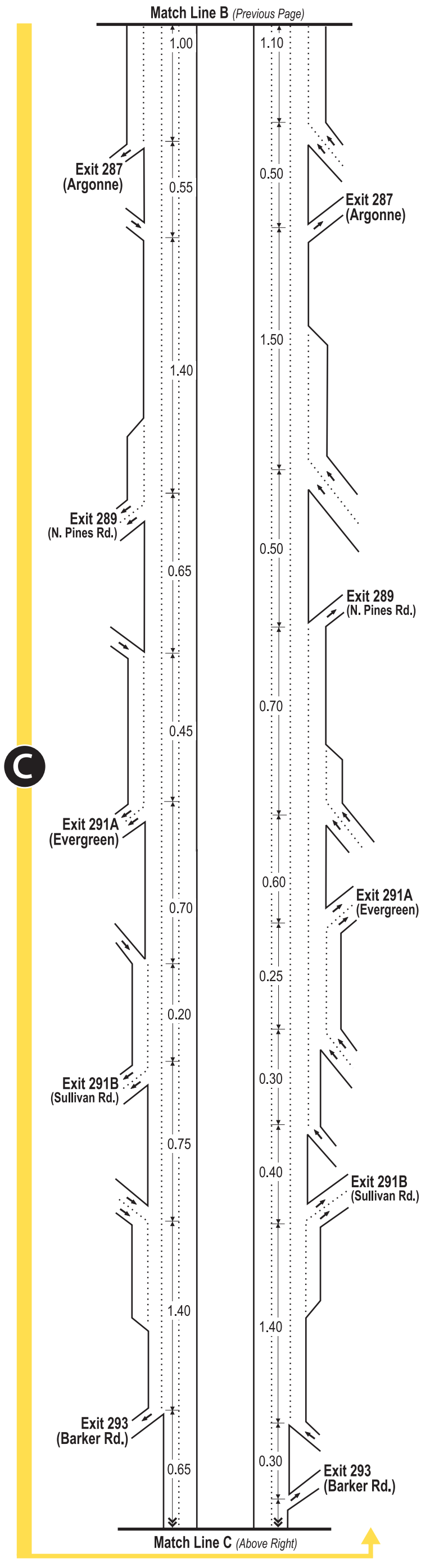
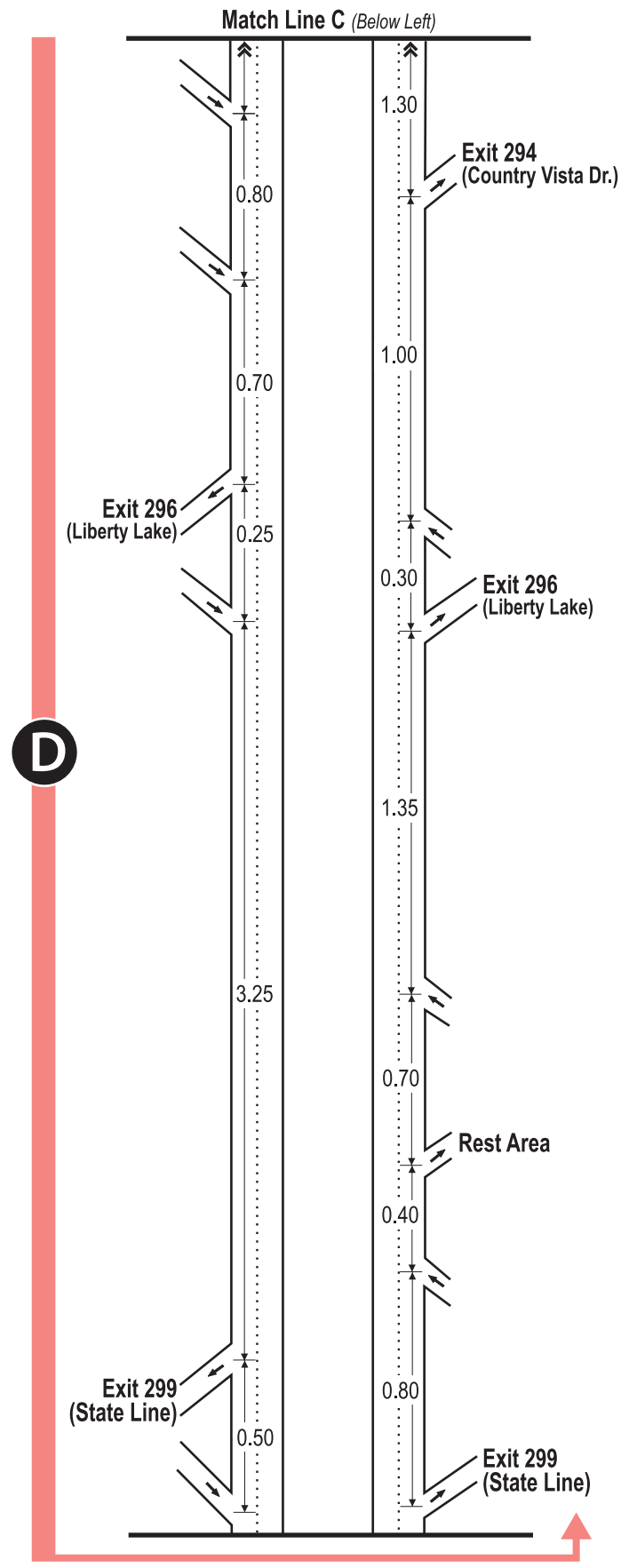
Figure 2a

I-90 Lane Geometry & Interchange Spacing





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LEGEND

X - Segment (Color Coded)

0.00 - Distance In Miles Between Interchange Gore Areas (Rounded to Nearest 0.05)

0.00 - Merge or Weave Areas That Do Not Meet Current Performance Expectations or Have Observed Safety Problems

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Figure **2b**

I-90 Lane Geometry & Interchange Spacing

Traffic Volumes

Between 2012 and 2015, traffic volumes along I-90 increased by approximately 10 percent in each direction. Figure 3 illustrates the growth in traffic volumes in each of the corridor's four segments.

- Segment B, through downtown Spokane, experienced the highest westbound growth rate with a nearly 16 percent increase in westbound traffic volumes and nearly a 12 percent increase in eastbound traffic volumes.
- Segment D, east of Spokane Valley, experienced the largest percentage increase in eastbound traffic volumes with an increase over 13 percent.

Traffic volumes on I-90 increased by more than 10% in each direction over the last four years, which contributes to decreased travel time reliability.

Figure 4 illustrates the average hourly and daily traffic volumes along the corridor's four segments. Volumes are based on data from 2012 to 2014.

- Segment B, through downtown Spokane, experiences the highest traffic volumes on the corridor with more than 85,000 vehicles per day. Segment A, west of Spokane, experiences the lowest traffic volumes with over 30,000 vehicles per day.
- Morning peak volumes show a westbound commute-related directionality, evening peak volumes show an eastbound commute-related directionality, and midday traffic volumes are balanced. This suggests that congestion and reliability issues are more likely to occur westbound in the mornings and eastbound in the evenings

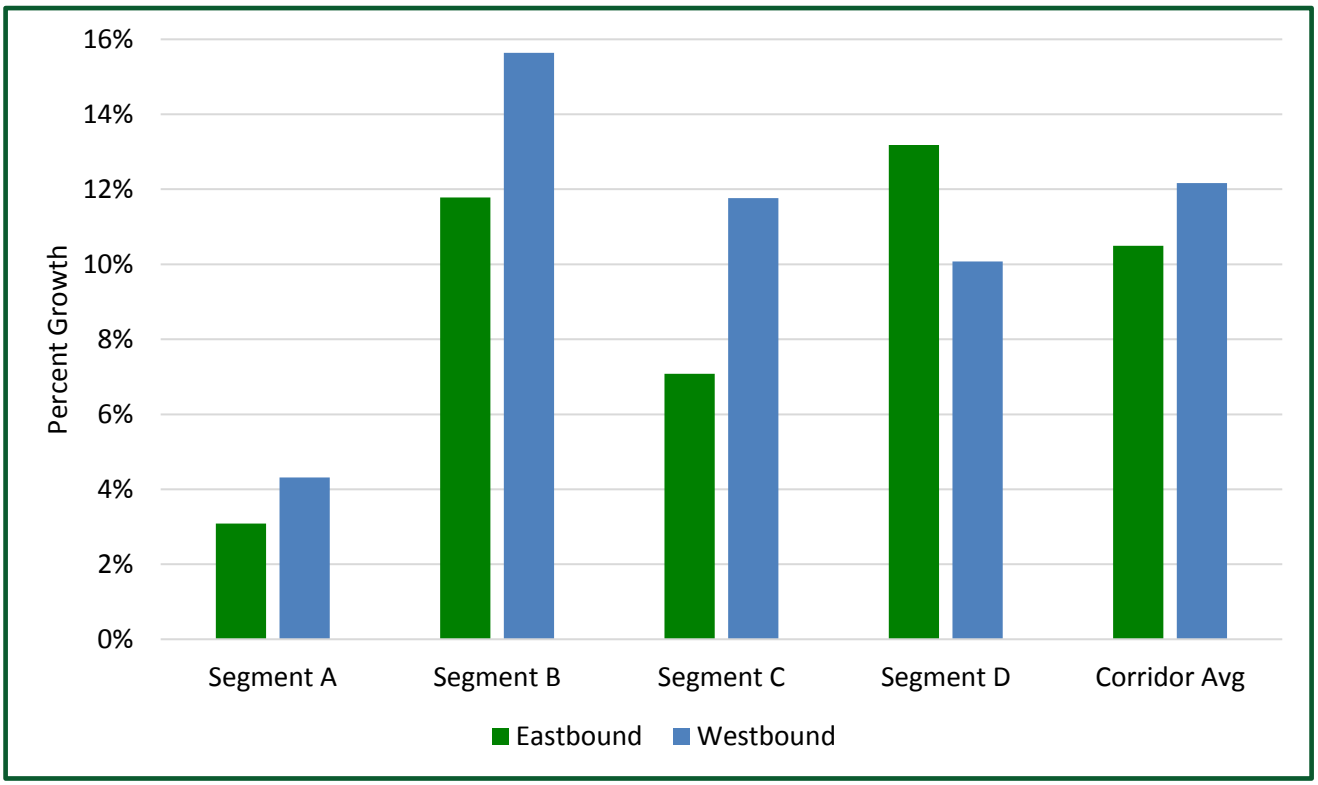


Figure 3: Traffic Volume Change Between 2012 and 2015 (*Data Source: PeMS*)

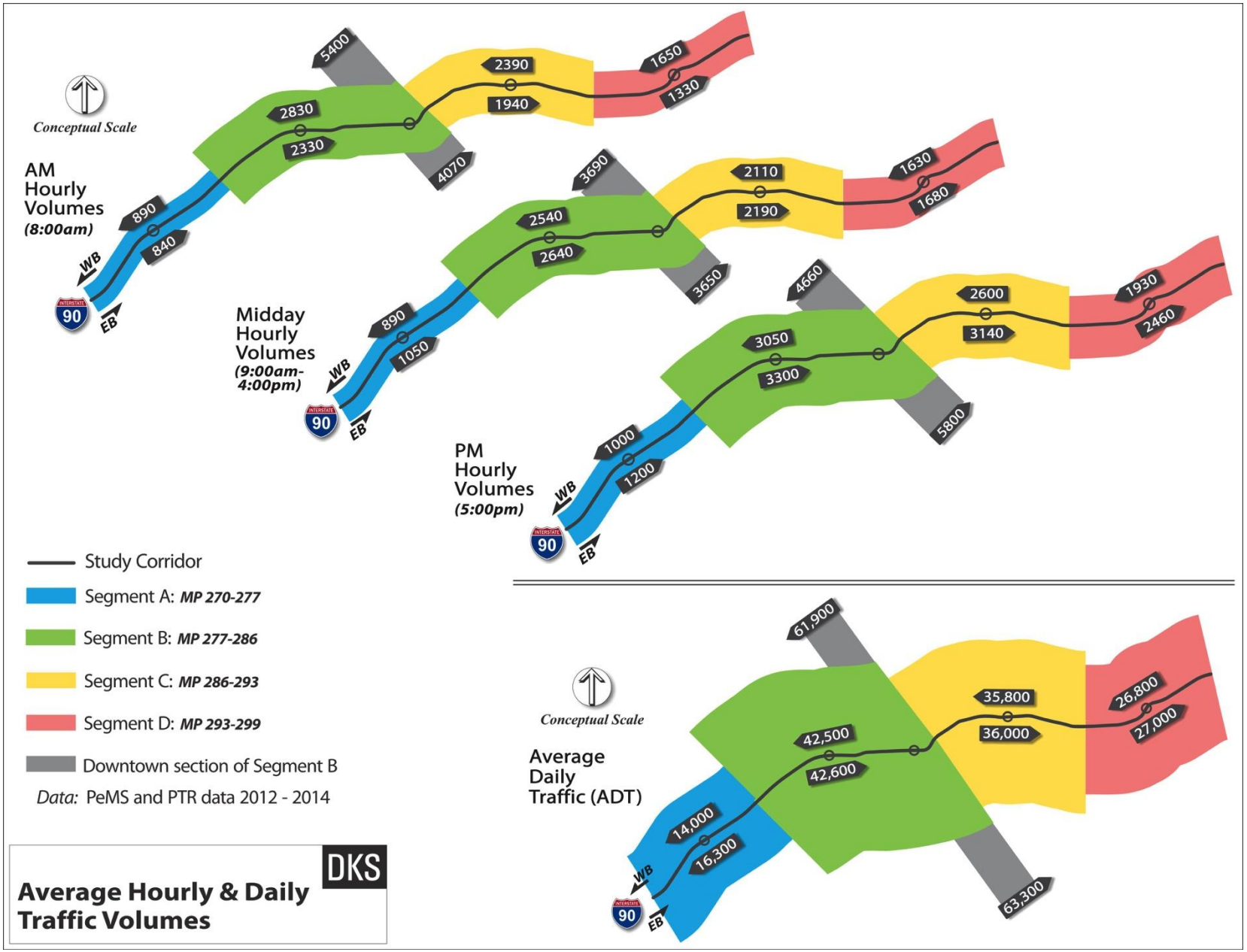


Figure 4: Average Hourly & Daily Traffic Volumes

Travel Time Reliability

Travel time reliability is a measure of how consistent travel times are from day to day. Drivers want to know that their travel time will be consistent from one day to the next, and tend to remember the days when travel time is longer than normal. The travel time reliability measure is also a good indicator of the amount of delay caused by congestion and or unexpected incidents.

In addition to heavy volumes during peak periods, many other factors affect the safe and efficient flow of traffic on I-90. Examples are shown in Figure 5.

For this analysis, planning time is used to determine the reliability of trips on I-90 in the a.m., midday, and p.m. peak time periods. Planning time is a measure of how much time is necessary to ensure on-time arrival 95 percent of the time, and is an indicator of congested conditions. For example, if a trip normally takes 20 minutes, but the 95th percentile travel time is 32 minutes, then the traveler must plan to leave 32 minutes prior to arrival to ensure on-time arrival. The closer the planning time is to the average travel time, the less congested the trip.

Travel time and traffic volume trends for are shown by segment in Figure 6 through Figure 9.

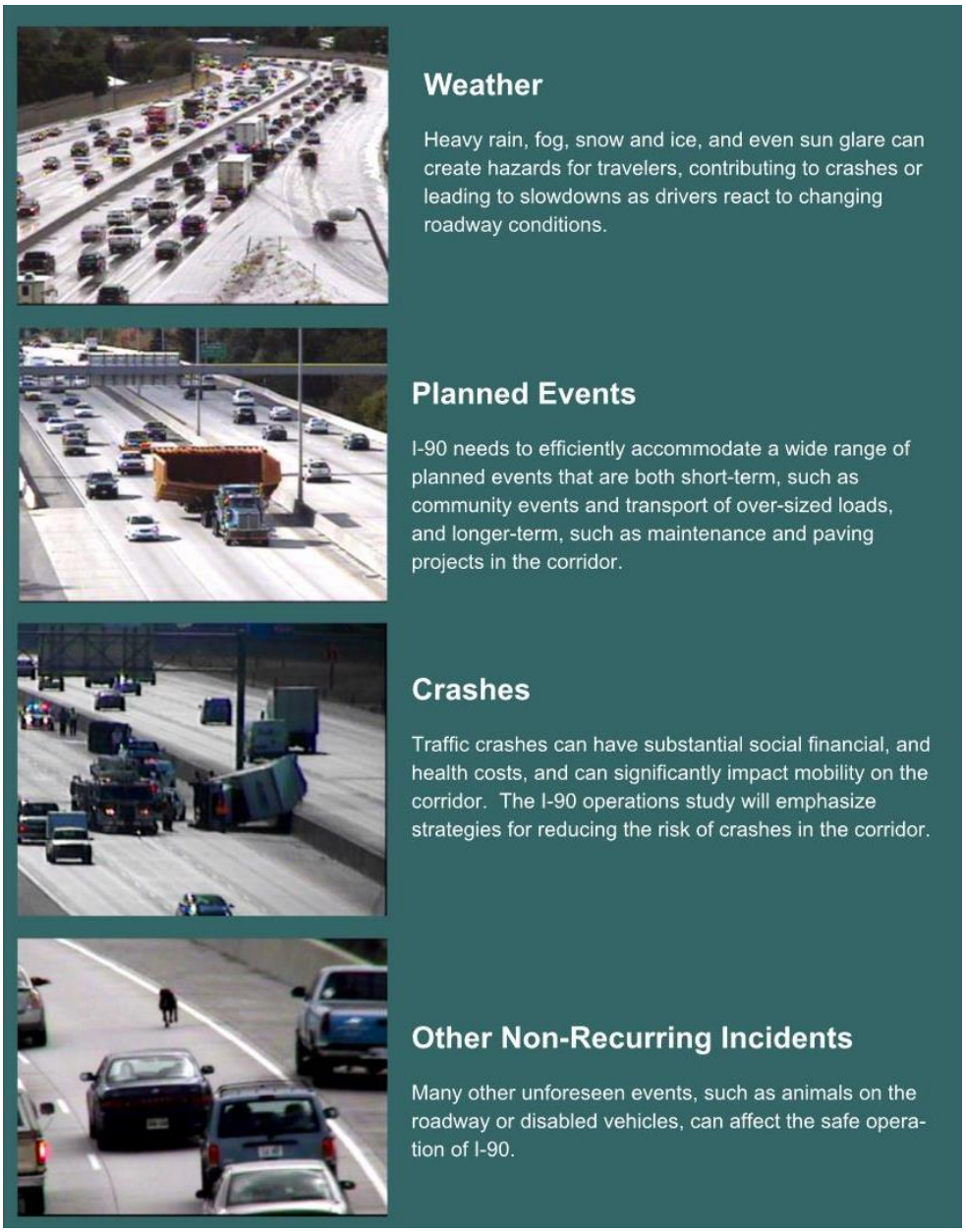


Figure 5: Additional factors affecting travel time

Segment A provides access to Spokane International Airport and the communities west of downtown Spokane. As illustrated in Figure 6, it experiences the least amount of variation in travel times for any of the segments. Although traffic volumes between 2012 and 2015 have increased 9% in the eastbound p.m. peak direction, travel time reliability has remained the same.

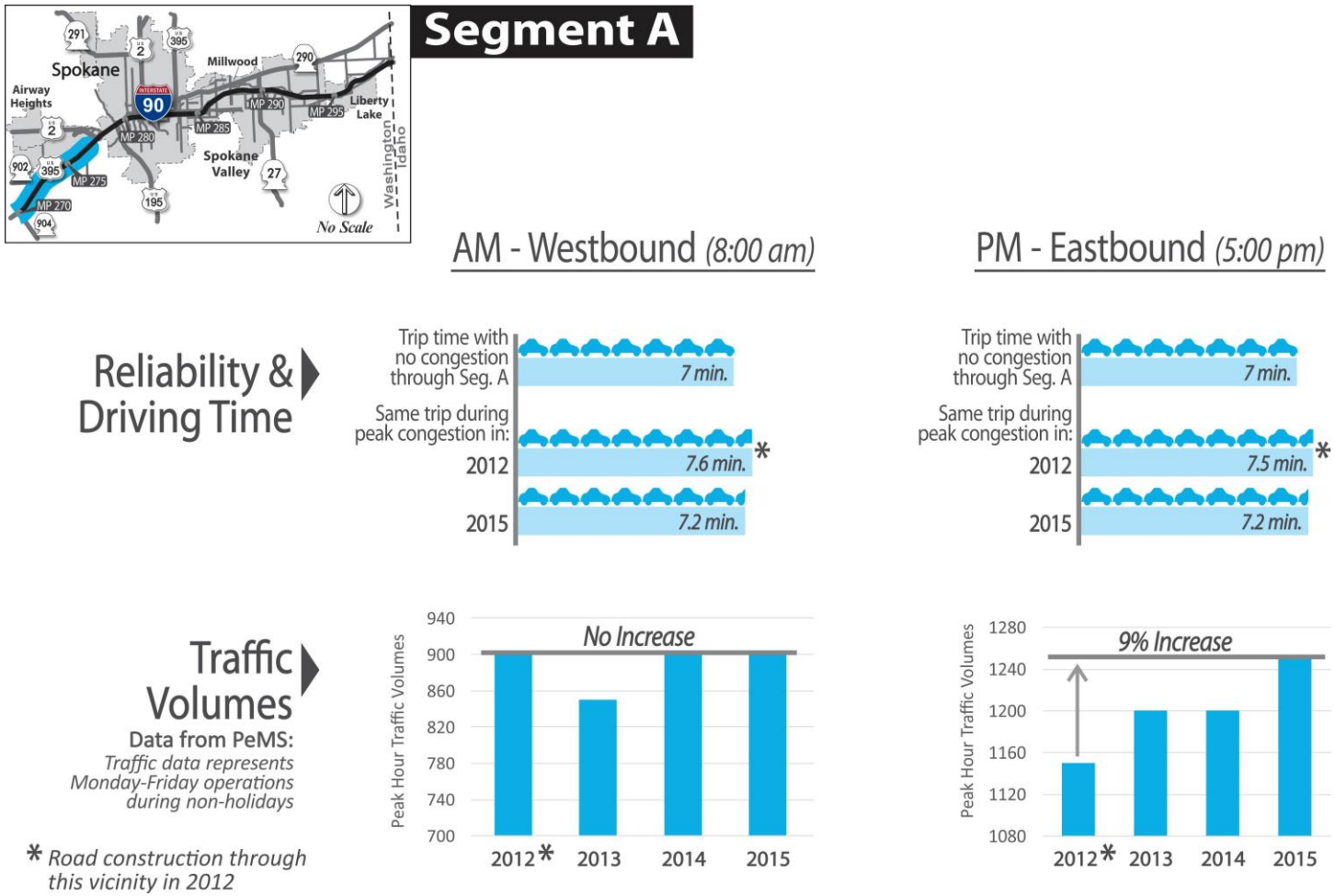


Figure 6: Travel Time Reliability for Segment A

Segment B, through downtown Spokane, experiences the greatest variation in travel times for any of the segments. As illustrated in Figure 7, during the a.m. peak period, westbound travelers must plan an additional 1.5 minutes to ensure on-time arrival 95 percent of the time, and eastbound travelers during the p.m. peak period must plan over three minutes of additional travel time.

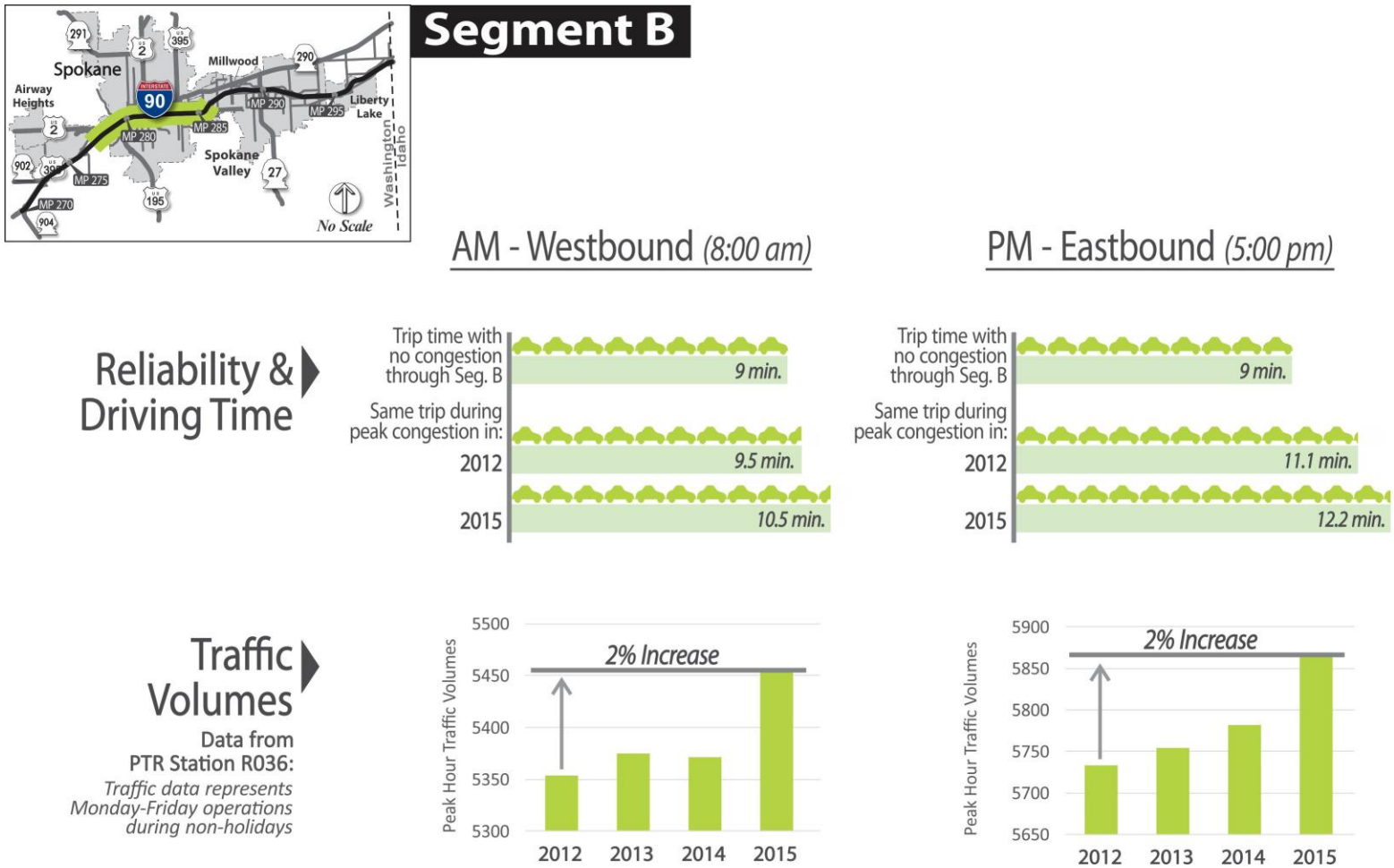


Figure 7. Travel Time Reliability for Segment B

Segment C, Spokane Valley, has experienced significant growth in traffic volumes, and, as illustrated in Figure 8, motorists must plan more than one minute of additional travel time in the p.m. peak to ensure on-time arrival 95 percent of the time.

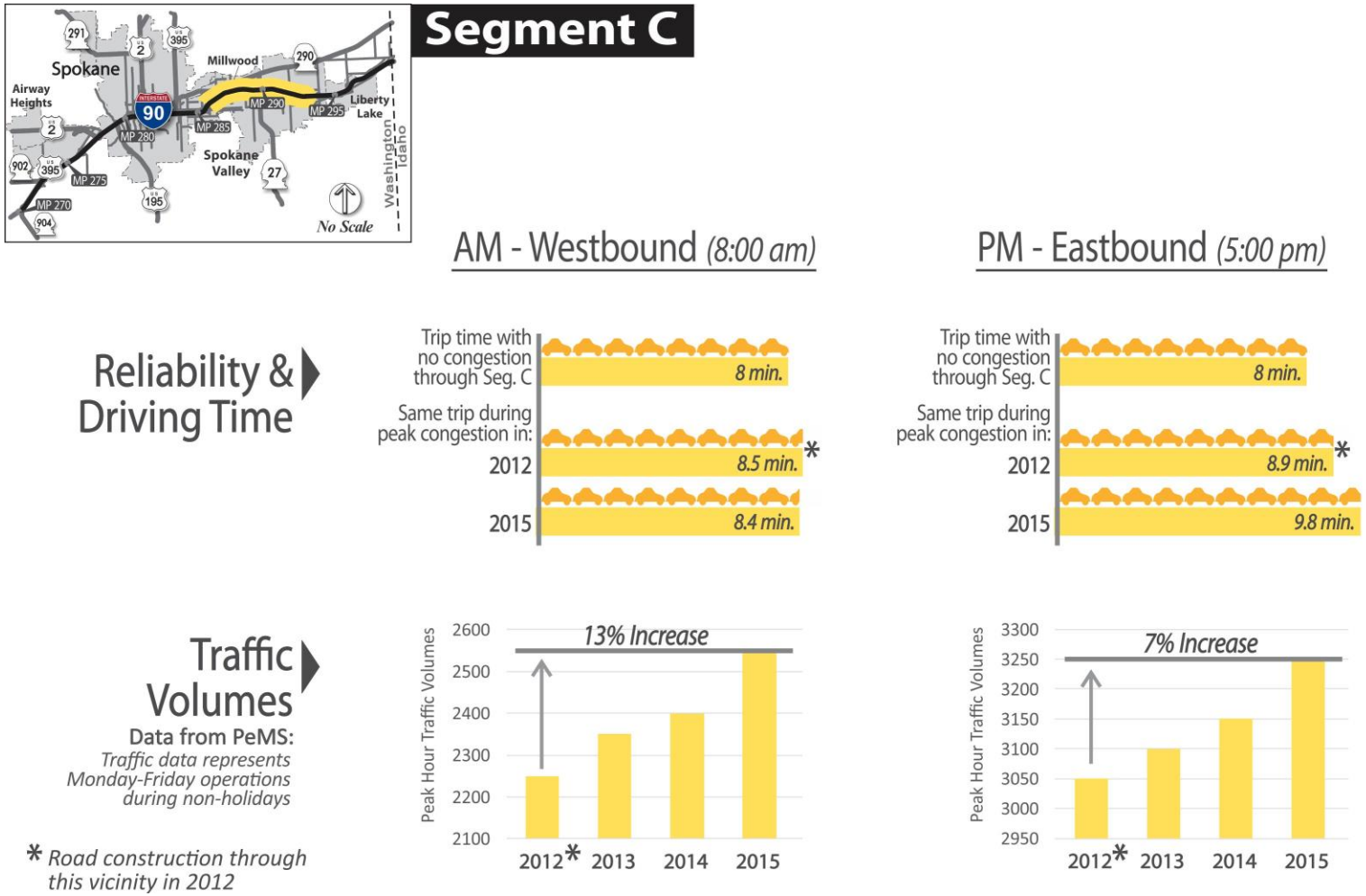


Figure 8. Travel Time Reliability for Segment C

Segment D, east of Spokane Valley, has experienced significant growth in traffic volumes, and, as illustrated in Figure 9, motorists must plan one additional minute of travel time to ensure on-time arrival 95 percent of the time in both the westbound and eastbound directions.

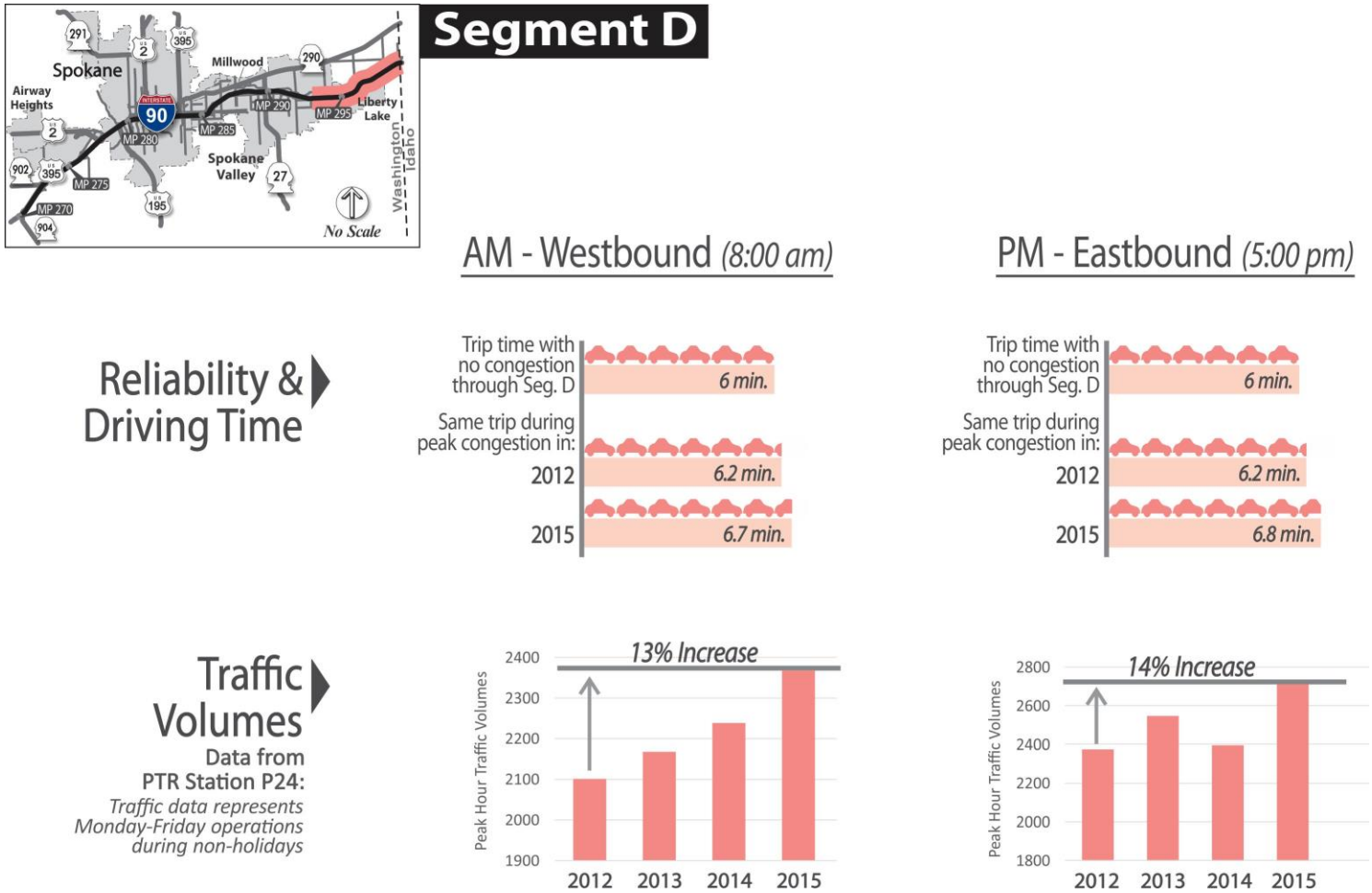


Figure 9. Travel Time Reliability for Segment D

WSDOT Corridor Capacity Summary

WSDOT publishes the Corridor Capacity Report annually[2], which documents performance measures on the state's highway system. For the I-90 Spokane area, the report focuses on the segment of I-90 from Division Street to Argonne Road. The most recent publication from 2016 uses data from 2013 and 2015, and identified the following key findings that are relevant to the corridor system management and operations:

- Annual vehicle delay increased by 99 percent (from 40.6 to 80.6 thousand hours). Contributing factors include increased traffic volumes, and increased crashes from 190 in 2013, to 225 in 2015. (*Note that WSDOT defines vehicle delay as when average speeds are slower than 85 percent of the posted speed limit.)*
- Average a.m. peak hour westbound travel time increased from 9 to 10 minutes. The planning time, which is the amount of time necessary to arrive on-time 95 percent of the time, remained steady at 12 minutes.
- Average p.m. peak hour eastbound travel time remained steady at 10 minutes, yet the planning time increased from 13 to 15 minutes, which indicates the p.m. peak eastbound travel time has become less reliable.
- During the p.m. peak hour typical eastbound congestion from Division Street extended 3.8 miles and lasted 60 minutes, an increase of 3.3 miles and 35 minutes compared to 2013.
- During the a.m. peak hour typical westbound congestion increased by 1.0 mile and lasted 10 minutes longer compared to 2013.
- For westbound travel there was up to a 32 percent chance of experiencing congestion during peak weekday commute periods; for eastbound travel there was up to a 44 percent chance of experiencing congestion during peak weekday commute periods.
- In the westbound direction, travelers had a 5 percent chance of encountering severe congestion, which WSDOT defines as speeds slower than 36 mph, during peak commute periods.
- In the eastbound direction, travelers had a 20 percent chance of encountering severe congestion during peak commute periods.

TRANSPORTATION SYSTEM MANAGEMENT AND OPERATIONS ACTIVITIES

WSDOT uses both intelligent transportation systems (ITS) and transportation demand management (TDM) strategies within the I-90 corridor to actively manage traffic flow, respond to the impact of incidents, evaluate roadway operations and support travel choices. Using a combined set of tools to monitor, measure and communicate traffic conditions allows WSDOT to take an active approach to traffic management in the corridor.

This section provides an overview of existing intelligent transportation system (ITS) and transportation demand management (TDM) strategies currently used.

[2] The Draft 2016 Corridor Capacity Report. The 15th Edition of the annual Congestion Report. Washington State Department of Transportation. Nov 2016. http://www.wsdot.wa.gov/Accountability/Congestion/2015.htm

ITS Devices in the Corridor

A suite of ITS components, as shown in Figure 10, are in place on I-90 today that monitor, measure and communicate traffic conditions. Figure 11 and Figure 12 show where these types of devices are located along the I-90 corridor.

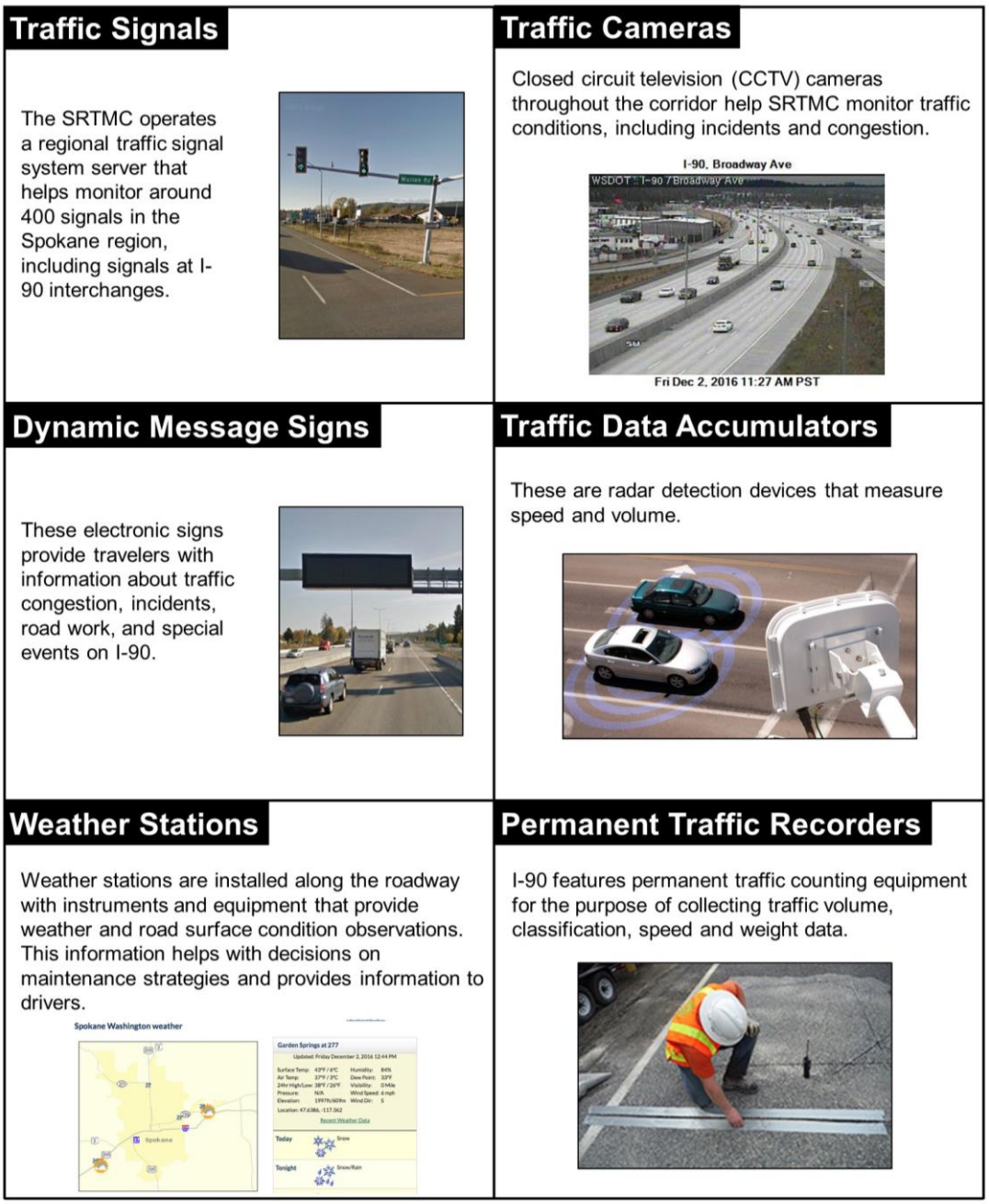


Figure 10: ITS devices in the corridor

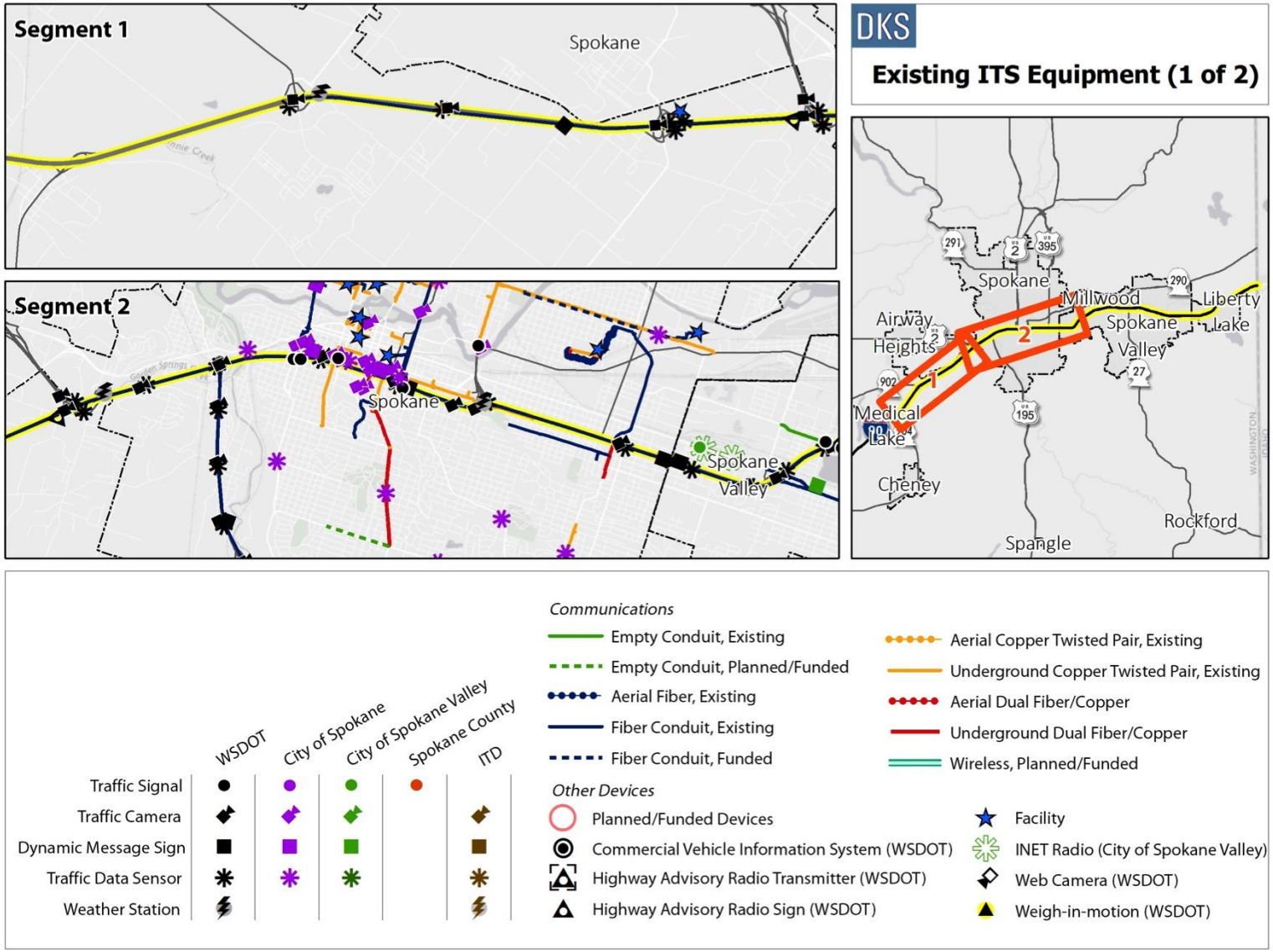


Figure 11: Existing ITS Equipment (1 of 2)

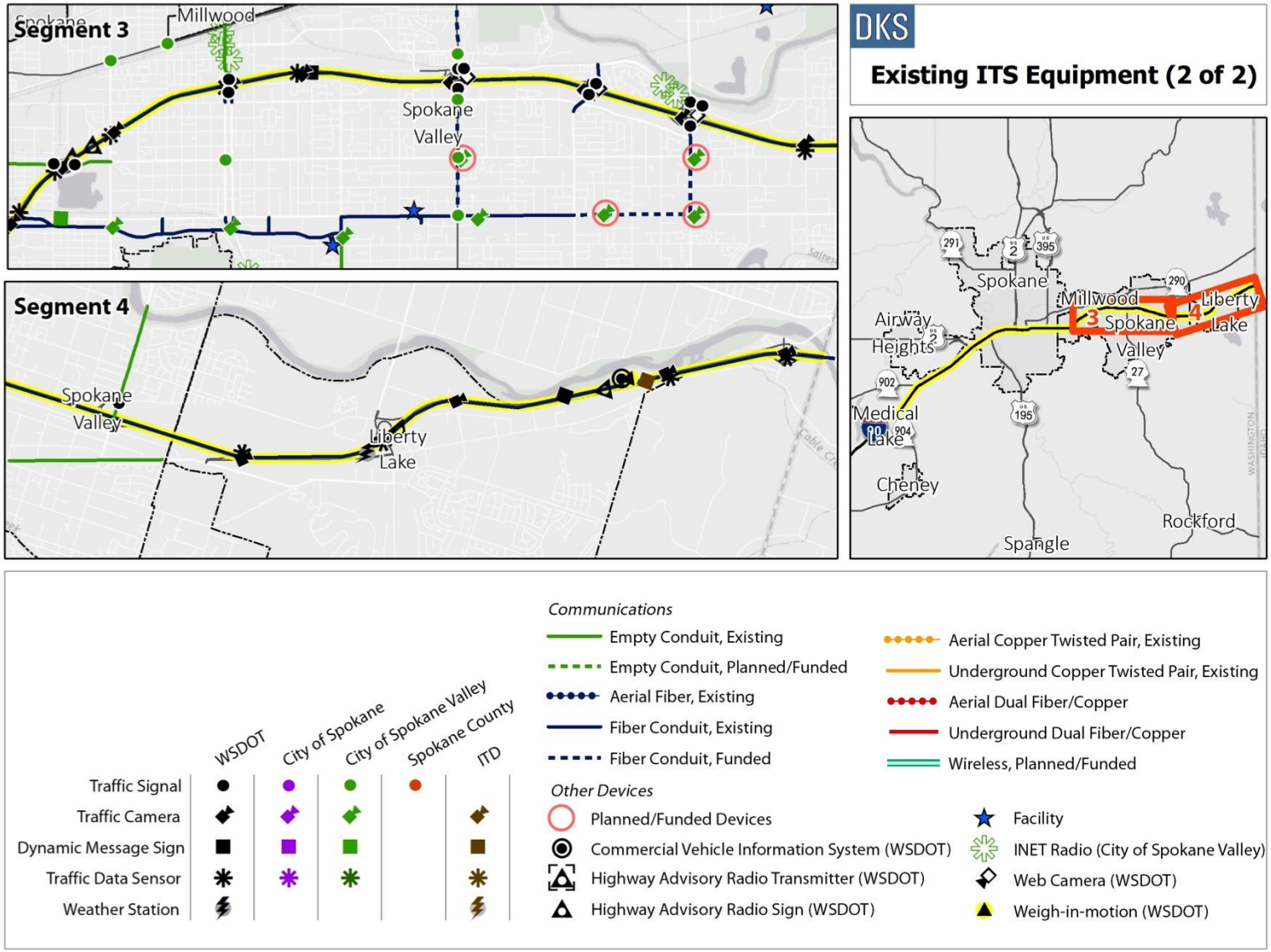


Figure 12: Existing ITS Equipment (2 of 2)

Transportation Demand Management Programs

Transportation Demand Management (TDM) is an approach to reduce congestion and improve mobility through policies and programs.

In Spokane County, Commute Trip Reduction (CTR) alternatives are promoted by the county, which administers the regional CTR program[3]. The county works with hundreds of employers to match employees with alternative transportation rather than driving a single-occupant vehicle. The CTR program promotes biking, walking, transit, carpool/vanpool, compressed work weeks, and telecommuting.

As the population increases in Spokane County and along the I-90 corridor, the CTR program's important role in managing demand on the transportation system will continue.

Spokane Regional Traffic Management Center (SRTMC)

SRTMC is a team of professionals working 24/7 with multiple jurisdictions to deliver reliable transportation information services, locally and regionally, to create a safe and efficient travel experience for everyone.

TMC operators staff the center around the clock, year-round, evaluating and reacting to events that impact travel and roadway safety. By notifying responders and posting information to the web, 511, and email/text alerts, SRTMC operators help to reduce congestion and collisions.

By linking the infrastructure and technology resources of the agency partners who make up the SRTMC, those organizations are better able to support each other through equipment sharing and incident coordination.

With more than 100 live streaming camera feeds available, 23 electronic variable message signs, 10 highway advisory radio (HAR) AM transmitters, various intelligent transportation system devices such as volume/speed detectors, and hundreds of traffic signals, the SRTMC is the hub of the region's transportation management system.

Incident Response Program

WSDOT calls their dedicated incident response program Dedicated Roving Patrols. They respond to incidents along I-90 between WA 904 (milepost 270) and the Washington/Idaho state line (milepost 299). In addition to I-90, the dedicated roving patrols respond to calls from the Washington State Police on all state routes within the Greater Spokane Area which includes: Spokane County, Whitman County, Stevens County, Pend Oreille County and occasionally Adams County.

The Dedicated Roving Patrols operate three trucks and have two full time drivers. The program is hoping to add a third full time driver in the summer of 2017 to work during peak commute around and weekend. The patrols operate on two daily shifts Monday through Friday: morning 5:30 a.m. to 1:30 p.m., and evening 12:30 p.m. to 8:30 p.m. Weekends and holidays are covered using "call-outs".

[3] http://www.mycommute.org/

INCIDENT AND CRASH EVALUATION

As a busy urban corridor, incidents along I-90 are frequent occurrences that endanger travelers and contribute to non-recurring congestion and unreliable travel times. This section presents information on the incidents occurring in the corridor, 89% of which were categorized as something other than a collision. This section also presents finding from crash data and results from the predictive safety analysis conducted for I-90. The purpose of the evaluation is to identify high crash locations (hot spots), common crash types, and contributing factors to inform the development of safety countermeasures. Ultimately, this project will define proposed strategies aimed at reducing the number of crashes and incidents along the I-90 corridor, as well as improving clearance times when crashes and incidents do occur.

The crash and incident evaluation examines crash data from WSDOT crash reports, incident data from WSDOT's incident records database, and uses a predictive safety analysis to determine crash hot spots and predict locations that have a higher potential for crashes.

WSDOT Incident Data Analysis

WSDOT Incident data includes crashes, as well as other events such as disabled vehicles, debris on the roadway, construction or maintenance events, and dead animals that impact roadways. Incidents are reported to the Spokane Regional Traffic Management Center (SRTMC) by maintenance personnel or Washington State Police (WSP), or detected on a TMC camera feed. While not every roadway incident is reported, this data set provides valuable insight into event types, frequency, locations, and other trends that future strategies can address.

The SRTMC logs incidents on I-90. The project team evaluated five years of incidents (2011 through 2015) to identify trends that could indicate an operational need on the corridor.

Table 3 shows the percentage of capacity lost when lanes are effectively closed by an incident. An incident need not block a travel lane to generate a loss in capacity that increases travel delay and creates a safety hazard.

Table 3: Freeway Capacity Changes

Number of Highway Lanes	Percent Facility Capacity Lost by Blockage Type			
	Shoulder	1 Lane	2 Lanes	3 Lanes
2 Lanes	19%	65%	100%	N/A
3 Lanes	17%	51%	83%	100%
4 Lanes	15%	42%	75%	87%

Source: Transportation Research Board. Highway Capacity Manual, 2010.

The following list defines some of the more common event types observed on the study corridor:

- Disabled Vehicle – A blocking or non-blocking vehicle that is unable to move without assistance and is attended by at least one person.
- Abandoned Vehicle – Any vehicle that is not occupied and left unattended on a right-of-way.

- Collision – Single or multi-vehicle collision, on or off the roadway (e.g. crash, or accident)
- Debris – A foreign object blocking or not blocking the roadway which will require removal by road crews or law enforcement.
- Pedestrian - Person walking, hitch hiking, standing, or biking on the right-of-way and requiring a response to remove from the right-of-way.
- Other Incident – Any event not covered by other event types.
- Lane Closure – Any WSDOT, City, County, Valley, contract, or WSP-designated lane closure for one or both directions of the roadway.
- Construction – Construction-related lane and road closures, or other construction info worthy of logging. May alternatively be categorized as lane closure.
- Maintenance – Work such as striping, drain cleaning, barrier repairs, pothole fixes, fencing, and other duties routinely performed by road maintenance crews.
- Closure – Any WSDOT, City, County, Valley, contract, or WSP-designated road closure in one or both directions of a roadway.
- Fire – Any building, structure, trees, brush, or other material on fire potentially or actually impacting travel. Vehicle fires are separate.
- Vehicle Fire – A vehicle that has visible flames or smoke caused by fire.
- Signs – Issues with roadway signs, e.g. knocked down, leaning, missing, dirty, vandalized.
- Trees – Trees that are blocking all or part of a roadway, or affecting power and phone lines, or leaning in such a way that they may be a hazard to motorists.
- Signals – All signal device events; outages, signals in flash mode, not cycling properly, and signal or light pole knock-downs due to weather or collision. This also applies to cameras, DMS, and HAR equipment.
- Dead Animal – Report of a dead animal on or near the roadway that needs to be removed.
- Medical Emergency – Medical emergencies reported to TMC or observed via CCTV, such as a slumped driver, intoxication, heat exhaustion/stroke, fainting, or other calls for medical aid.

Between 2011 and 2015, 19,390 incidents occurred along the study corridor; the equivalent of roughly 10 incidents per day over the 30-mile corridor. The incidents locations were equally divided between travel directions (9,357 eastbound and 9,189 westbound). In some instances, the location was unknown or noted as “both”.

Table 4 shows the incident type, frequency of each type of incident and direction of travel where the event occurred. The incident is recorded as "both" when it impacts travel in the eastbound and westbound direction. Table 4 breaks out incidents that represent greater than 1 percent of the total. Some event types such as "Bridge" and "Medical Emergency" accounted for less than 1 percent of the total incidents and are included in the "Other/Unknown" category.

The most frequent type of incident was a disabled or abandoned vehicle, which commonly takes up a shoulder lane (if a shoulder is present) and can reduce capacity by 15 to 19 percent, depending on the number of lanes (see Table 3). Aside from the "unknown/other" category, which accounted for 25 percent of all incidents, the next most common type was a collision, accounting for 11 percent of all incidents, followed by debris (9 percent) and then maintenance and construction activities (6 percent).

Table 4: Incident Types (2011-2015)

Type of Incident	Total Number by Type	Percentage by Type	Direction Impacted			
			Eastbound	Westbound	Both	Unknown
Disabled or Abandoned Vehicle	7267	37%	3500	3500	210	57
Other/Unknown	4784	25%	2302	2268	174	40
Collision	2161	11%	1039	1015	84	23
Debris	1795	9%	905	811	62	17
Maintenance/ Construction	1130	6%	532	541	46	11
Pedestrian	873	5%	417	422	28	6
Dead Animal	227	1%	118	98	9	2
Signals	238	1%	105	110	19	4
Lane Closure	180	1%	91	77	12	0
Complaint	131	1%	76	48	7	0
Signs	149	1%	72	72	3	2
Fire	127	1%	50	68	8	1
Closure	101	1%	46	49	4	2

Figure 13 shows the distribution of incidents between 2011 and 2015. Over the five years evaluated, the number of incidents on I-90 increased by about 40 percent.

Incidents increased by 40% over the last five years, which contributes to decreased travel time reliability.

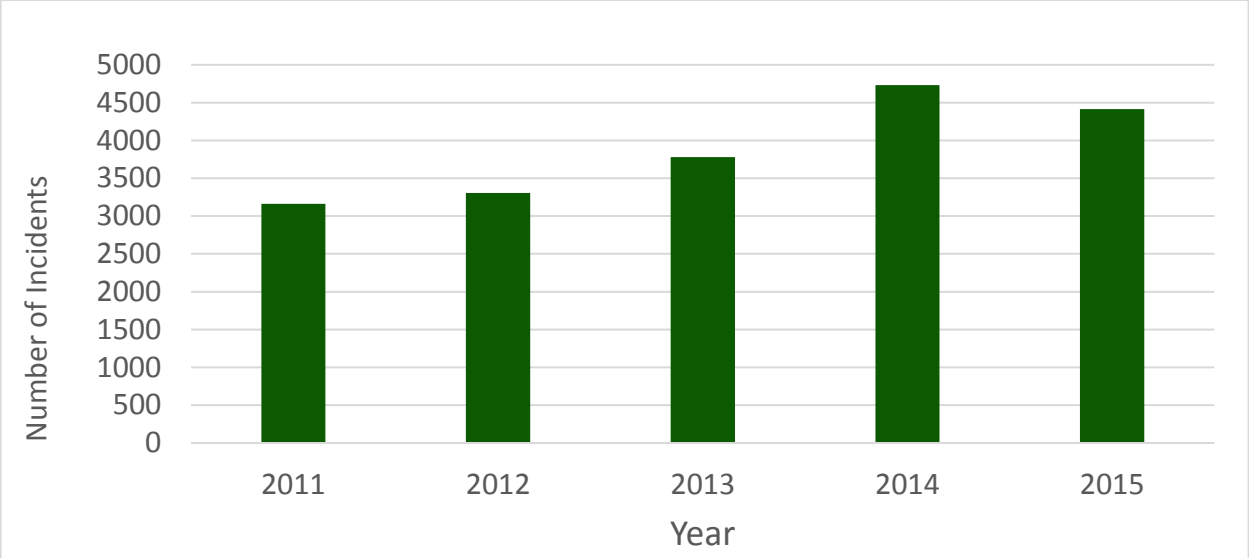


Figure 13: Total Incidents by Year

Figure 14 shows total incidents by month between 2011 and 2015. The number of reported incidents peak during the summer months (June, July, and August).

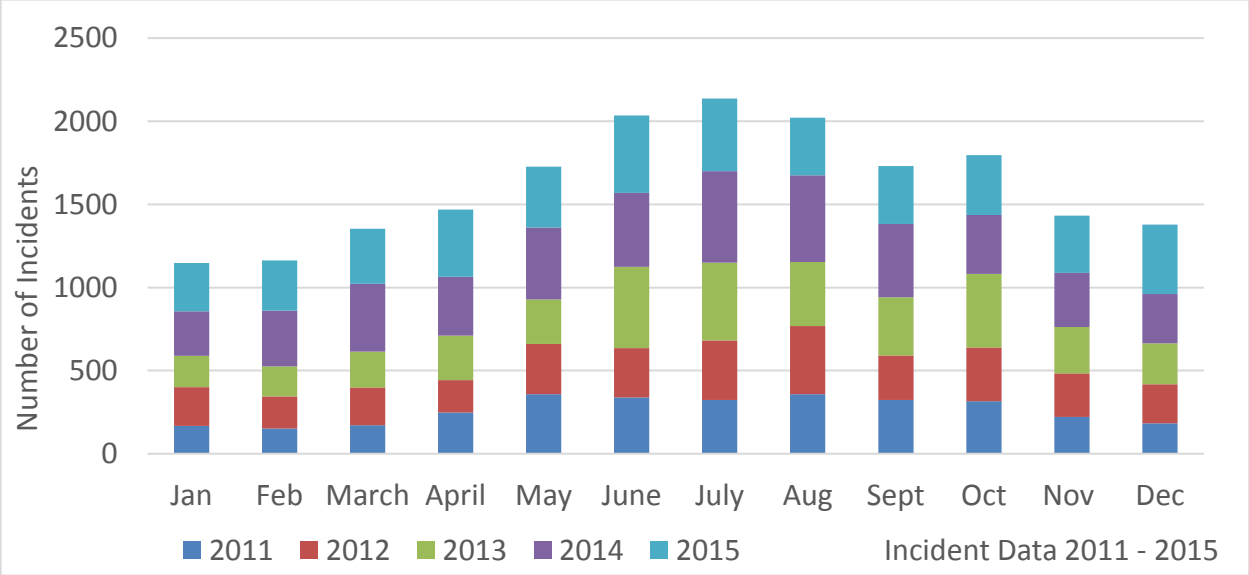


Figure 14: Total Incidents by Month

Figure 15 shows the total incidents over five years by milepost and direction. Incidents spike between mileposts 279 to 283, which correlates to the section of I-90 through downtown Spokane.

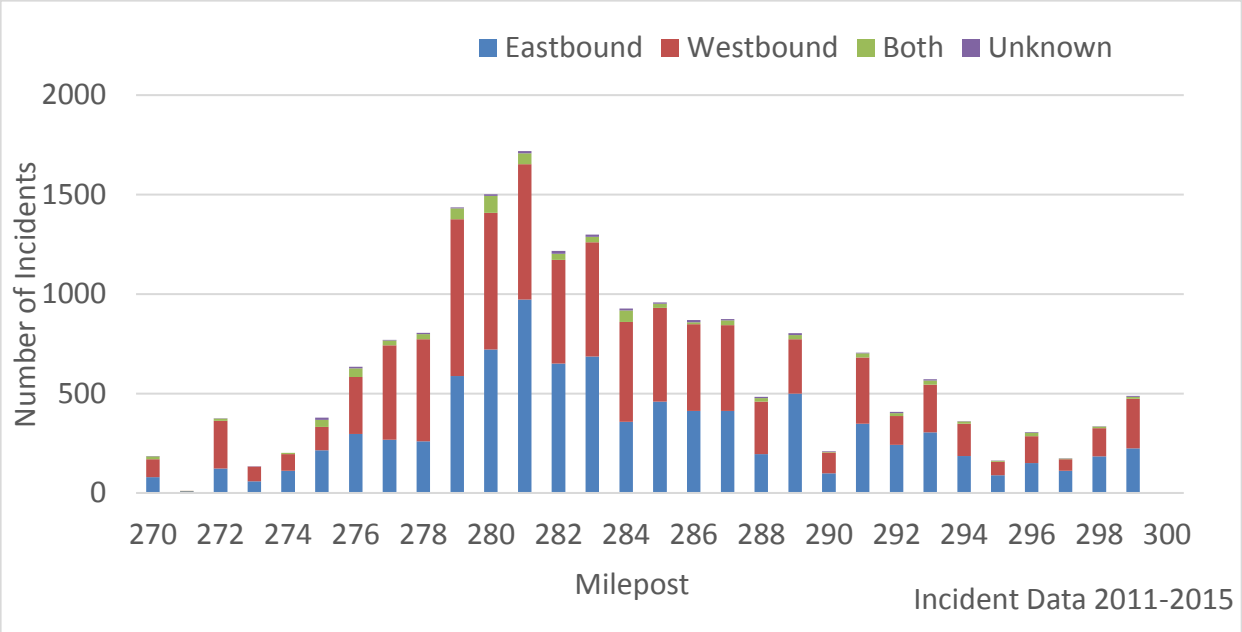


Figure 15: Incidents by Milepost and Direction

Figure 16 shows the distribution of debris events along the I-90 corridor. The occurrence of debris on the roadway spikes between Rosamond Ave (MP 279) and Broadway (MP 287). Roadway debris, particularly in the travel lanes, poses a safety hazard to travelers.

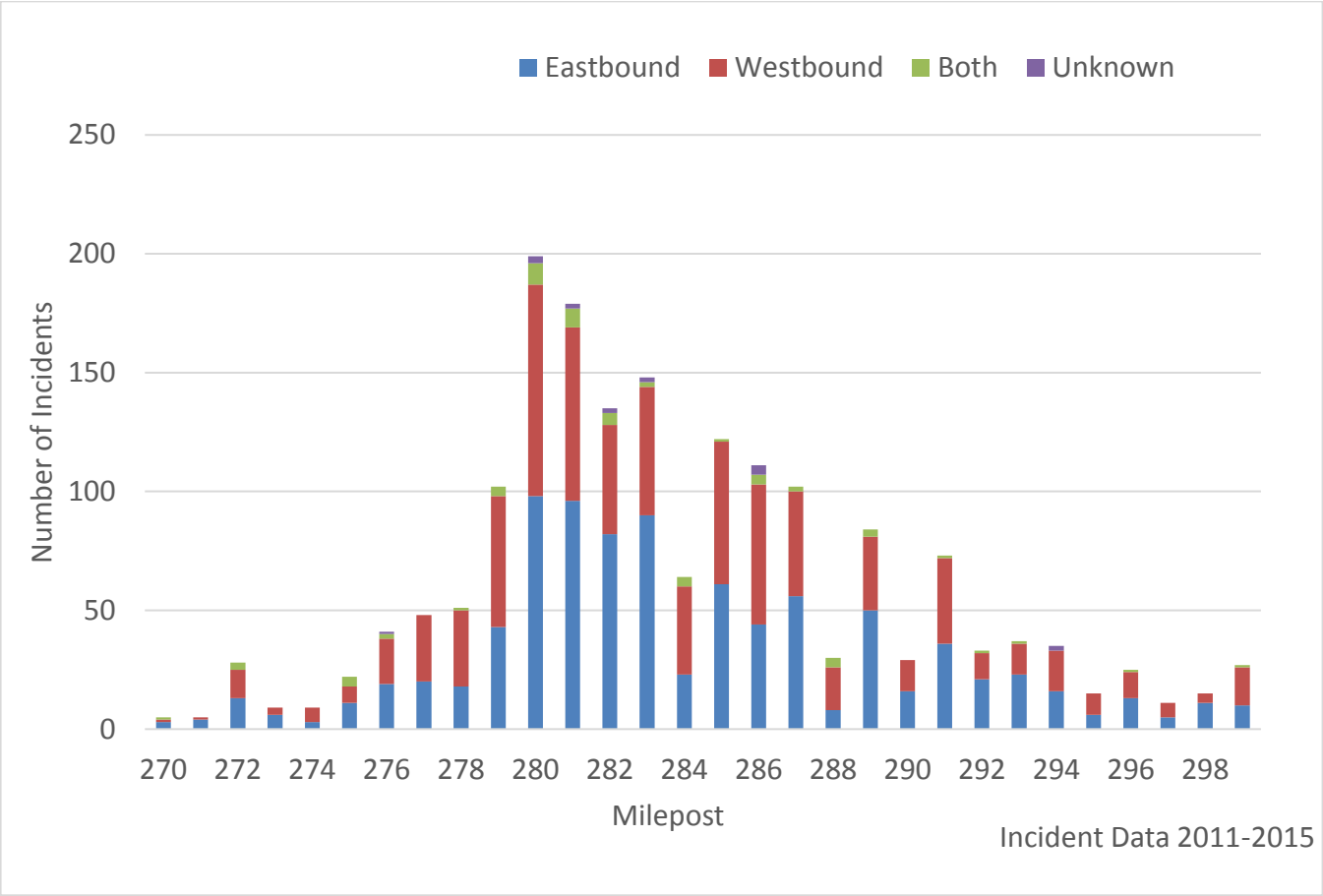


Figure 16: Debris Events by Milepost

Crash Analysis

The WSDOT Crash Data and Reporting Branch provides geocoded crash records based on officer-reported motor vehicle crashes on State facilities. This section presents an overview of the crash locations, contributing circumstances, and trends present in the I-90 study corridor crash records collected for the most recent five complete years (2011 to 2015).[4]

Between 2011 and 2015, I-90 mainline experienced 2,392 total crashes. Year-to-year crash totals have been steadily rising. Since 2012, I-90 crashes increased 22 percent as illustrated in Figure 17. An additional 1,307 crashes occurred on the interchange ramps and at the ramp terminals during the same five-year period. In total, the I-90 corridor including ramps and ramp terminals experienced 3,699 total

In 2011 there were 172 work zone crashes during an extensive rehabilitation project, far more than the typical 20 per year. This increase in work zone crashes contributed to a higher overall number of crashes, and does not portray the increasing trend since 2012.

[4] Under 23 United States Code, Section 409, this data cannot be used in discovery or as evidence at trial in any action for damages against the WSDOT or any jurisdictions involved in the data.

crashes between 2011 and 2015, which is an average of 740 crashes per year or approximately two crashes per day in the corridor.

On the I-90 mainline, eight crashes resulted in a fatality and 17 resulted in a serious injury, as detailed by year in Figure 18. Reviewing the data reveals that fatal crashes decreased from four in 2011 to remain steady at one per year since 2012. The serious injury crashes show a decreasing trend from 2011 through 2014, but then increase in 2015. Of the eight fatalities that occurred between 2011 and 2015, all eight occurred during dark conditions, five involved drivers under the influence of alcohol, drugs, or medication, three involved a vehicle driving the wrong way, and three involved a pedestrian.

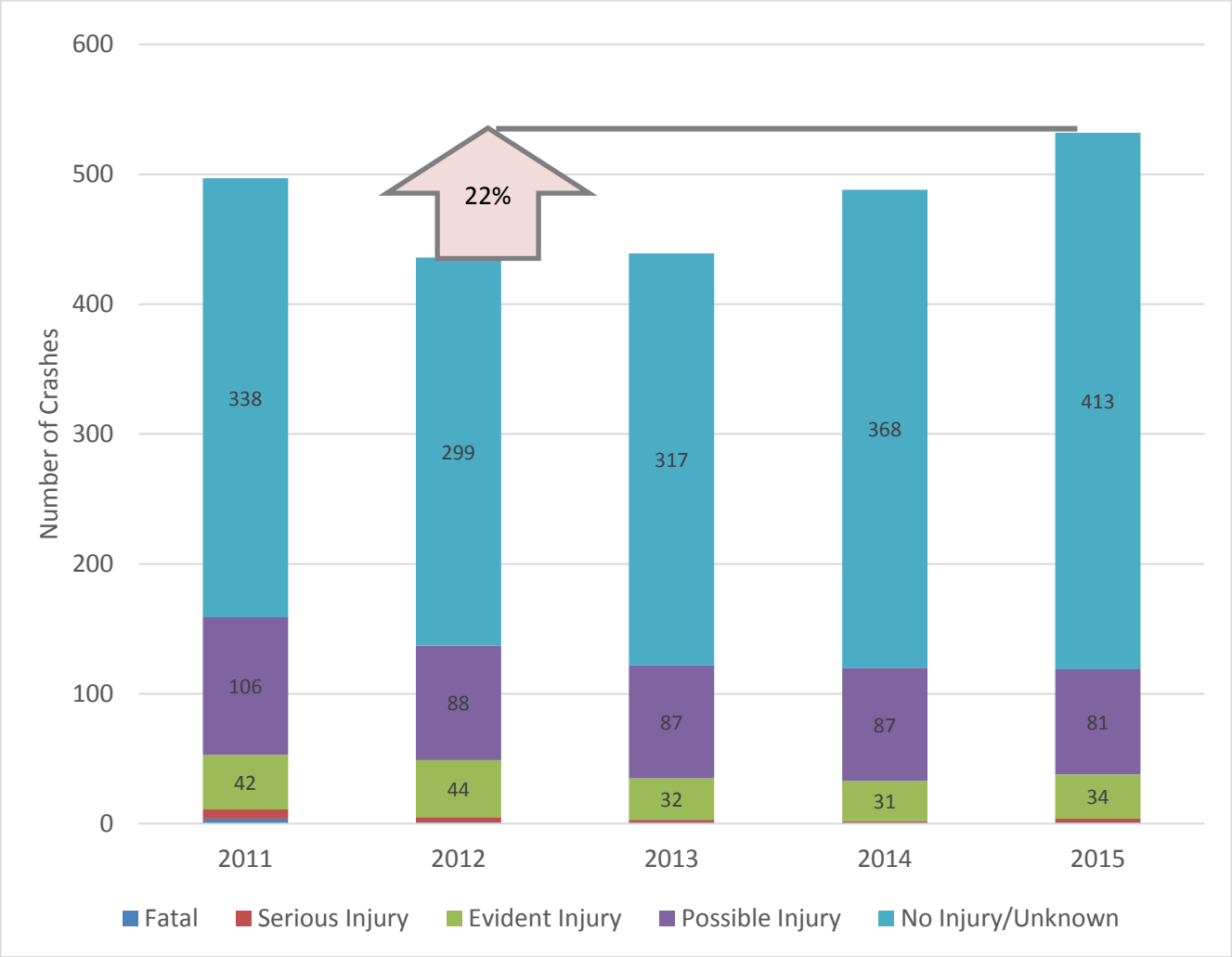


Figure 17: I-90 Mainline Crashes by Year and Severity

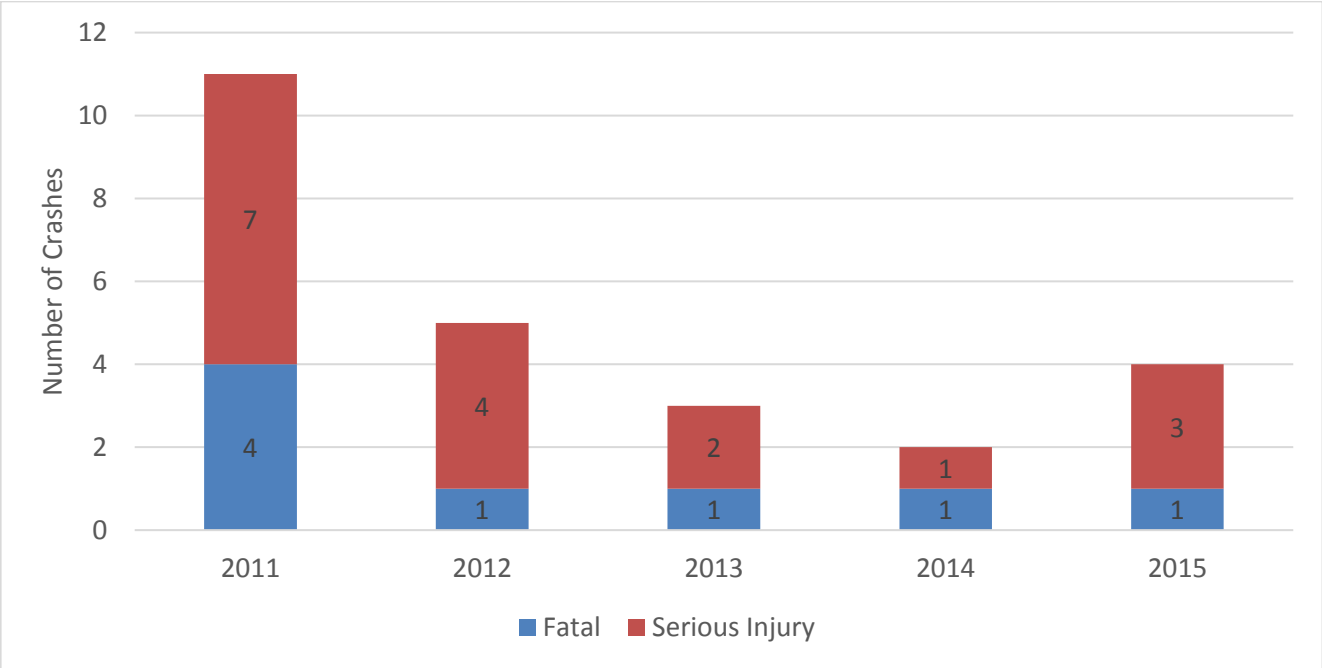


Figure 18: I-90 Mainline Fatal and Serious Injury Crashes

Work Zone Crashes

Over the five years analyzed, there was a total of 234 work zone related crashes on the I-90 mainline, as shown in Figure 19. In 2011 a particularly high number of work zone related crashes occurred (172 on the mainline), which contributes to the higher overall number of crashes in 2011 compared to the other years. Work zone crashes involve both crashes that occur within a work zone as well as crashes that occur due to a backup from a work zone. During 2011 there was an extensive rehabilitation project. Of the seven serious injury crashes in 2011, four involved work zones. In following years, the work zone crashes were generally less than 25 on the mainline and five or less on the ramps.

Almost 25 percent of all work zone crashes occurred around milepost 279, near the US-195 interchange. Two thirds of which occurred in the eastbound direction, as shown in Figure 20. At milepost 279 there were a total of 58 crashes over the five years analyzed. Of those 58 crashes, 51 occurred in 2011 during the extensive rehabilitation project.

A majority of the work zone crashes were rear-end crashes (70%). Side swipes were the second most common crash type (16%).

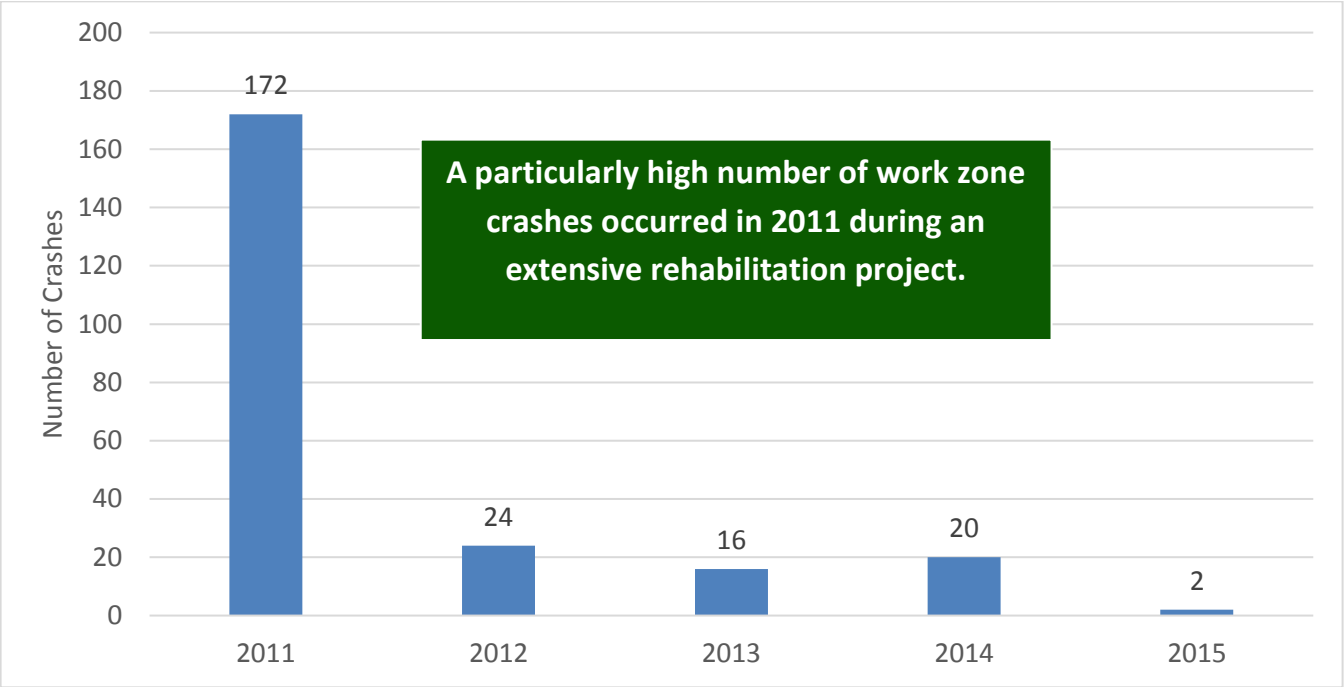


Figure 19: Work Zone Crashes on I-90 Mainline

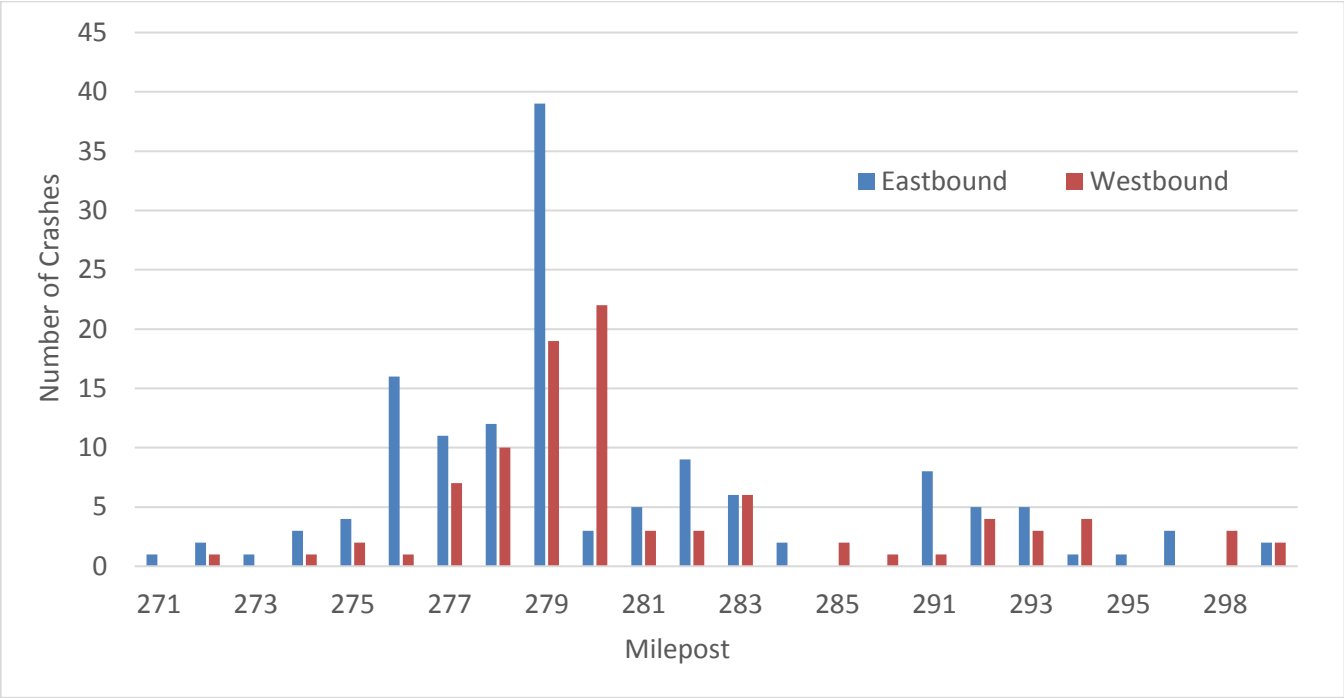


Figure 20: Work Zone Crashes by Milepost

Crash Type

On the I-90 mainline, the most frequent crash types are rear-end and sideswipe, which accounts for 1,416 of the 2,392 crashes, or 59 percent.

Crashes with a fixed object are the third most common crash type accounting for 708 crashes, or 30 percent of total crashes.

Common poor driving behaviors including exceeding a reasonably safe speed, following too closely, and inattention contributed to 63 percent of crashes on the I-90 mainline.

Figure 21 shows crash severity by different crash types on the I-90 mainline as defined by the first object hit.

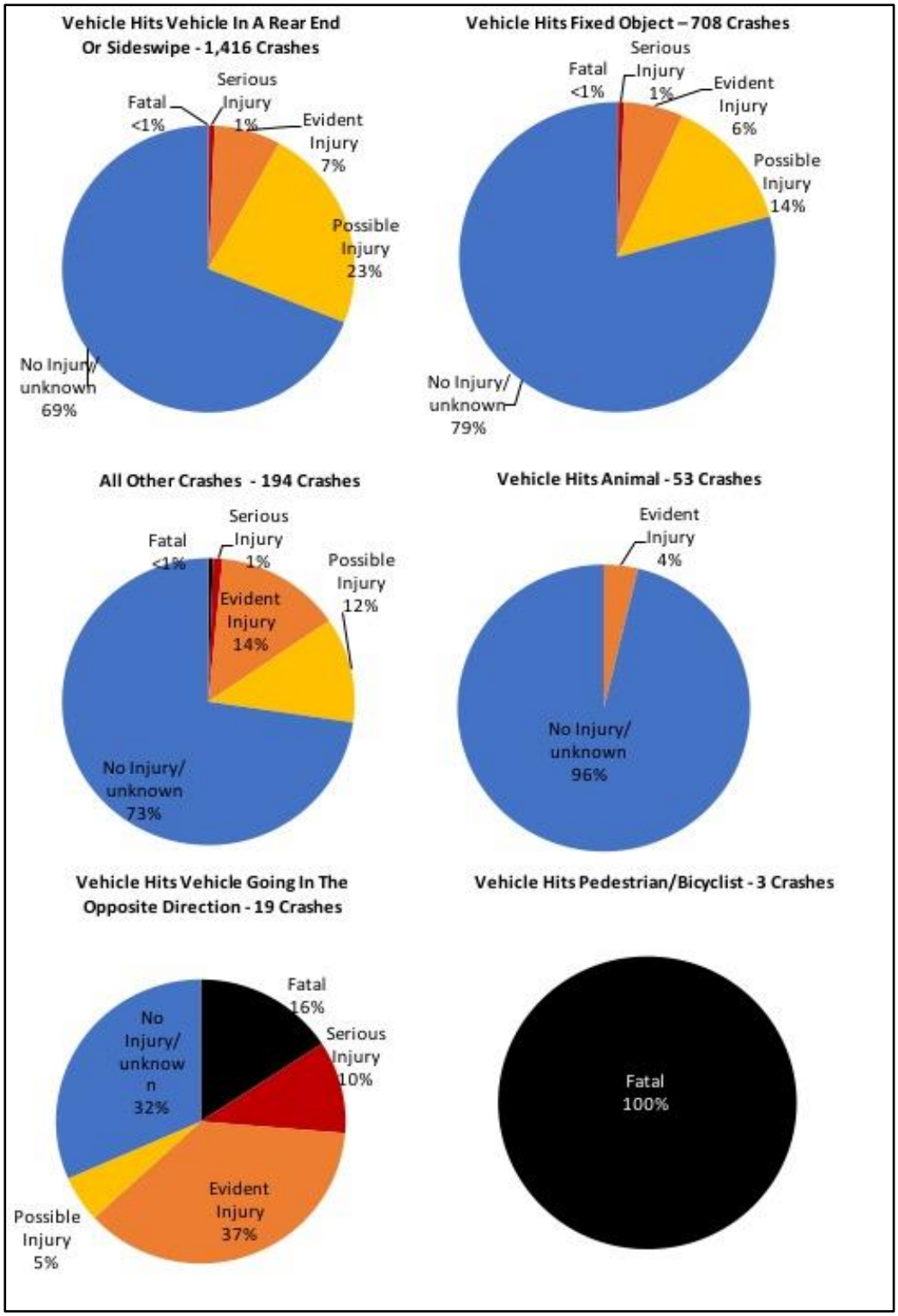


Figure 21: Crash Severity by Type on I-90 Mainline

Crash Frequency and Contributing Factors

Table 5 and Table 6 summarize I-90 crash frequency and contributing factors by segment and travel direction. Table 5 presents the total crashes on I-90 mainline by segment and contributing factors. The three most common contributing factors were: inclement weather, exceeding a reasonably safe speed, and following too closely. Together, these factors contribute to 84 percent of all crashes in the study corridor. Driver inattention is a factor in 15 percent of mainline crashes and heavy-vehicles are involved in 10 percent of mainline crashes.

Table 5: I-90 Mainline Crash Contributing Factors by Segment and Direction

Segment / Direction	Annual Average Daily Traffic	Crash Frequency		Contributing Factors				
		Total Crashes	High Severity Crashes	Exceeding Reasonably Safe Speed	Following too closely	Inattention	Inclement Weather Road Surface	Heavy Vehicle Involved Crashes
Segment A (MP 270– 277)	**30,300**	**251**	**8**	**39%**	**10%**	**8%**	**43%**	**13%**
Eastbound	16,300	135	7	32%	16%	10%	35%	13%
Westbound	14,000	116	1	47%	3%	6%	52%	13%
Segment B (MP 277– 286)	**85,100**	**1272**	**12**	**26%**	**25%**	**17%**	**30%**	**12%**
Eastbound	42,600	671	8	27%	25%	18%	27%	12%
Westbound	42,500	601	4	26%	25%	16%	33%	13%
Segment C (MP 286– 293)	**71,800**	**499**	**2**	**38%**	**10%**	**10%**	**50%**	**7%**
Eastbound	36,000	231	1	37%	9%	11%	45%	7%
Westbound	35,800	268	1	40%	12%	9%	54%	7%
Segment D (MP 293–299)	**53,800**	**371**	**4**	**27%**	**11%**	**17%**	**31%**	**5%**
Eastbound	27,000	228	3	22%	12%	18%	28%	7%
Westbound	26,800	143	1	36%	8%	17%	36%	3%
Study Corridor Total	**62,200**	**2392**	**25**	**30%**	**18%**	**15%**	**36%**	**10%**

Notes: More than one contributing factor can apply to each crash, and not all contributing factors are shown, therefore percentages may not add to 100%.
Bold indicates bidirectional segment value.
Darker red colors indicate higher proportion of contributing factor compared with other study corridor segments.

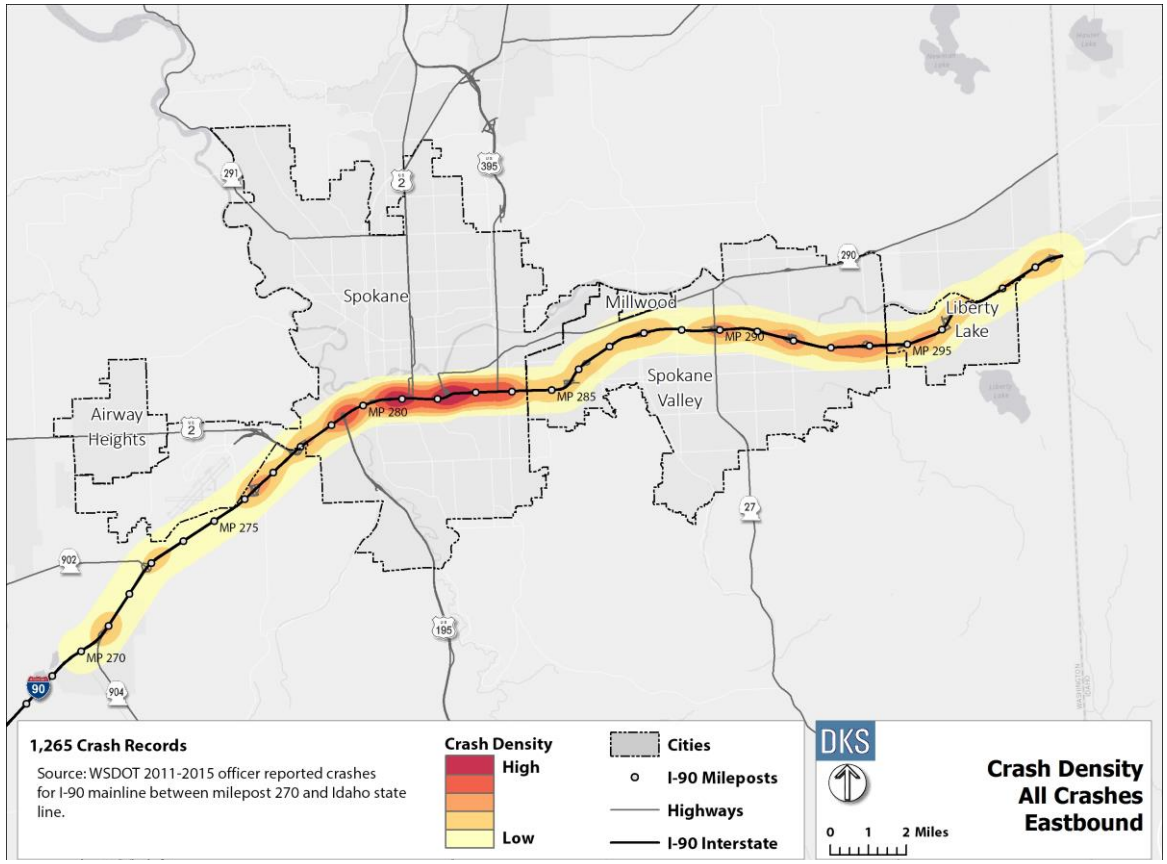
Table 6 presents the crash frequency and contributing factors at each interchange. The table includes crashes that occurred on the ramps or at the intersections at the ramp terminals. As with mainline crashes, the three most common contributing factors were: inclement weather, exceeding a reasonably safe speed, and following too closely. Together, these factors contribute to 57 percent of all crashes at the interchanges.

Table 6: Interchange Crash Frequency and Contributing Factors

Interchange	Crash Frequency		Contributing Factors				
	All Crashes	High Severity Crashes	Exceeding Reasonably Safe Speed	Following Too Closely	In-attention	Inclement Weather Road Surface	Heavy Vehicle Involved Crashes
Exit 270 - SR 904/Four Lakes/Cheney	18	0	44%	6%	17%	44%	0%
Exit 272 - SR 902/Medical Lake	17	0	35%	6%	12%	41%	18%
Exit 276 - Geiger Boulevard/Grove Rd.	8	0	50%	0%	25%	75%	0%
Exit 277 - US 2/Garden Springs Rd.	40	0	55%	3%	3%	45%	5%
Exit 279 - SR 195	55	1	20%	36%	22%	11%	2%
Exit 280 - Maple St./4th Ave/Walnut St.	365	6	7%	26%	15%	18%	5%
Exit 281 - US 2 Browne St. /Division St. Couplet	164	5	13%	12%	13%	23%	5%
Exit 282 - SR 290	47	1	47%	4%	13%	47%	2%
Exit 283A - Altamont St./2nd Ave./3rd Ave.	8	0	13%	25%	25%	25%	0%
Exit 283B - Thor St./Freya St./2nd Ave./3rd Ave.	30	0	10%	20%	17%	13%	17%
Exit 285 - Sprague Ave.	83	1	31%	12%	12%	27%	2%
Exit 286 - Broadway Ave.	45	1	18%	22%	16%	24%	9%
Exit 287 - Argonne Rd.	81	2	11%	14%	16%	22%	4%
Exit 289 - SR 27/Pines Rd.	46	0	13%	22%	15%	13%	0%
Exit 290 - Evergreen Rd.	55	1	25%	20%	7%	22%	2%
Exit 291 - Sullivan Rd.	133	1	11%	11%	11%	28%	7%
Exit 293 - Barker Rd.	36	0	6%	17%	28%	17%	6%
Exit 294 - Sprague Ave./Business Route 90	5	0	20%	0%	20%	0%	0%
Exit 296 - Liberty Lake Rd./Harvard Rd.	58	0	0%	16%	22%	14%	5%
Exit 299 - Idaho Rd./Spokane Bridge Rd.	13	0	31%	8%	8%	23%	0%
Study Corridor Interchanges Total	**1307**	**19**	**16%**	**18%**	**14%**	**23%**	**5%**

I-90 All Crashes Hot Spots

Along the I-90 corridor, safety is a primary concern. As a busy urban corridor, crashes and other incidents along I-90 are frequent occurrences that endanger travelers and contribute to non-recurring congestion and travel time unreliability. The most frequent contributing circumstances include three common driver behaviors: exceeding a reasonably safe speed, following too closely, and inattention. Together, these behaviors are involved in about 60 percent of crashes on the Interstate 90 mainline. Crash density for all eastbound crashes is shown in Figure 22 and crash density for all westbound crashes is shown in Figure 23.



Traveling Eastbound

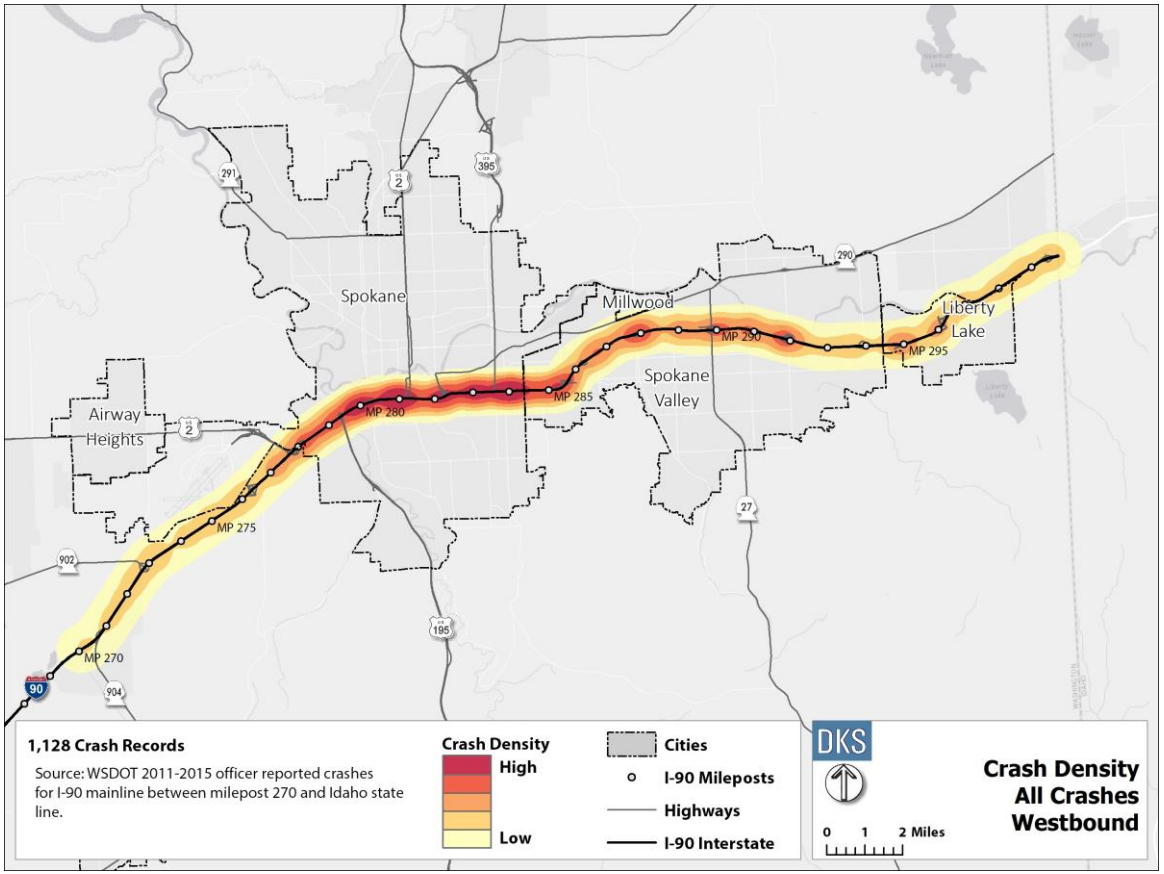
Eastbound crashes are concentrated through downtown Spokane (MP 279 -284). Crashes are strongly clustered in the evening peak period.

Segment B (downtown Spokane) has the highest frequency of crashes (1,271 total, of which 671 are eastbound). Segment B also has the highest crash rate, at 0.91 crashes per million vehicle miles traveled (MVMT).

At 30 percent of all crashes, exceeding a reasonably safe speed is the most common contributing factor to crashes along the mainline study corridor.

Source: WSDOT, officer reported crashes 2011-2015.

Figure 22: I-90 Crash Density - All Crashes Eastbound



Traveling Westbound

Westbound crashes are also concentrated through downtown Spokane (MP 279 -284). Crashes are strongly clustered in the evening peak period.

Segment B (downtown Spokane) has the highest frequency of crashes (1,271 total, of which 600 are westbound). Segment B also has the highest crash rate, at 0.91 crashes per million vehicle miles traveled (MVMT).

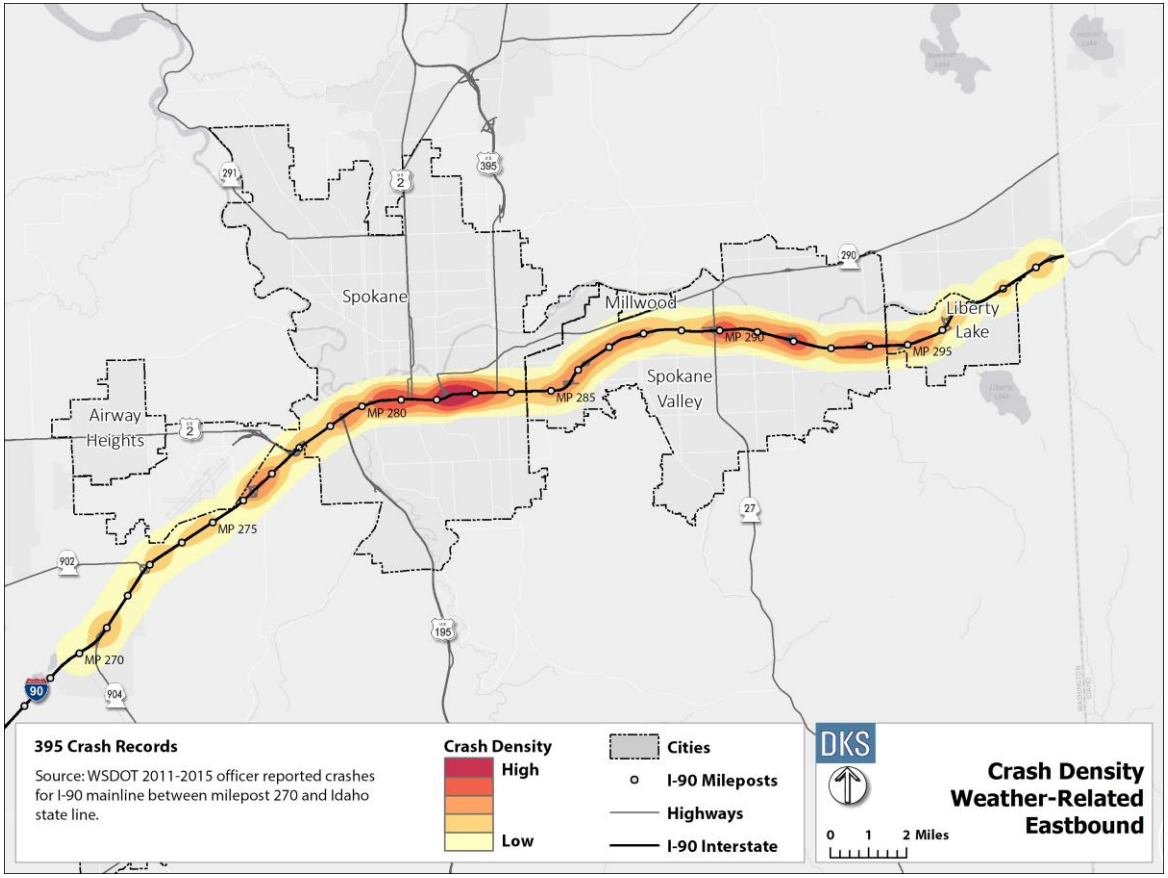
At 30 percent of all crashes, exceeding a reasonably safe speed is the most common contributing factor to crashes along the mainline study corridor.

Source: WSDOT, officer reported crashes 2011-2015.

Figure 23: I-90 Crash Density - All Crashes Westbound

I-90 Weather-Related Crashes Hot Spots

Inclement weather road surfaces – such as ice, snow, or water – were a notable factor in crashes along the I-90 corridor. Although primarily occurring during winter months, inclement weather was involved in 36 percent of mainline crashes. In Spokane Valley, half of all crashes involved inclement weather road surfaces. Weather-related crashes include a higher proportion of a.m., midday, and overnight crashes. Speed is a prominent contributing factor for these crashes. Figure 24 illustrates weather-related eastbound crashes and Figure 25 illustrates all weather-related westbound crashes.



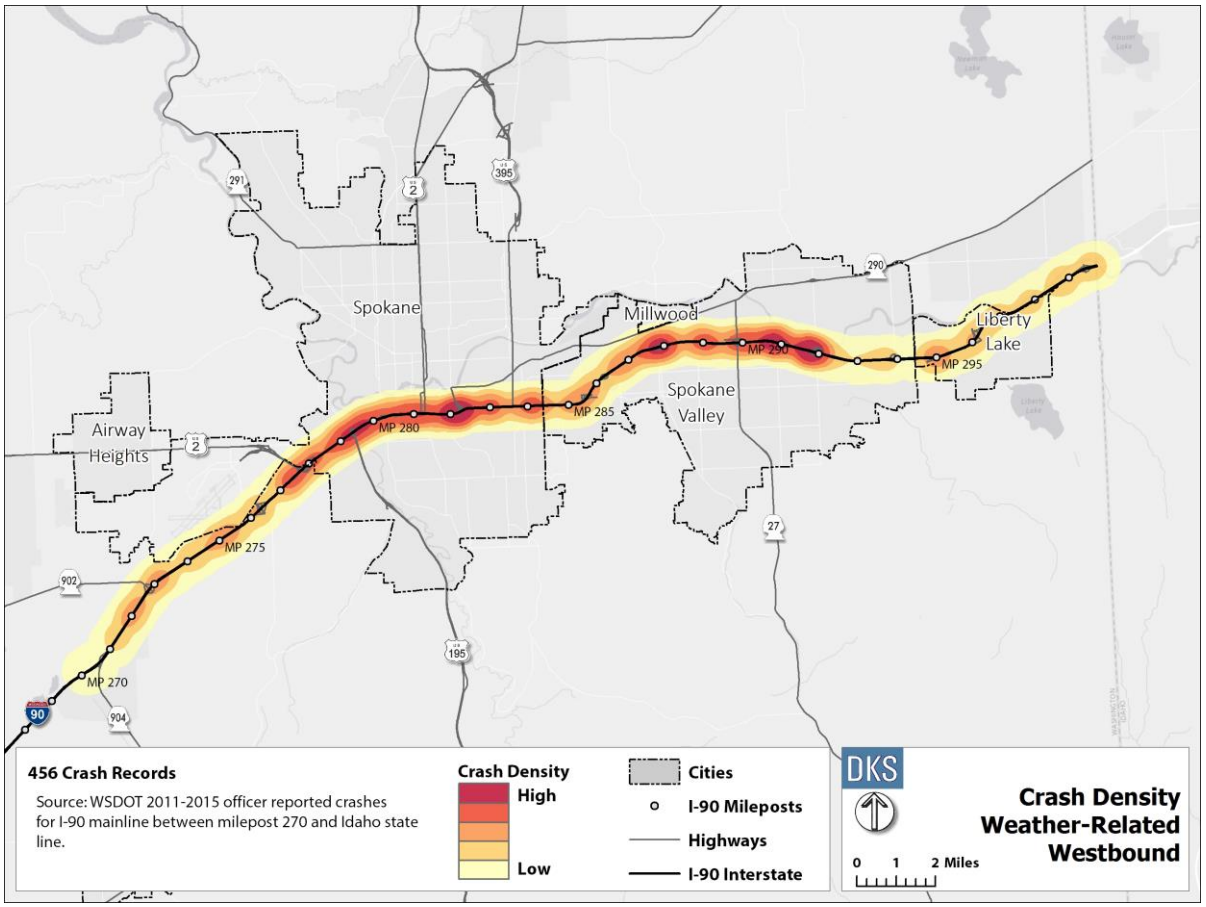
Traveling Eastbound

Weather-related crashes occur almost exclusively between November and February, and include a higher proportion of a.m., midday, and overnight crashes.

More eastbound weather related crashes occur in the downtown Spokane segment than any other segment as shown in the graphic. Each year, approximately 80 eastbound crashes occur during inclement weather on this segment of I-90.

Source: WSDOT, officer reported crashes 2011-2015.

Figure 24: Crash Density - Weather-Related Eastbound Crashes



Traveling Westbound

Weather-related crashes occur almost exclusively between November and February, and include a higher proportion of a.m., midday, and overnight crashes

Westbound weather related crashes are more frequent in the segments through downtown Spokane and Spokane Valley. Each year, nearly 100 westbound crashes occur during inclement weather on this segment of I-90.

Source: WSDOT, officer reported crashes 2011-2015.

Figure 25: Crash Density - Weather-Related Westbound Crashes

I-90 Interchange Ramp and Terminals Crash Hot Spots

More than 1,300 crashes occurred at interchanges and ramp terminals between 2011 and 2015. These 1,300 crashes include crashes on both the ramps and at the ramp intersection terminals. Interchanges are common locations for rear-end and side swipe crashes due to stopped vehicles exiting the Interstate at locations such as Division Street that experiences queuing from the exit ramp traffic signals, and due to vehicles entering the Interstate that often enter in platoons as they depart traffic signals at the entrance ramps. Along the I-90 corridor, three interchanges experience the highest number of crashes as illustrated in Figure 26: Maple St/Walnut St, Division St/Browne St, and Sullivan Rd.

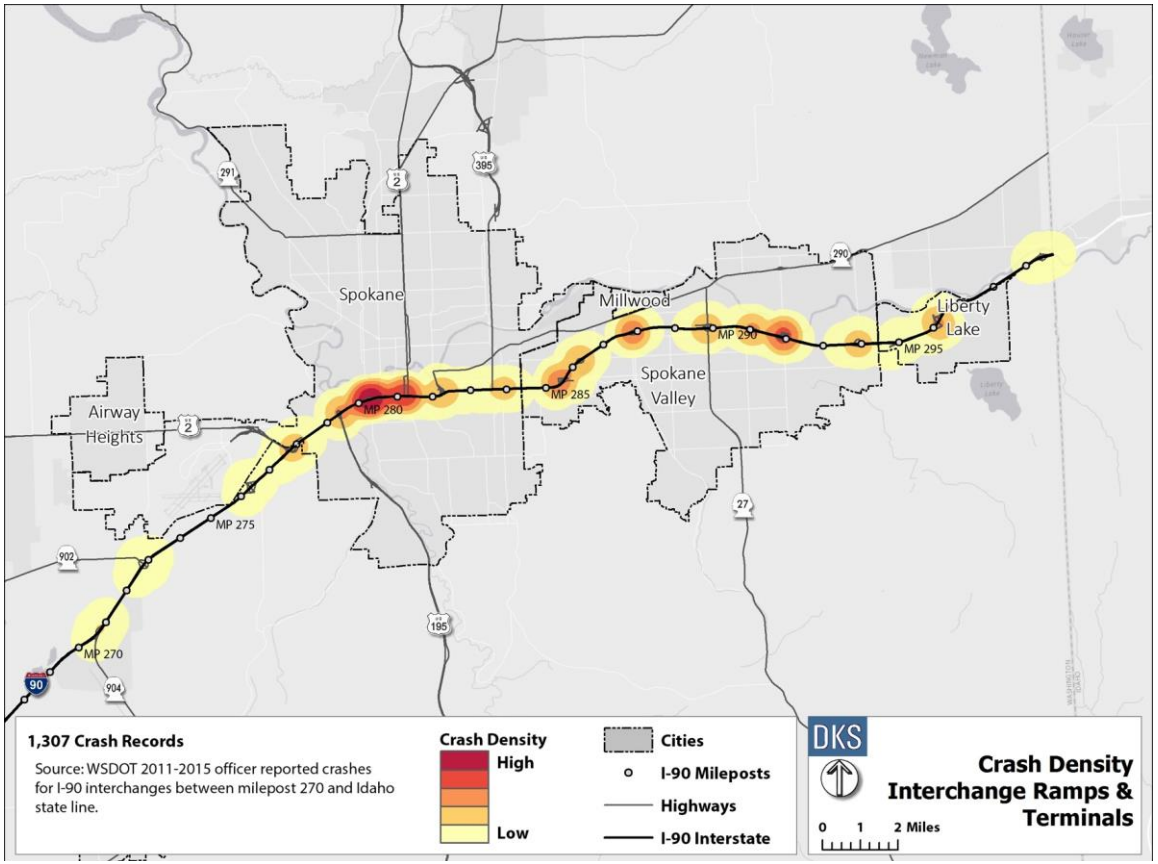


Figure 26: Crash Density - Interchange Ramps and Terminals

Interchange Ramps

As shown in the graphic, the three interchanges with the highest number of crashes include:

- Exit 280 - Maple St/Walnut St
- Exit 281 – Division St/Browne St
- Exit 291 – Sullivan Rd

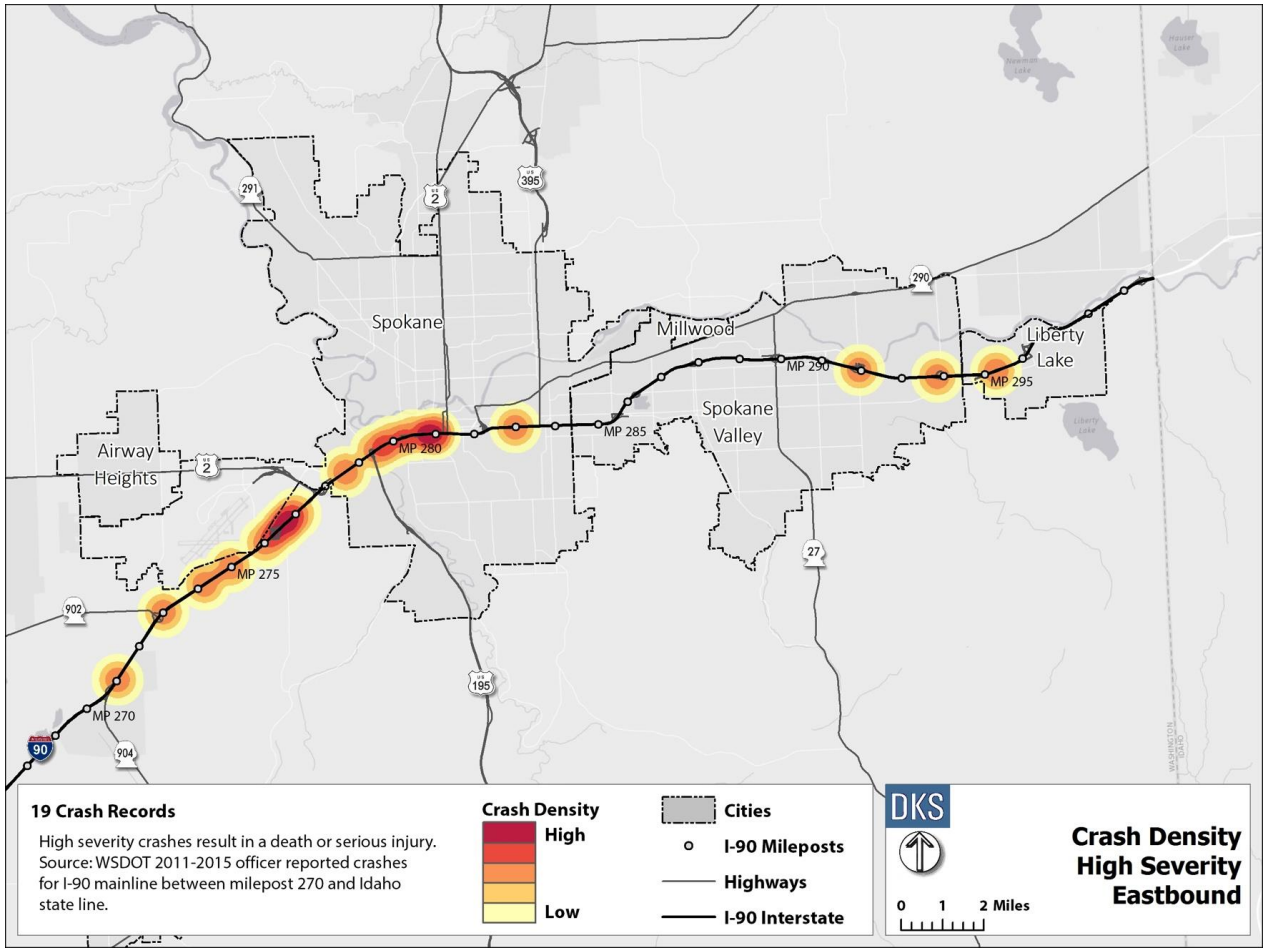
With 365 crashes, or 28 percent of all interchange crashes, exit 280 - Maple Street/Walnut Street is the most crash prone interchange.

Exit 281 – Division St/Browne St, and Exit 291 Sullivan Road each experienced more than 100 crashes each.

Source: WSDOT, officer reported crashes 2011-2015.

I-90 High Severity Crash Hot Spots

High severity crashes include fatal and serious injury collisions, and accounted for 25 of the 2,392 I-90 mainline crashes between 2011 and 2015. The top contributing factor to high severity crashes is driving under the influence, which contributed to nearly 25 percent of all high severity crashes. Figure 27 illustrates high-severity eastbound crashes and Figure 28 illustrates high-severity westbound crashes.



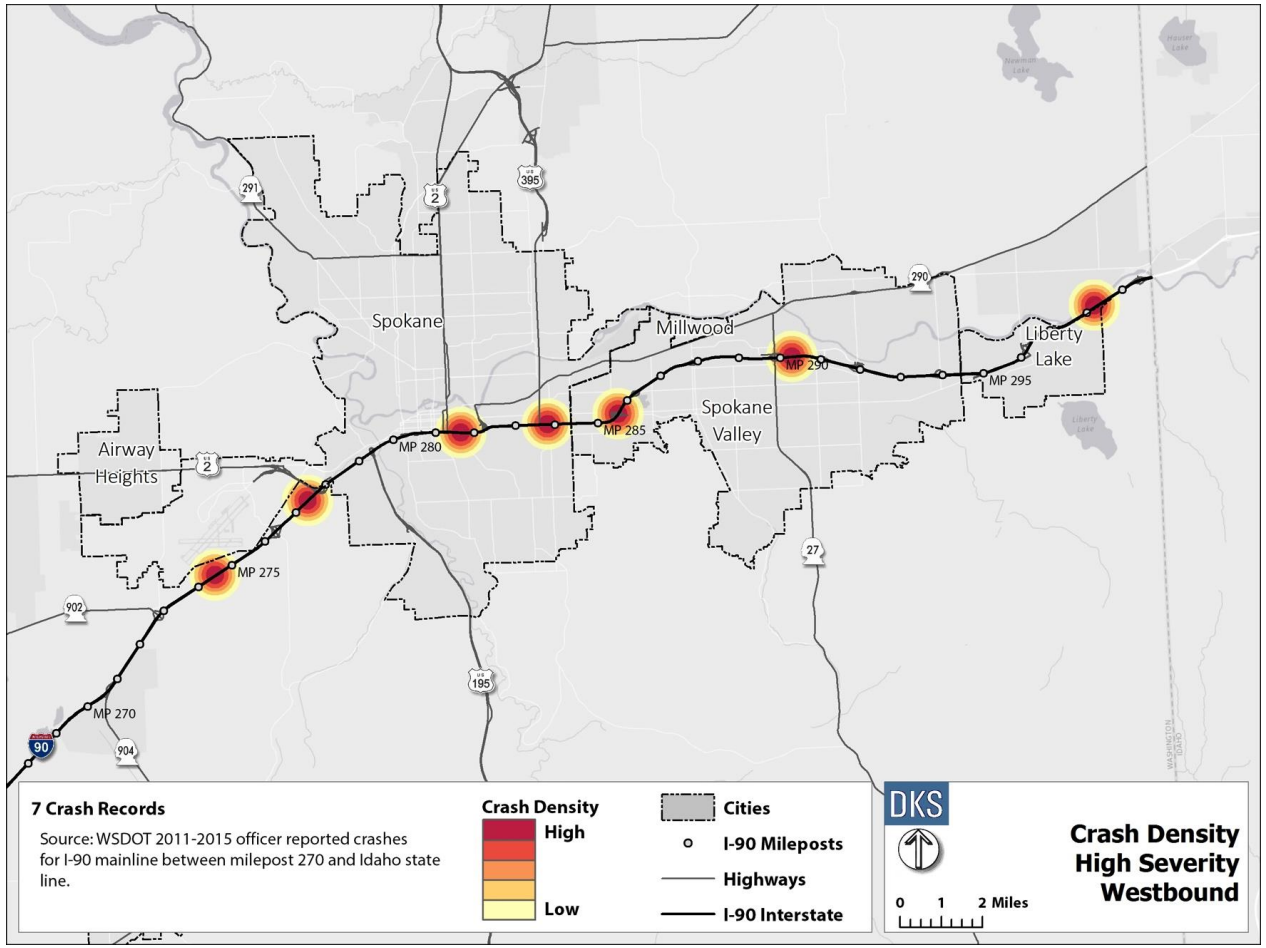
Traveling Eastbound

Segment B (downtown Spokane) has the highest frequency of high severity crashes (12). Segment B also has the highest crash rate, at 0.91 crashes per million vehicle miles traveled (MVMT).

The eastbound direction experienced twice as many high severity crashes than westbound with most occurring west of MP 280.

Source: WSDOT, officer reported crashes 2011-2015.

Figure 27: Crash Density - High Severity Eastbound



Traveling Westbound

Segment B (downtown Spokane) has the highest frequency of high severity crashes (11). Segment B also has the highest crash rate, at 0.91 crashes per million vehicle miles traveled (MVMT).

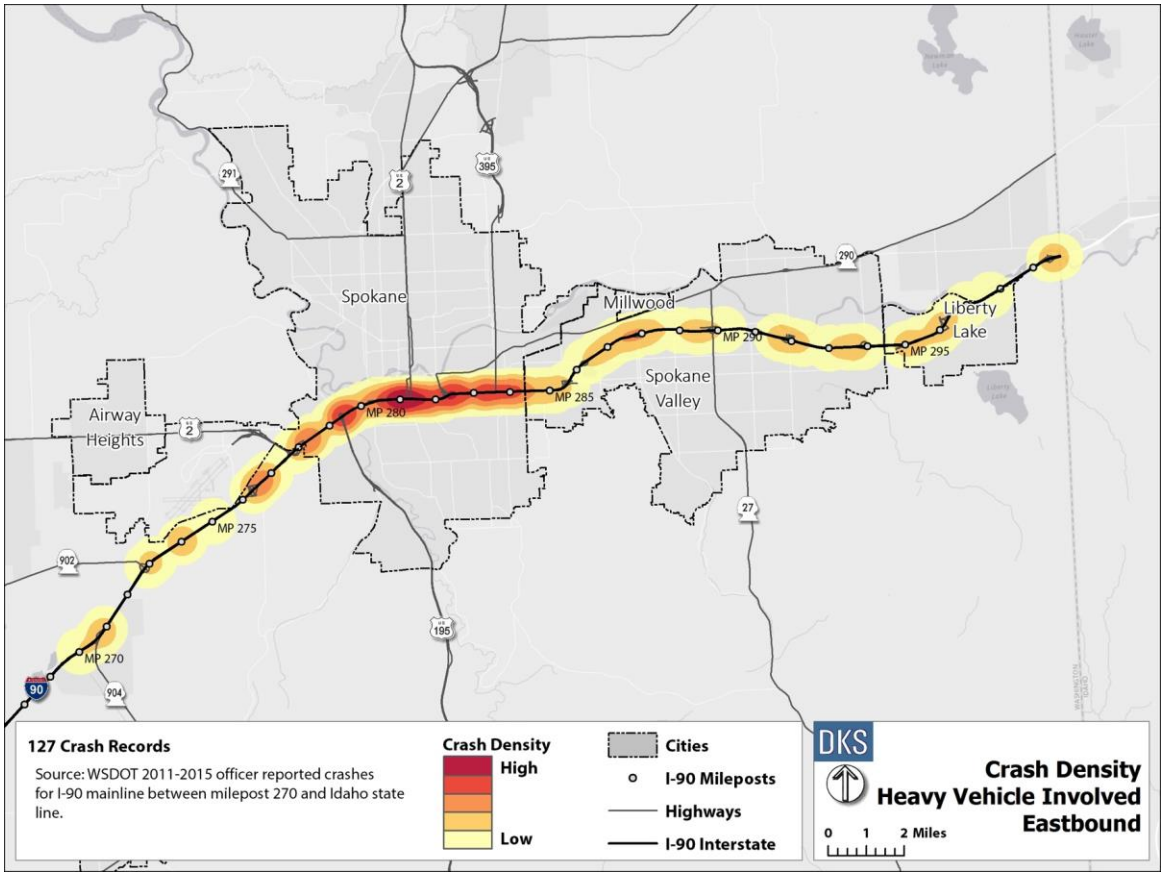
The eastbound direction experienced twice as many high severity crashes than westbound with most occurring west of MP 280.

Source: WSDOT, officer reported crashes 2011-2015.

Figure 28: Crash Density - High Severity Westbound

I-90 Heavy Vehicle Crash Hot Spots

Crashes involving heavy vehicles accounted for 10 percent of the 2,392 crashes on I-90 mainline and five percent of the 1,307 crashes at the interchanges, totalling more than 350 crashes over the five-year period between 2011 and 2015. Three interchanges, Exit 272 SR904 and Exit 283B Freya St, and Exit 286 Broadway, experienced a higher percentage of crashes involving heavy vehicles than other interchanges. At Exit 272 heavy vehicles accounted for 18 percent of the 17 crashes, 17 percent of the 30 crashes at Exit 283B, and 9 percent of the 45 crashes at Exit 286. Figure 29 illustrates eastbound crashes involving heavy vehicles and Figure 30 illustrates westbound crashes involving heavy vehicles.



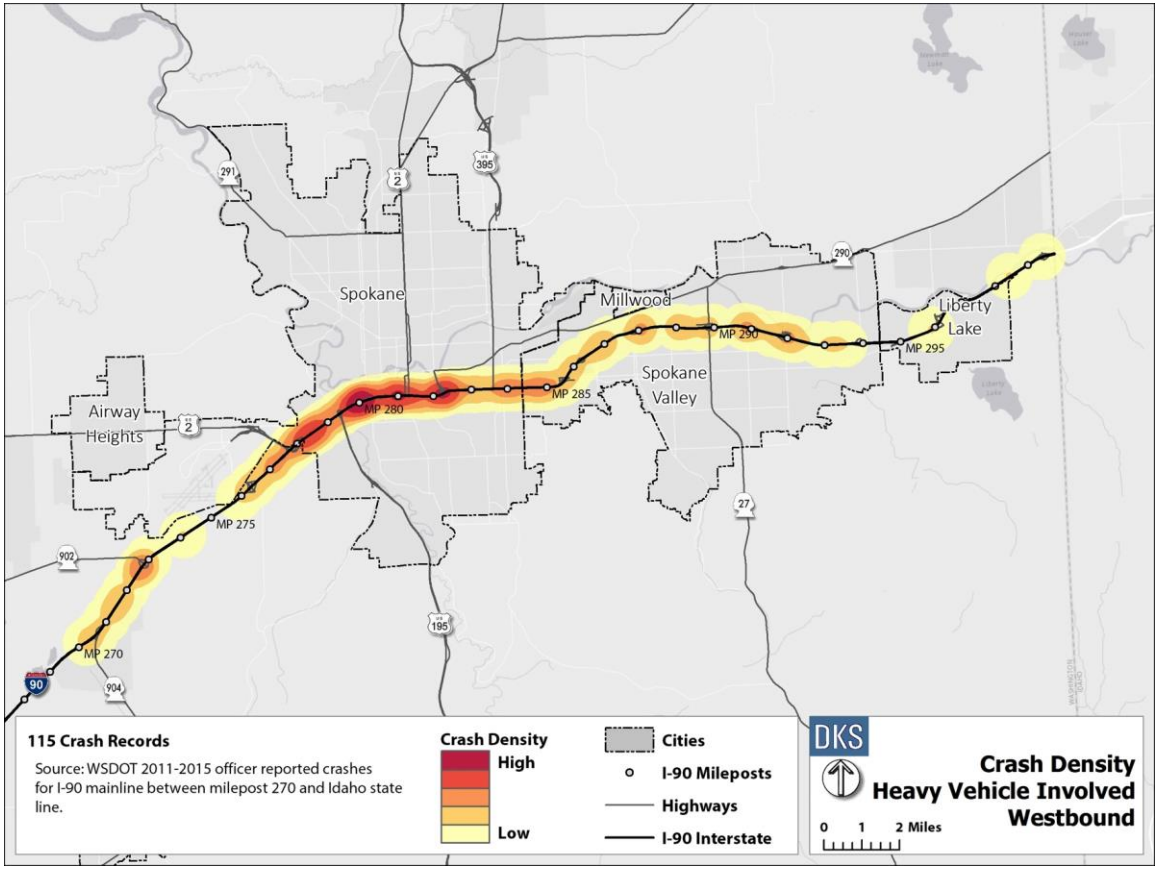
Traveling Eastbound

The majority of crashes involving heavy vehicles occur in the downtown Spokane segment and west between MP 276 and 284, and frequently involve a driver failing to grant right-of-way to a vehicle.

Although segment C has the second highest overall vehicle volumes, it experienced fewer crashes involving heavy vehicles.

Source: WSDOT, officer reported crashes 2011-2015.

Figure 29: Crash Density - Heavy Vehicle Involved Eastbound



Traveling Westbound

The majority of crashes involving heavy vehicles occur in the downtown Spokane segment and west between MP 276 and 284, and frequently involve a driver failing to grant right-of-way to a vehicle.

Although segment C has the second highest overall vehicle volumes, it experienced fewer crashes involving heavy vehicles.

Source: WSDOT, officer reported crashes 2011-2015.

Figure 30: Crash Density - Heavy Vehicle Involved Westbound

Predictive Safety Analysis

A predictive safety analysis helps identify locations with safety performance issues. It can predict the number of fatal and injury crashes based on the relationship between roadway characteristics including roadway geometry, cross section elements, roadside barriers, and safety. The I-90 predictive safety analysis looked at the safety performance of key interchanges, including mainline segments and weaving locations, using the Enhanced Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges (ISATe).[5] One advantage of predictive analysis is that it highlights opportunities for operational countermeasures for implementation. The analysis achieves this by isolating the impacts of geometric and traffic volumes from driver behavior and road conditions (i.e. weather). Review of the individual crash reports provides further insight in the process of selecting countermeasures for further evaluation.

The predictive safety analysis was conducted for two segments: the section of I-90 between US 2 and Broadway interchanges, and for Sullivan interchange. These locations were identified as crash hot spots in the WSDOT crash data evaluation that warranted further analysis. The full ISATe results are included in the appendix.

Methodology

ISATe provides a structured methodology to estimate the expected average crash frequency for a freeway with known characteristics and an available crash history. The project study area is divided into one or more sites, each of which is constant with respect to certain geometric features. Using a spreadsheet tool, the geometric design and traffic characteristics of each site are modeled and used to estimate the safety performance for a typical freeway with similar geometry and traffic volumes. The underlying mathematical functions for ISATe were developed using data from Washington State freeways, and thus does not require local calibration. The actual crash history of the freeway is combined with the model outputs to produce a reliable estimate of the long-term crash frequency for the site, including distributions by severity and type of crash.

- **Observed Crash Frequency** is the number of crashes reported in a specific time period. Each observed crash is assigned to a site, and observed crashes are categorized by severity (fatal-and-injury or property damage only), type (multiple vehicle or single vehicle), and location (freeway segment or ramp entrance/exit area). Due to the random nature of crashes, the observed crash frequency at a specific location often fluctuates over time. An important aspect of the ISATe analysis is that it takes the observed crashes and smooths the data so that abnormal spikes do not compromise the results (see "expected crash frequency" definition below).
- **Predicted Crash Frequency** is the number of crashes forecast for a specific time period by the ISATe model based on geometric design and traffic characteristics. The predicted crash frequency represents a consistent estimate of the "typical" anticipated safety performance for the specific set of conditions modeled. The predicted crash frequency has two main components:

[5] FHWA website, Crash Modification Factors in Practice, http://safety.fhwa.dot.gov/tools/crf/resources/cmfs/alternative.cfm

- **Safety Performance Functions (SPFs)** are formula that model the relationship between traffic volume and crash frequency, for a basic site condition. For instance, there is one SPF for "Urban Six-Lane Divided Freeway Segments" that returns a predicted crash frequency for any traffic volume within the valid range.
- **Crash Modification Factors (CMFs)** are variables that represent the impact of specific geometric designs and traffic characteristics. Initial crash predictions are multiplied by CMFs to obtain a new crash prediction. CMFs greater than one indicate an increase in crash frequency, while CMFs less than one indicate a decrease. The differences between the actual site to be modeled and the basic site condition of the SPF are expressed through CMFs. For instance, a basic site condition might be six-foot wide shoulders while the site to be modeled has twelve-foot wide shoulders. The reduction in crashes predicted by this difference would be represented through a CMF less than one.

- **Expected Crash Frequency** combines the observed crash frequency with the predicted crash frequency using a technique called the Empirical-Bayes Method, described in detail in the HSM. By incorporating the observed crash history, the impacts of non-modeled factors are factored in. Site specific variations that are not modeled include environmental conditions, driver behavior, maintenance conditions, congestion, and the innumerable other details that make each site unique. ***The expected crash frequency is considered to be the most reliable estimate of the long-term safety performance of an actual site under the modeled conditions, and is therefore recommended for use when calculating the potential benefits of implementing safety countermeasures.***
- **Excess Expected Crash Frequency** is defined as the expected crash frequency minus the predicted crash frequency. The comparison of expected crashes to the predicted crashes evaluates a site's performance versus a typical similar site. Positive excess expected values indicate more crashes than a typical similar site, while negative excess expected values indicate less crashes than a typical similar site. Negative values do not necessarily indicate acceptable safety performance, only that safety performance is consistent with the understood impacts of the modeled geometric designs and traffic conditions.
- **Percent Excess Expected** is defined as the excess expected crash frequency divided by the predicted crash frequency. This presents the same analysis as the excess expected crash frequency, but it is normalized in a way that makes it easier to compare sites with varying lengths and traffic volumes. As with excess expected crash frequency, positive values indicate sites that are expected to experience more crashes than typical similar sites, and negative values indicate sites that are expected to experience fewer crashes than typical similar sites.

Analysis and Results for Downtown Segment

This ISATe analysis builds on an initial investigation by WSDOT[6], which looked at the entire length of the downtown section of I-90 as a single site. To better understand the safety issues at specific points in the downtown section of I-90, this analysis disaggregated the data into multiple sites, shown in Figure 31.

[6] Collision Data Analysis, 2015 ER Project Definition Countermeasure Recommendations. I-90/US 2 Garden Springs I/C to Broadway Rd Interchange. WSDOT.

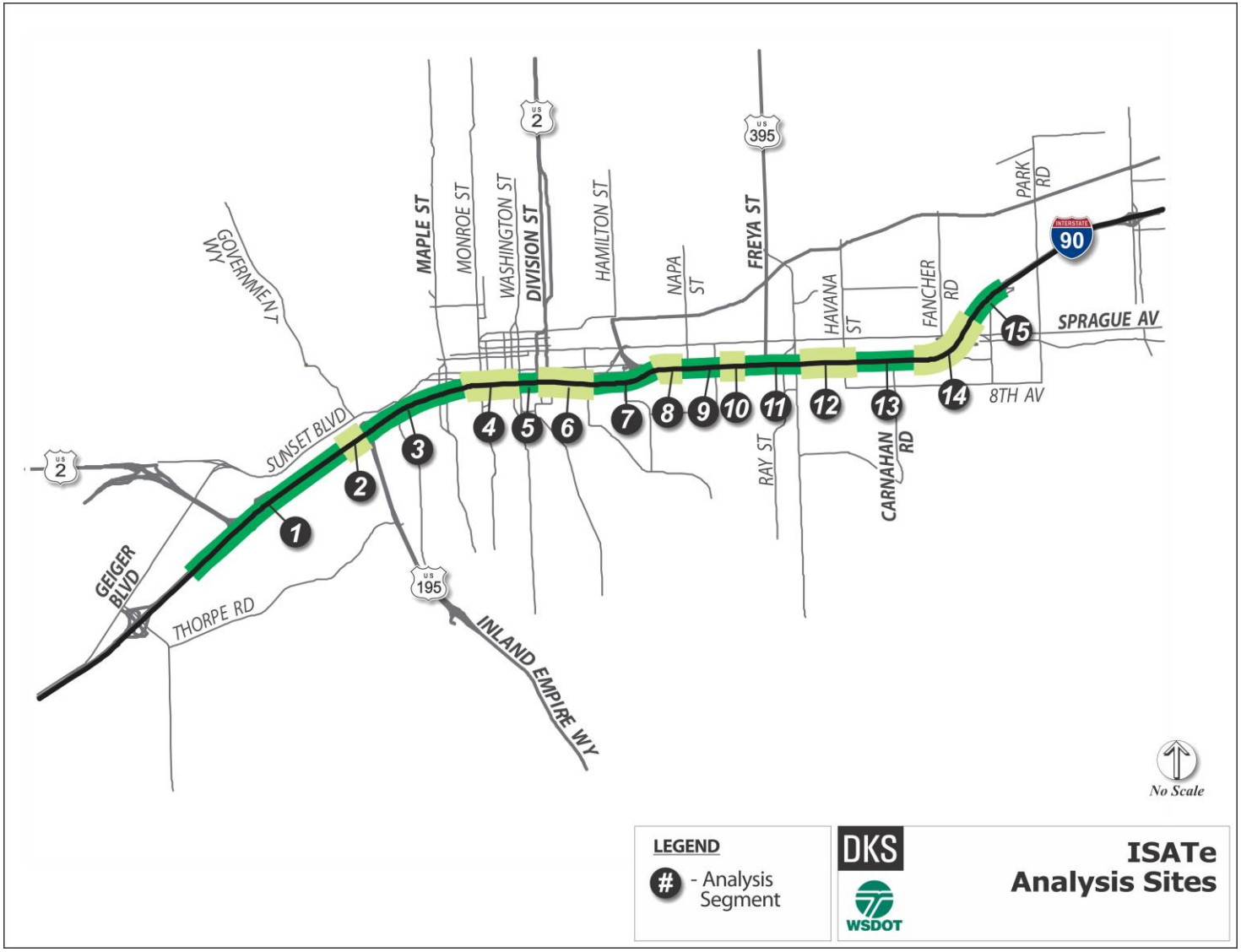


Figure 31: ISATe Analysis Sites for Downtown Segment

The ISATe results for the I-90 mainline through the downtown Spokane area are summarized in Table 7. The analysis found that several of the sites had excess expected crashes, indicating that they experience more crashes than would be expected at a similar site. The areas with excess expected crashes higher than 20 percent include:

- US 195 Interchange area (site 2), with 60% excess expected crashes.
- The section between Monroe and Division (site 4), with 44% excess expected crashes.
- Freya Street Interchange area between ramps (site 11), with 43% excess expected crashes.
- The section between US 195 and Monroe Street (site 3), with 31% excess expected crashes.
- Division Interchange area (site 5), with 20% excess expected crashes.

Five sites had a high percentage of excess expected crashes:

- **US 195 Interchange**
- **I-90: Monroe to Division**
- **Freya Interchange**
- **I-90: US 195 to Monroe**
- **Division Interchange**

For sites that do not show excess expected crashes, the CMFs and SPFs should be considered before determining there are no safety issues at the site. Sometimes the CMFs alone can be an indicator of a safety issue. In this study, sites 6, 8, 10, 12, and 13 do not have positive excess expected crashes; however, these sites have CMFs that indicate crashes are more likely at those locations. The Freya on-ramp (site 12) illustrates this caveat. It has a very short merge area (less than 300 feet). The Freya ramp entrance geometry dictated a high CMF that resulted in a high number of predicted crashes. Relative to other sites, site 12 does have a high expected crash frequency, but not greater than the predicted value at this site due to the site's geometry. Table 7 lists whether a site experienced excess expected crashes and if not, whether there were contributing factors to consider for safety improvements. The full ISATe results are included in Appendix A.

Table 7: ISATe Results - I-90 Through Downtown Spokane

Site No.	Site Description	Included On-Ramps	Site Extents		Site Length (miles)	Are there excess expected crashes? If not, what were the determining factors?	Percent Excess Expected
1	US 2 to US 195	US 2 EB on-ramp	277.74	279.2	1.46	Yes	4%
2	US 195 Interchange	US 195 WB on-ramp US 195 EB on-ramp	279.2	279.55	0.35	Yes	60%
3	195 to Monroe	WB Maple on-ramp EB Walnut on-ramp WB Monroe on-ramp	279.55	280.63	1.08	Yes	31%
4	Monroe to Division	WB on-off ramp aux lane (Browne to Lincoln weave) EB Monroe on-ramp EB aux lane (Monroe to Division)	280.63	281.16	0.53	Yes	44%
5	Division Interchange (between ramps)	None	281.16	281.36	0.2	Yes	20%
6	Division to Conklin	EB Division on-ramp (2 lanes) WB Hamilton on-ramp	281.36	281.96	0.6	No - Note that the model accounts for a high lane change CMF (~1.4 to 1.5) which increases the expected crashes	
7	Hamilton Interchange	None	281.96	282.5	0.54	Yes	8%
8	East of Hamilton	EB on-ramp from Hamilton WB on-ramp from 2nd/Altamont - weave area	282.5	282.75	0.25	No - Note that the model accounts for a high lane change CMF (~1.9 to 2.3) which increases the expected crashes	
9	Napa to Nelson	Portion of EB Altamont on-ramp	282.75	283.29	0.54	Yes	12%

Table 7: ISATe Results - I-90 Through Downtown Spokane continued

Site No.	Site Description	Included On-Ramps	Site Extents		Site Length (miles)	Are there excess expected crashes? If not, what were the determining factors?	Percent Excess Expected
10	Nelson to Haven or Fiske? (Figure 26 needs updated too)	Portion of EB Altamont on-ramp WB weave (aux lane) between Freya on-ramp and Exit 283A (2nd/Altamont) EB weave (aux lane) between Altamont on-ramp and Freya off-ramp	283.29	283.46	0.17	No - Note that the model accounts for a high lane change CMF (~1.6) which increases the expected crashes	
11	Freya Interchange (between ramps)	None	283.46	284.05	0.59	Yes	43%
12	East of Freya Interchange	EB Freya on-ramp Beginning portion of EB Havana on-ramp	284.05	284.59	0.54	No - Note that the model accounts for a high ramp entrance CMF (~1.8) which increases the expected crashes	
13	Custer to Koren	Main portion of EB Havana on-ramp WB on-ramp from Fancher and Sprague	284.59	285.16	0.57	No - Note that the model accounts for a moderate lane change CMF (~1.2 to 1.3) which increases the expected crashes	
14	Fancher/Sprague Interchange	WB Broadway on-ramp	285.16	285.91	0.75	No	
15	Nixon to Broadway	None	285.91	286.24	0.33	No	

Figure 32 provides a breakdown of the observed crash types at each analysis site in the downtown Spokane segment. A high percentage of the crash types in the downtown Spokane are rear-end crashes. This finding correlates with the ISATe findings for sites with high excess expected crashes.

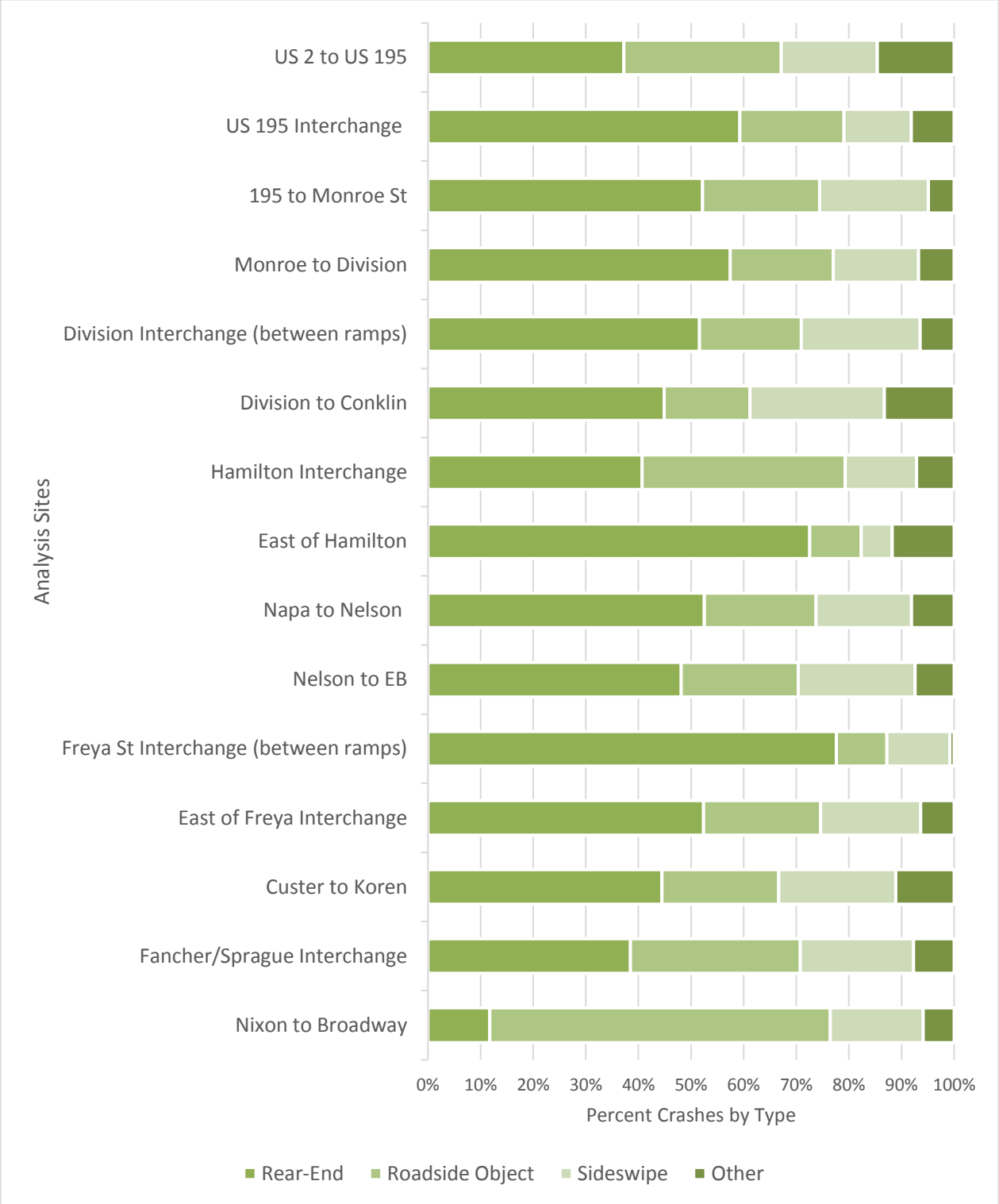


Figure 32: Observed Crash Type Proportions at Downtown Predictive Analysis Sites

Analysis and Results for Sullivan Interchange

An ISATe analysis was also completed for the Sullivan Road interchange that lies outside of the downtown segment. This location was identified as a crash hotspot in the WSDOT crash history analysis. The Sullivan Road interchange was divided into seven analysis sites as shown in Figure 33.

Site 4 was the only site with excess expected crashes, which includes the westbound on-ramp from Sullivan Road. As shown in Figure 33, the westbound on-ramp has a tight radius and a merge area less than 500 feet long, which likely contribute to safety issues. With this level of detail, the results can indicate very specific parts of the roadway to target safety improvements.

Figure 33: Sullivan Road Interchange Analysis Sites

PLANNED AND FUNDED PROJECTS

Several systems and infrastructure projects are funded or planned for the I-90 corridor. These projects may affect how the corridor operates as they are implemented over the next 20 years. Planning for operations on the corridor should account for these projects, which are documented in this section. Projects summarized here include:

- ITS projects
- The North Spokane Corridor
- Additional regional infrastructure projects along I-90

WSDOT and the Idaho Transportation Department (ITD) have implemented ITS strategies for improving system operations in the I-90 corridor. Both agencies adopted ITS plans in 2007 to establishes policies and guide development and investment:

- *WSDOT Eastern Washington ITS Implementation Plan*, 2007[7]
- *Idaho Transportation Department (ITD) I-90 Corridor ITS Strategic Plan*, 2007

In 2013, the Spokane Regional Transportation Management Center (SRTMC) completed the *Spokane Region ITS Systems Plan*[8], working with WSDOT, SRTC, the cities of Spokane and Spokane Valley, Spokane County, and Spokane Transit Authority. The *Spokane Region ITS Plan* took into consideration both the WSDOT and ITD plans for the section of I-90 within the study corridor. Overall, the *Spokane Region ITS Plan* provides strategies to improve system operations by relieving congestion, enhancing safety, providing services to travelers, and assisting transportation system operators in implementing suitable traffic management strategies. It focuses on increasing the efficiency of existing transportation infrastructure, which enhances the overall system performance and reduces the need to add capacity by adding travel lanes through roadway widening.

Recommended projects from the *Spokane Region ITS Plan* are shown in the Planned and Funded Projects section of this memorandum.

ITS Projects

The 2013 Spokane Region ITS Plan laid a vision, supporting goals, and key projects for several TSMO service areas. Projects that are funded or in progress are shown in Table 8.

[7] http://www.srtc.org/Documents/Documents-Maps/Other_documents/er_final_its_implementation_plan_mar2007.pdf
[8] http://www.srtc.org/Documents/Documents-Maps/Other_documents/Spokane_Region_ITS_Systems_Plan_2013.pdf

Table 8: Spokane Region ITS Plan Projects

Project	Lead Agency	Elements	Priority Ranking	Project Cost (2013 $)	Status
WSDOT F: CCTV Upgrades	WSDOT	Upgrade CCTV cameras on I-90 between US 2 and Argonne Rd) and associated equipment and communications.	Medium	$480,000	Complete
WSDOT-G: I-90 Ramp and Arterials Counters	WSDOT	Install traffic sensors on I-90 ramps and adjacent arterial roadways to support planning, operations, and traveler information.	High	$960,000	Scoping
SR-10: SRTMC Equipment Maintenance and Infrastructure Upgrades	SRTMC	Support ongoing hardware and software maintenance of SRTMC systems. Continuous cost that needs to be secured every biennium.	High	$2,000,000	Current open work order.
SR-13A: Advanced Transportation Management System Upgrade	SRTMC	Upgrade supports CCTV camera control, dynamic message sign control, highway advisory radio control, traffic data station monitoring, weather station monitoring and forecasting, traveler information.	High	Phase 1- $1,790,000	Underway, scheduled completion August 2017
SR-13B: Advanced Transportation Management System Upgrade	SRTMC	Upgrade supports ramp metering, variable speed limit control, regional snow plow activity map, ROADS system interface, travel time estimates	High	Phase 2- $1,000,000	Will be completed in conjunction with 13A

Project	Lead Agency	Elements	Priority Ranking	Project Cost (2013 $)	Status
STA-15: Real-time Park and Ride Traveler Information	STA	Provide travelers with real time information about park and ride lot occupancy.	Low	$500,000	Recently installed at Jefferson and Mirabeau Park and Rides
STA: Liberty Lakes Service	STA	Expanding service to the 174 Liberty Lake Express		Not provided	Sept 2017
STA: New Transit Center	STA	West Plains Transit Center		Not provided	Construction begin in 2017

North Spokane Corridor

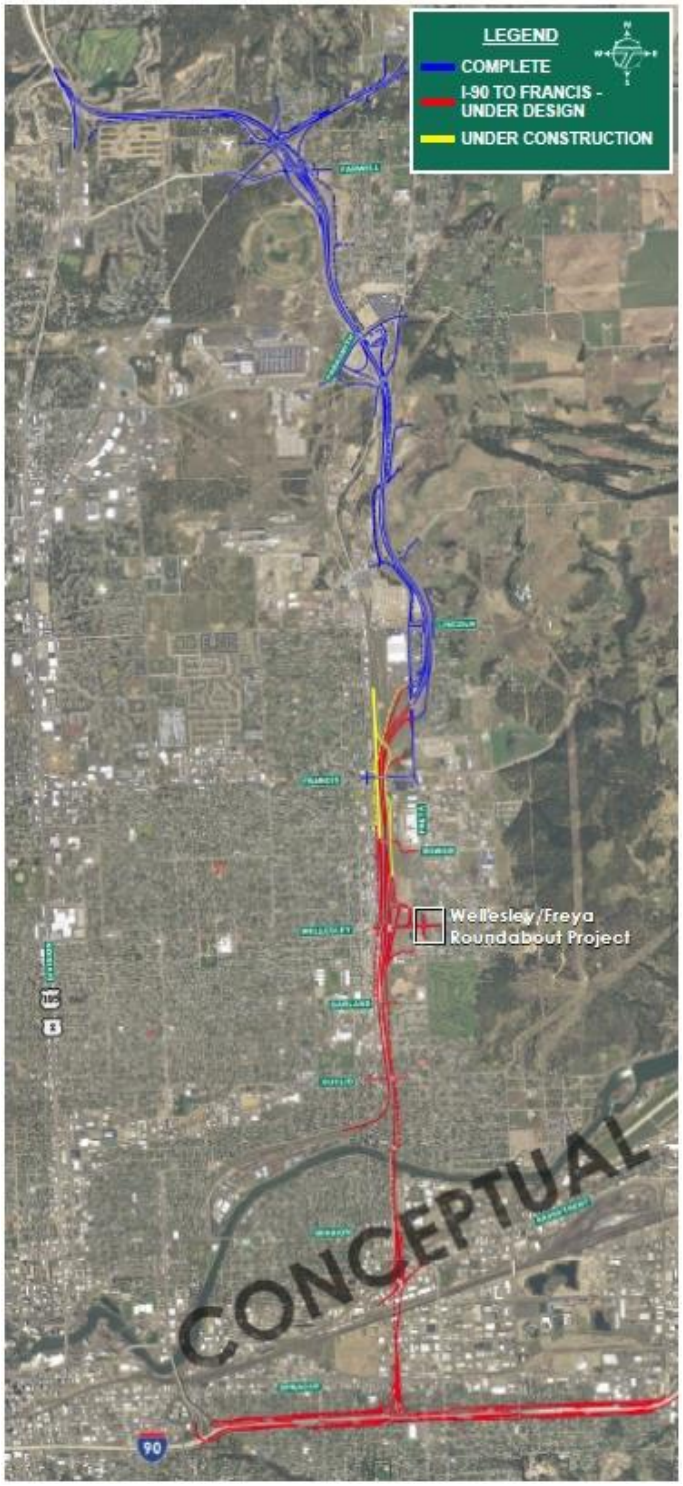


Figure 34: North Spokane Corridor Conceptual Alignment and Current Status

The North Spokane Corridor (NSC) is a planned 10.5-mile limited access north-south corridor that will link I-90 at the south end with US 2 and US 395 to the north. Figure 34 shows the planned alignment of the corridor, which is being funded and constructed in phases.

The north segment, between E Francis Avenue and US 395 to the north, is complete. Additional segments and a new interface at I-90 are planned in the region's Metropolitan Transportation Plan, discussed in the next section. The NSC is fully funded for construction to I-90, and is estimated to be complete in 2027.

Continued development of the NSC and ultimately connecting this new major north-south facility to I-90 will likely have a future impact on I-90 operations. The conceptual connection to I-90 is shown in Figure 35.

Figure 35: NSC Conceptual I-90 Connection

Other Planned and Funded Projects

Several projects in the study corridor have been identified in SRTC's financially constrained Metropolitan Transportation Plan (MTP)[9]. Some of the projects in the MTP have either already been constructed or are underway. Table 9 shows projects, cost estimates, planned timeframe, and whether the projects are complete or in progress.

Table 9: SRTC Metropolitan Transportation Plan Projects

MTP Project ID	Project	Description	Project Cost (2011 $)	Status
Short-term projects (2011-2015)				
4	I-90 – Sullivan Interchange to Barker Road	Construct general purpose lanes	$19,000,000	Complete
21	I-90 – Barker Road Interchange	Construct general purpose lanes and replace Barker interchange	$26,500,000	Planned
Medium-term projects (2016-2025)				
8	I-90 Freya westbound off-ramp	Ramp modifications	$3,000,000	Complete
13	I-90 – Barker Interchange to Harvard Interchange	Construct general purpose lanes	$32,000,000	Planned
18	I-90 – Henry Road Interchange	Replace Green Acres Interchange with one at Henry Road	$26,500,000	Planned
22	North Spokane Corridor – I-90 North Access Connection Phase 1	Construct interchange and roadway for half of facility	$190,000,000	Planned
23	North Spokane Corridor – Collector Distributor System Phase 1	Reconstruct I-90 with C-D System Phase 1	$82,000,000	Planned
Long-term projects (2026-2035)				
2	North Spokane Corridor – I-90 North Access Connection Phase 2	Construct interchange and roadway for half of facility	$187,000,000	Planned
4	I-90 Medical Lake Interchange	Interchange modifications	$7,500,000	Planned
5	North Spokane Corridor – Collector Distributor System Phase 2	Reconstruct I-90 with C-D System Phase 2	$230,000,000	Planned
21	I-90 – Harvard Interchange to Idaho State Line	Construct general purpose lanes and structures	$115,000,000	Planned

Source: SRTC Spokane 2011-2035 Metropolitan Transportation Plan

[9] Spokane Regional Transportation Council, Horizon 2040 Metropolitan Transportation Plan for the Spokane Metropolitan Planning Area, 2013, http://www.srtc.org/mtp_2040.html

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APPENDIX A: ISATE RESULTS

DRAFT -- ISATe Summary for I-90 SRMP 277.74 to 286.24

Crash terminology for predictive analysis (Highway Safety Manual)

Observed crash frequency:	The number of crashes recorded in the actual empirical crash data (2011-2015)
Predicted crash frequency:	The number of crashes predicted by the HSM model, without considering actual empirical crash data.
Expected crash frequency	The number of crashes that is likely in the long-run, considering both model predictions and empirical crash data (using Empirical-Bayes method)
Excess Expected crash frequency:	The difference between the predicted crash frequency and the expected crash frequency.

**** Positive values of Excess Expected Crash Frequency are highlighted and indicate ISATe expects higher crash frequencies (in the long run) at the site vs. the model predictions (the baseline).***

EE% here defined as (Excess Expected / Predicted), or "Excess Expected crash frequency as a percentage of Predicted crash frequency

		5-year Total Values				
		Fatal-and-Injury	Property Damage Only	Crash Total	Length (ı	Per Mile
Site 1 Crashes	Observed	37.0	97.0	134.0	1.46	91.8
US2 to US195	Predicted	39.5	90.4	129.9	1.46	89.0
includes EB on ramp from US 2	Expected	40.7	94.6	135.3	1.46	92.7
	Excess Expected	**1.2**	**4.2**	**5.4**	**1.46**	**3.7**
	EE%	**3%**	**5%**	**4%**	**100%**	**4%**
Site 2 Crashes	Observed	32.0	53.0	85.0	0.35	242.9
195 Interchange	Predicted	12.8	28.8	41.5	0.35	118.7
includes all 195 ramps	Expected	22.7	43.7	66.4	0.35	189.7
	Excess Expected	**10.0**	**14.9**	**24.9**	**0.35**	**71.0**
	EE%	**78%**	**52%**	**60%**	**100%**	**60%**
Site 3 Crashes	Observed	47.0	137.0	184.0	1.08	170.4
195 to Monroe St	Predicted	37.8	83.9	121.7	1.08	112.7
	Expected	42.6	116.2	158.9	1.08	147.1
	Excess Expected	**4.8**	**32.3**	**37.2**	**1.08**	**34.4**
	EE%	**13%**	**39%**	**31%**	**100%**	**31%**
Site 4 Crashes	Observed	54.0	94.0	148.0	0.53	279.2
Monroe to Division	Predicted	31.1	62.6	93.7	0.53	176.8
includes WB on-off ramp aux lane	Expected	47.2	87.9	135.2	0.53	255.1
	Excess Expected	**16.2**	**25.3**	**41.5**	**0.53**	**78.3**
	EE%	**52%**	**40%**	**44%**	**100%**	**44%**
Site 5 Crashes	Observed	4.0	27.0	31.0	0.2	155.0
Division Interchange	Predicted	7.9	17.1	25.0	0.2	125.2
	Expected	6.3	23.8	30.1	0.2	150.6
	Excess Expected	**-1.6**	**6.7**	**5.1**	**0.2**	**25.4**
	EE%	**-20%**	**39%**	**20%**	**100%**	**20%**
Site 6 Crashes	Observed	30.0	68.0	98.0	0.6	163.3
Division to Garfield	Predicted	34.2	73.1	107.3	0.6	178.9
Includes EB on-ramp	Expected	32.7	70.0	102.7	0.6	171.2
	Excess Expected	**-1.5**	**-3.1**	**-4.6**	**0.6**	**-7.7**
	EE%	**-4%**	**-4%**	**-4%**	**100%**	**-4%**
Site 7 Crashes	Observed	36.0	104.0	140.0	0.54	259.3
Hamilton Interchange	Predicted	33.4	79.8	113.2	0.54	209.6
	Expected	35.9	97.6	133.5	0.54	247.2
	Excess Expected	**2.5**	**17.8**	**20.3**	**0.54**	**37.6**
	EE%	**8%**	**22%**	**18%**	**100%**	**18%**
Site 8 Crashes	Observed	11.0	40.0	51.0	0.24	212.5
includes EB on ramp from Hamilton	Predicted	22.3	45.6	67.9	0.24	282.8
include WB on ramp from 2nd - weave area	Expected	14.3	41.0	55.3	0.24	230.4
	Excess Expected	**-8.0**	**-4.6**	**-12.6**	**0.24**	**-52.4**
	EE%	**-36%**	**-10%**	**-19%**	**100%**	**-19%**
Site 9 Crashes	Observed	23.0	76.0	99.0	0.54	183.3
Napa to Nelson (no ramps?)	Predicted	26.9	61.5	88.4	0.54	163.6
	Expected	26.1	73.1	99.2	0.54	183.7
	Excess Expected	**-0.8**	**11.6**	**10.9**	**0.54**	**20.1**
	EE%	**-3%**	**19%**	**12%**	**100%**	**12%**
Site 10 Crashes	Observed	6.0	21.0	27.0	0.17	158.8
WB weave to Exit 283A (2nd/Altamont)	Predicted	12.7	29.2	41.9	0.17	246.3
EB weave to Exit 283 B (Freya)	Expected	8.7	21.7	30.4	0.17	178.8
	Excess Expected	**-4.0**	**-7.5**	**-11.5**	**0.17**	**-67.5**
	EE%	**-31%**	**-26%**	**-27%**	**100%**	**-27%**
Site 11 Crashes	Observed	32.0	93.0	125.0	0.59	211.9
Freya St Interchange (between ramps)	Predicted	25.5	57.2	82.8	0.59	140.3
	Expected	32.1	85.9	118.0	0.59	199.9
	Excess Expected	**6.5**	**28.7**	**35.2**	**0.59**	**59.6**
	EE%	**26%**	**50%**	**43%**	**100%**	**43%**
Site 12 Crashes	Observed	15.0	48.0	63.0	0.54	116.7
EB Freya on-ramp	Predicted	30.6	68.9	99.5	0.54	184.3
	Expected	21.2	52.9	74.0	0.54	137.1
	Excess Expected	**-9.5**	**-16.0**	**-25.5**	**0.54**	**-47.2**
	EE%	**-31%**	**-23%**	**-26%**	**100%**	**-26%**
Site 13 Crashes	Observed	20.0	34.0	54.0	0.57	94.7
Custer to Koren	Predicted	35.1	79.0	114.1	0.57	200.2
WB on-ramp from Fancher	Expected	25.5	43.8	69.2	0.57	121.5
	Excess Expected	**-9.7**	**-35.2**	**-44.9**	**0.57**	**-78.7**
	EE%	**-27%**	**-45%**	**-39%**	**100%**	**-39%**

DRAFT -- ISATe Summary for I-90 SRMP 277.74 to 286.24

Crash terminology for predictive analysis (Highway Safety Manual)

Observed crash frequency:	The number of crashes recorded in the actual empirical crash data (2011-2015)
Predicted crash frequency:	The number of crashes predicted by the HSM model, without considering actual empirical crash data.
Expected crash frequency	The number of crashes that is likely in the long-run, considering both model predictions and empirical crash data (using Empirical-Bayes method)
Excess Expected crash frequency:	The difference between the predicted crash frequency and the expected crash frequency.

**** Positive values of Excess Expected Crash Frequency are highlighted and indicate ISATe expects higher crash frequencies (in the long run) at the site vs. the model predictions (the baseline).***

EE% here defined as (Excess Expected / Predicted), or "Excess Expected crash frequency as a percentage of Predicted crash frequency

		5-year Total Values				
		Fatal-and-Injury	**Property Damage Only**	**Crash Total**	**Length (ı**	**Per Mile**
Site 14 Crashes	Observed	16.0	49.0	65.0	0.75	86.7
Fancher/Sprague Interchange	Predicted	34.5	78.1	112.6	0.75	150.1
	Expected	25.6	56.7	82.3	0.75	109.8
	Excess Expected	**-8.9**	**-21.4**	**-30.3**	**0.75**	**-40.3**
	EE%	**-26%**	**-27%**	**-27%**	**100%**	**-27%**
Site 15 Crashes	Observed	6.0	11.0	17.0	0.33	51.5
Nixon to Broadway	Predicted	14.7	33.4	48.2	0.33	145.9
WB on ramp	Expected	9.6	16.8	26.4	0.33	80.0
	Excess Expected	**-5.1**	**-16.6**	**-21.7**	**0.33**	**-65.9**
	EE%	**-35%**	**-50%**	**-45%**	**100%**	**-45%**
Project Total Crashes	Observed	369.0	952.0	1321.0	8.49	155.6
	Predicted	399.0	888.7	1287.7	8.49	151.7
	Expected	391.2	925.7	1317.0	8.49	155.1
	Excess Expected	**-7.7**	**37.0**	**29.3**	**8.49**	**3.4**
	EE%	**-2%**	**4%**	**2%**	**100%**	**2%**

Exit 291 - Sullivan Road

Crash terminology for predictive analysis (Highway Safety Manual)

Observed crash frequency:	The number of crashes recorded in the actual empirical crash data (2011-2015)
Predicted crash frequency:	The number of crashes predicted by the HSM model, without considering actual empirical crash data.
Expected crash frequency	The number of crashes that is likely in the long-run, considering both model predictions and empirical crash data (using Empirical-Bayes method)
Excess Expected crash frequency:	The difference between the predicted crash frequency and the expected crash frequency.

**** Positive values of Excess Expected Crash Frequency are highlighted and indicate ISATe expects higher crash frequencies (in the long run) at the site vs. the model predictions (the baseline).***

EE% here defined as (Excess Expected / Predicted), or "Excess Expected crash frequency as a percentage of Predicted crash frequency

		Fatal-and-Injury	Property Damage Only	Crash Total
Site 1 Crashes	Observed	4.0	12.0	16.0
0.14 mi	Predicted	6.8	13.9	20.7
	Expected	5.1	11.9	17.0
	Excess Expected	-1.7	-2.0	-3.7
Site 2 Crashes	Observed	2.0	7.0	9.0
0.1 mi	Predicted	4.2	8.8	13.0
	Expected	2.7	7.0	9.7
	Excess Expected	-1.5	-1.8	-3.3
Site 3 Crashes	Observed	3.0	8.0	11.0
0.14 mi	Predicted	4.0	9.7	13.7
	Expected	3.6	8.5	12.2
	Excess Expected	-0.4	-1.1	-1.6
Site 4 Crashes	Observed	14.0	21.0	35.0
0.25 mi	Predicted	8.2	18.7	26.9
	Expected	10.7	20.3	31.1
	Excess Expected	2.6	1.6	4.2
	EE%	0.3		
Site 5 Crashes	Observed	4.0	10.0	14.0
0.15 mi	Predicted	4.3	10.3	14.6
	Expected	4.0	10.2	14.2
	Excess Expected	-0.3	-0.1	-0.3
Site 6 Crashes	Observed	7.0	11.0	18.0
0.17 mi	Predicted	5.1	11.7	16.7
	Expected	5.1	10.8	15.9
	Excess Expected	0.0	-0.8	-0.9
Site 7 Crashes	Observed	6.0	8.0	14.0
0.42 mi	Predicted	12.9	27.7	40.6
	Expected	9.3	12.9	22.2
	Excess Expected	-3.6	-14.9	-18.5
Project Total Crashes	Observed	40.0	77.0	117.0
1.37 mi	Predicted	45.5	100.8	146.2
	Expected	40.5	81.6	122.2
	Excess Expected	-4.9	-19.1	-24.1

* Excess Expected Crash Frequency:
Positive values indicate ISATe expects higher crash frequencies at the site vs. the model average.

FINAL REPORT

I-90 Operations Study

May 2018

Appendix B

Needs, Goals, and Objectives Memorandum

DKS

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MEMORANDUM

DATE: February 15, 2017

TO: Mike Bjordahl (WSDOT)
Larry Frostad, P.E. (WSDOT)
Glenn Wagemann P.E. (WSDOT)
Monica Harwood, P.E. (WSDOT)

FROM: Jim Peters, P.E., Principal
Deena Platman, Project Manager
Jennifer Bachman, P.E., Deputy Project Manager
Ray Delahanty, AICP

SUBJECT: I-90: Four Lakes to Idaho Stateline Operations Study
Goals, Operations Objectives, and Needs Memorandum P16159-000

The I-90: Four Lakes to Idaho Stateline identifies current issues and needs related to safety in the corridor and develops an operations strategy for improving safety and managing travel flow over the next 10 years. This memorandum documents the goals, operations objectives, and needs for the 30-mile stretch of I-90 through metropolitan Spokane.

The memorandum is organized in two sections. The first section recommends goals and supporting operations objectives. The second section describes the needs identified on the corridor.

Goals and operations objectives were developed in coordination with Washington State Department of Transportation (WSDOT) staff and reflect input from the study's public engagement process and consideration of findings from the existing conditions analysis.

Project needs were defined through the study's existing conditions analysis as well as input from WSDOT staff, the Study Advisory Group (SAG), and public input at the Study Open House.

Goals and Operations Objectives

This section documents the recommended goals and operations objectives that will guide the selection and prioritization of operational strategies for the I-90 corridor. The purpose and general guidelines for developing the goals and operations objectives are as follows:

> **Goals** help establish the direction of the plan. The goals establish high-level policy direction, but do not indicate how the goal will be achieved.
>
> **Operations Objectives** are specific steps necessary to achieve the goals. In some cases, objectives follow the SMART criteria: specific, measurable, achievable, relevant, and time bound. Note that not all objectives fit this approach. The following questions determine if an objective meets the SMART criteria:
>
> - Specific: Can it be used to answer questions about who is involved; what should be accomplished, where it will take place, when it will take place, and whether there are requirements or constraints?
> - Measurable: Does the objective quantify how success will be measured?
> - Attainable: Given the capacities of the agencies involved, is the objective likely to be achieved in the time frame given?
> - Relevant: Is the objective something that should be done? And why?
> - Time Bound: Does the objective define a specific timeframe for it to be accomplished?

The three recommended goals and supporting operations objectives for I-90 corridor operations improvement are shown below. Current WSDOT business practices, like least cost planning, will be utilized to identify strategies that will work toward meeting the objectives.

Goal 1: Improve safety performance for all I-90 corridor users

a) Objective: Meet Washington State Safety Plan Target Zero goals of zero traffic fatalities and serious injuries by 2030.

b) Objective: Reduce weather-related crashes.

c) Objective: Reduce rear-end crashes.

d) Objective: Reduce pedestrian and bicycle crashes at ramp terminals.

Goal 2: Enable efficient management and operations of the I-90 Corridor

a) Objective: Improve clearance times for all lane blocking incidents.

b) Objective: Improve construction and maintenance work zone management policy.

c) Objective: Improve coordination between agencies and districts that maintain, operate or respond to incidents or planned events along the facility.

d) Objective: Improve travel time reliability along the corridor.

Goal 3: Enhance traveler information along the I-90 Corridor

a) Objective: Communicate real-time road conditions to travelers using any mode (passenger vehicle, freight, or transit).

b) Objective: Enhance available pre-trip and en-route traveler information.

c) Objective: Provide information about planned events or work zones that impact travel at least 24 hours prior to the occurrence.

This study will advance a variety of strategies to achieve these goals and operations objectives. Some strategies may be technically or politically complex to implement. These influencing factors will be considered in the evaluation screening of potential strategies so they can be recognized, and the opportunities and challenges can be addressed early in the process.

Examples of opportunities include:

- Existing policies that are supportive of transportation system management and operations
- A track record of cross- agency collaborative management including the Spokane Regional Transportation Management Center (SRTMC)
- An existing base of operations technologies (ex. Variable Messages Signs) and strategies (ex. Incident Response program) are currently in place and active.

Examples of challenges include:

- Political issues or public perception issues
- Availability of funding and resources
- Existing infrastructure such as roadway geometry may limit which strategies are viable.

As the study progresses, these opportunities and challenges will be considered to help determine the feasibility of various strategies and narrow to a recommended package of strategies to advance toward implementation.

I-90 Corridor Needs

This section documents the I-90 corridor needs identified based on the existing conditions analysis and stakeholder engagement. Stakeholder engagement included discussion with WSDOT project staff, input from a range of stakeholders at the SAG workshop, a public open house, and an online questionnaire that was distributed to WSDOT eastern region staff. The SAG workshop and public open house were both held on December 13, 2016.

Key findings highlighted in the existing conditions memorandum include:

- Crashes on I-90 steadily increased over the past five years.
- Crash hot spots on I-90 occur at:
    - Eastbound on-ramp from US 195
    - Eastbound and westbound on-ramps at the Hamilton Street interchange
    - Eastbound on-ramp from Freya Street
    - Interchange at Exit 280: Maple/4th/Walnut/Division including on-ramps, off-ramps and terminals intersections
    - Interchange at Exit 281: Division/Browne Street including on-ramps, off-ramps and terminals intersections
- Crashes occur on I-90 about 93% of the days during a given year.
- Traffic impacting Incidents have increased 40% over the past five years.
- Traffic volumes increased by about 10% between 2012 and 2015.
- Travel time reliability has steadily decreased, especially through the downtown Spokane section.
- Several interchanges through the downtown Spokane area and to the west are closely spaced and do not meet current performance expectations.
- Several on- and off-ramps, particularly through the downtown Spokane area, have merge and weave areas that are short and do not meet current performance expectations.
- Vehicle queues that regularly extend onto I-90 form at some off-ramps.

This memorandum identifies and prioritizes needs along the corridor based on the stakeholder input and findings from the existing conditions report. The needs are organized into three categories:

- Traffic Operations - Table 1
- Incident Management - Table 2
- Traveler Information and Performance Data -

- Table 3

Under the Traffic Operations category, the needs are organized into either corridor-wide or location-specific needs. An example of a corridor-wide need is "reduced incident clearance time throughout I-90 corridor," whereas an example of a location-specific need is "short eastbound weaving section between Altamont and Freya." A relative priority for each need is assigned based on input from the SAG workshop.

Table 1: Traffic Operations Issues and Needs

Identified Need	Description	Priority	Source
Corridor-Wide			
Need to better utilize local roadway network	• Separate local versus regional trips • Preserve parallel routes • Potential economic benefit	High	SAG Workshop
Need to improve transit travel time reliability	• Reliable travel time • Not competitive right now	High	SAG Workshop
Need to reduce distracted driving		High	SAG Workshop
Need to improve alternate routing during events		Medium	SAG Workshop
Need to provide safe pedestrian and bicycle crossings at I-90 interchanges	• Facilities for alternative modes to travel cross I-90	Medium	SAG Workshop
Need to better manage traffic diverted to local streets during an incident on I-90		Medium	SAG Workshop
Need to improve work zone traffic control and work zone safety		Medium	SAG Workshop
Location-Specific			
Segment B – US 2 to Broadway Interchange (MP 277-286)			
Need to improve ramp and merge area geometry that do not meet current performance expectations	• US 195 eastbound on-ramp – short merge lane	High	Survey/ SAG Workshop/ Existing Conditions Report
	• Eastbound Maple on-ramp (Exit 280)	High	
	• Freya on-ramp westbound prior to Exit 283A	High	
	• Eastbound from Hamilton on-ramp to Exit 283A (Altamont) – The short distance between the on and off ramps in this section creates weave and merge issues	High	

Identified Need	Description	Priority	Source
	• 2nd/Browne/Lincoln westbound (Exit 281 and 280B) – issues with weaving, aggressive driving, and closely spaced ramps	Medium	
	• 3rd Avenue (Altamont) eastbound (Exit 283A) during PM peak - On-ramp is bottleneck and short weaving section to 3rd/Thor/Freya off-ramp creates safety challenges	Medium	
	• Eastbound from 4th east of Freya - Lack of acceleration lane length (first on-ramp from 283B)	Medium	
Need to reduce high severity crashes	• West of MP 280 in the eastbound direction (eastbound direction has over double the frequency of high severity crashes)	High	Existing Conditions Report
Need to reduce crashes	• Eastbound crashes are concentrated through downtown Spokane (MP 279 – 284) in PM peak conditions • Westbound crashes are more evenly distributed along Segment B (US2 Exit 277 to the Broadway Interchange Exit 286) • Exit 280 (Maple/4th/Walnut) – Interchange with the highest number of crashes (365 crashes over five years from 2011 through 2015 at the ramps or terminal intersections of that interchange). 27.9% of all interchange crashes. • Exit 281 - SR 2 at Browne Street/Division Street couplet (More than 100 crashes over five years from 2011 through 2015 identified in existing conditions)	High	Existing Conditions Report
Need to reduce the use of I-90 for local trips	• Sprague to Hamilton in both travel directions but especially westbound	High	SAG Workshop
Need to improve Downtown traffic flow to help with I-90 flow	• Provide wayfinding to parking • One way streets cause confusion for drivers	High	SAG Workshop

Identified Need	Description	Priority	Source
Need to reduce queuing on I-90 due to off-ramps	• Division eastbound off-ramp (Exit 281) during PM peak (Monroe on-to Division – off-weave)	High	SAG Workshop
	• Maple/Walnut westbound on-ramp during PM (Exit 280A) - 4th to northbound Walnut movement congested by queuing on northbound Walnut. May be an opportunity to improve signal timing	Medium	
	• Maple/Walnut eastbound off-ramp (Exit 280) during PM peak. Note poor visibility for merging traffic	Medium	
	• Lincoln westbound off-ramp (Exit 280B) during PM peak	Medium	
Need to provide shoulder area	• Lack of shoulders between 195 (MP 279) and Hamilton (MP 282)	Medium	
Need to reduce recurring congestion spreading	• Freya interchange area (MP 283 area) • Westbound at Sprague on-ramp (Exit 285) - Heavy congestion around Fancher and back from merge point	Medium	SAG Workshop
Need to improve parallel/ alternative routes to I-90	• Focus parallel facilities include: 3rd, 2nd, Trent, Sprague	Medium	SAG Workshop
Need to provide chain-up areas	• Sunset Hill area (vehicles currently exit I-90 to chain up)	Low	SAG Workshop
Segment C – Broadway Interchange to Barker Interchange (MP 286-293)			
Need to reduce crashes	• Exit 291B - Sullivan Road. More than 100 crashes identified in existing conditions for both directions	High	Existing Conditions Report
Need to reduce vehicle queuing on I-90	• Argonne westbound off ramp (Exit 287) – seasonal fluctuation and peak queuing during summer months • Barker eastbound (Exit 293)	Medium	SAG Workshop
Segment D – Barker Interchange to State Line (MP 293-299)			
Need to improve roadway geometry	• Westbound on ramp from Harvard (296) – short merge spacing causes speed differential between merging traffic and through traffic	Medium	SAG Workshop
Need to reduce vehicle queuing on I-90	• Eastbound Exit 296 Harvard – AM peak hour queuing on I-90	Medium	SAG Workshop
	• Eastbound Liberty Lake Exit 296 during the PM peak hour - Congestion at signal spills onto I-90	Low	SAG Workshop

Table 2: Incident Management Issues and Needs

Identified Need	Description	Priority	Source
Need to reduce incident clearance time	• Lessen clearance time	High	SAG Workshop
Need to expand IRT coverage	• More staff/trucks needed during peaks and weekends	High	SAG Workshop
Need to develop TIM partnerships	• More training, concurrence • Build relationships with local law enforcement. Continued and improved building on WSP partnership • Provide regular TIM training	High	SAG Workshop
Planned and emergent work zones	• Time of closure versus peak periods • Preparedness to handle safety, minimize impact of work zones	High	SAG Workshop
Need to develop traffic routing plans during events		Medium	SAG Workshop
Need to address wrong way drivers		Medium	SAG Workshop
Need to better manage weather incidents	Key locations: • Sunset hill • Broadway curve	Medium	SAG Workshop
Need to improve incident response on the viaduct section of I-90	• No space for clearance operations to occur, no safe towing locations	Low	SAG Workshop

Table 3: Traveler Information and Performance Data Issues and Needs

Identified Need	Description	Priority	Source
Need to coordinate traveler information systems between agencies	• Traveler information system coordination amongst agencies could be improved	High	PMT
Need to educate travelers about current resources and improve utilization	• Get word out about traveler information services (including non-WSDOT sites– e.g. Waze) • 511 system • TMC website utilization by travelers	High	SAG Workshop
Need to improve traveler information to public during special events		High	SAG Workshop
Need to provide travelers with real-time parking information for the Downtown area	• Confusion finding parking/ unfamiliar drivers/special events	Medium	SAG Workshop
Need to expand social media use for providing traveler information	• Twitter, Facebook, etc.	Medium	SAG Workshop
Need to expand available information	• Meaningful, availability, parallel routes	Medium	SAG Workshop
Need to pursue public/private partnership on traveler information	• Weather sensors and congested areas	Medium	SAG Workshop
Need to better utilize VMS when not in use for traveler information.	• Option to use for public service announcements	Medium	SAG Workshop
Need to provide more field devices to display traveler information.	• Additional VMS	Medium	SAG Workshop

FINAL REPORT

I-90 Operations Study

May 2018

Appendix C

Evaluation and Screening Memorandum

DKS

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MEMORANDUM

DATE: May 1, 2018

TO: Mike Bjordahl (WSDOT)
Larry Frostad, P.E. (WSDOT)
Glenn Wagemann P.E. (WSDOT)
Monica Harwood, P.E. (WSDOT)

FROM: Jim Peters, P.E., Principal
Deena Platman, Project Manager
Jennifer Bachman, P.E., Deputy Project Manager

SUBJECT: I-90: Four Lakes to Stateline Operations Study
Evaluation and Screening Memorandum #4 P16159-000

This memorandum documents the screening process used to narrow a full-range of transportation system management and operational (TSMO) strategies to a select group of recommended strategies that best meet the needs, goals and operations objectives of the I-90 corridor between Four Lakes and the Idaho Stateline. The recommended strategies will advance to the next phase of study and evaluation, which will provide more detailed analysis of the strategies, and consider more specific implementation details. This memorandum includes an executive summary, the screening methodology, first and second level screening, recommended strategies and locations, lessons learned from past implementations, and the next steps.

EXECUTIVE SUMMARY

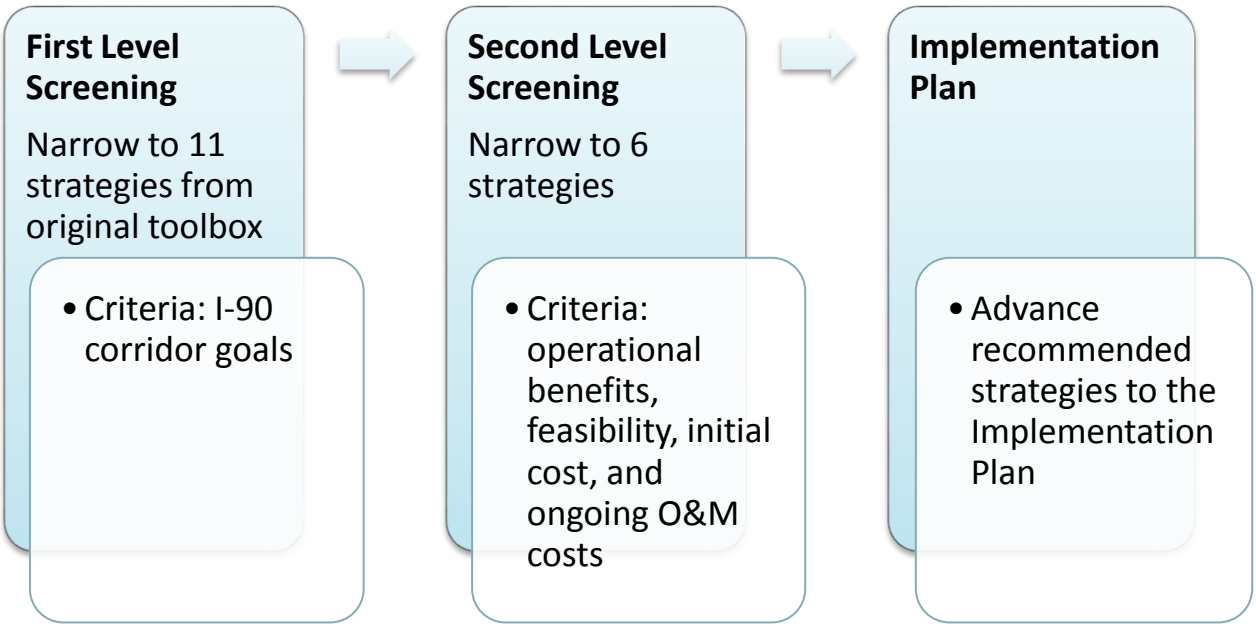
Applying a two-level screening process, the project team narrowed a full-range of TSMO strategies, identified in the toolbox provided in Attachment A, to those that best meet the identified needs, goals and operations objectives for the I-90 corridor study area and offer the best potential to improve safety and operations along the corridor. The first level of screening focused on selecting the strategies that could best achieve the project goals and meet the needs of the corridor. Strategies that best met the first level screening criteria, were considered for a second level of screening criteria that included: operational benefits, feasibility factors, implementation cost, and on-going operations and maintenance costs.

After both rounds of screening, the following strategies emerged as the ones with the best potential to improve safety and meet the needs of the I-90 corridor:

- **Active Traffic Management** – Install overhead gantry variable message signs and weather sensors along the freeway that can be used for thee key strategies: variable speed system, queue warning system, and dynamic lane control.
- **Ramp Metering** – Install ramp meters at on-ramps to manage the flow of entering vehicles, reduce crashes at merge areas, and minimize congestion on the mainline.
- **Ramp Closures –** Evaluate the potential to close ramps. Aside from the traffic analysis component of a ramp closure, the socio-economic and political factors need to be fully examined by WSDOT outside the scope of this project.
- **Wrong Way Driver Notification System** – Install detection along off-ramps that can detect wrong way drivers, sending notifications to the traffic management center (TMC) as well as notifying travelers on variable message signs (VMS) or in car navigation systems when possible.
- **Traffic Incident Management Strategies –** Enhance the existing traffic incident management strategies with the following three activities: develop TIM Teams, expand the Dedicated Roving Patrol Program, and establish instant tow contracts
- **Work Zone Management** – Implement work zone management strategies that improve safety in work zones. These strategies apply safety measures that inform drivers of work zone and worker locations, and they support a range of work zone durations from long-term stationary projects to short duration or even mobile projects.

SCREENING METHOD

Applying a two-level screening process, the project team narrowed a full-range of TSMO strategies, identified in the toolbox provided in Attachment A, to those that best meet the identified needs, goals and operations objectives for the I-90 corridor study area and offer the best potential to improve safety and operations along the corridor. The screening levels and applied criteria for each level are shown in the diagram below.



FIRST LEVEL SCREENING

The project team assembled a toolbox of TSMO strategies with potential to meet the I-90 project goals along the corridor. The TSMO strategies toolbox includes 31 strategies, organized into five categories:

- Traffic Operations and Management Strategies
- Maintenance and Construction Management Strategies
- Emergency and Incident Management Strategies
- Transit and Demand Management Strategies
- Infrastructure Improvement Strategies

The full toolbox is included as Attachment A:

Criteria – First Level Screening

The initial screening evaluated how well each strategy achieves the project goals. The project management team developed the three goals[1]:

Goal 1: Improve safety performance for all I-90 corridor users

a) Objective: Meet Washington State Safety Plan Target Zero goals of zero traffic fatalities and serious injuries by 2030.
b) Objective: Reduce weather-related crashes.
c) Objective: Reduce rear-end crashes.
d) Objective: Reduce pedestrian and bicycle crashes at ramp terminals.

[1] I:90 Four Lakes to Idaho Stateline Operations Study. Goals, Operations Objectives, and Needs Memorandum. Prepared for WSDOT by DKS Associates. Feb 2, 2017

Goal 2: Enable efficient management and operations of the I-90 Corridor

a) Objective: Improve clearance times for all lane-blocking incidents.
b) Objective: Improve construction and maintenance work zone management policy.
c) Objective: Improve coordination between agencies and districts that maintain, operate or respond to incidents or planned events along the facility.
d) Objective: Improve travel time reliability along the corridor.

Goal 3: Enhance traveler information along the I-90 Corridor

a) Objective: Communicate real-time road conditions to travelers using any mode (passenger vehicle, freight, or transit).
b) Objective: Enhance available pre-trip and en-route traveler information.
c) Objective: Provide information about planned events or work zones that impact travel at least 24 hours prior to the occurrence.

For the safety goal, the project team evaluated data from a range of studies that identified the type and degree to which different strategies can reduce crashes. The evaluation focused on safety benefits identified along similar corridors; therefore, if a strategy resulted in a 20 percent decrease in crashes at rural intersections, that benefit would not apply to the I-90 corridor. Two key resources were referenced for these strategies:

- **The ITS Benefit-Cost Database**[2] - This database developed by the ITS Joint Program Office (ITS JPO) of the US Department of Transportation is a searchable database that includes benefit results from specific ITS deployment projects. The reported benefits range from safety related benefits (crash reductions and crash severity), to operational and management related benefits (reduced travel times, reduced incident clearance times, and more).
- **The CMF Clearinghouse**[3] - The crash modification factor clearinghouse includes a compilation of studies that identify how different strategies can reduce crashes. A CMF is a multiplicative factor, that when used in conjunction with a countermeasure, provides the long-term change in expected number of crashes. The studies in the CMF Clearinghouse each have a quality rating between one to five stars, which indicates the confidence of the study results. A quality rating with five stars indicates the highest or most reliable ratings. For the I-90 toolbox, all of the noted CMFs have a quality rating of three or more stars.

For the remaining two goals, the project team evaluated on a qualitative basis how well each strategy aligns with the corridor needs and goals based on what the strategy can achieve.

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[2] Website: http://www.itsbenefits.its.dot.gov/
[3] CMF Clearinghouse website: http://www.cmfclearinghouse.org/index.cfm

The evaluation incorporates the following rating scale:

Icon	Meaning
	Best achieves the project goal
	Mostly achieves project goal
	Achieves some of the project goal
	Achieves little of the project goal
	Does not achieve the project goal

Using the goals as the first level screening criteria, 11 strategies are recommended for further screening as indicated in Table 1. As shown in the table, there are a few strategies recommended for further screening, but as part of another strategy. For example, including the road weather information system (RWIS) stations with the ATM strategy. There are also two strategies (Off-Ramp Traffic Signal Coordination, and Asset Management Software) that should be recognized as ongoing activities that WSDOT will continue to pursue, but separately from this project.

Table 1: Preliminary Screening Based on Project Goals

Strategy	Description	How well does the strategy meet each goal?			Recommend Strategy for Further Screening?
		1	2	3	
Traffic Operations and Management Strategies					
Active Traffic Management (ATM)	Install devices to create an active traffic management segment that uses a combination of operational strategies that work to fully optimize the existing infrastructure. On I-90 the key ATM strategies include: **variable speed system**, **queue warning system, and dynamic lane control**.	●	●	●	YES
Road Weather Information System Station	Add road weather information system (RWIS) stations along the corridor to relay real-time weather and pavement conditions to travelers.	○	◓	○	YES – include with ATM
Ice Warning Signs	Place activated warning signs in key locations that warn travelers when icy roadway conditions are present.	○	◓	○	YES – include with ATM
Ramp Metering	Install traffic signals on freeway ramp meters that alternate between red and green signals to control the flow of vehicles entering the freeway. Metering rates can be altered based on freeway and on-ramp traffic conditions.	●	●	●	YES
Ramp Closures (Permanent or Time of Day)	Close an on or off ramp at an interchange to achieve standard interchange spacing and reduce congestion and collisions resulting from substandard interchange spacing.	●	◒	●	YES
Integrated Corridor Management	With integrated corridor management, the various institutional partner agencies manage the transportation corridor as a system, rather than the more traditional approach of managing individual assets. Travelers could dynamically shift to alternative transportation options, even during a trip, in response to changing traffic conditions.	◓	●	○	YES
Real-Time Traveler Information	Explore options to improve real-time information for travelers including: dynamic message signs (DMS), onboard GPS devices, and 3rd party apps such as Inrix, HERE or WAZE.	◓	○	●	YES
Wrong Way Driver Notification System	Install a wrong way driver alert system on off-ramps that can detect wrong way drivers, activate signs to help deter the wrong way driver, and send a notification to the TMC so operators can monitor the car's movement using cameras and send messages to VMS or drivers with on-board systems.	◒	○	○	YES
Red Light Running Cameras	Install cameras at select intersections that can automatically detect when a vehicle runs a red light, take a picture, and issue a ticket.	○	●	●	Not at this time

Strategy	Description	How well does the strategy meet each goal?			Recommend Strategy for Further Screening?
		1	2	3	
	Traffic Operations and Management Strategies (cont.)				
Connected Vehicle Strategy	Implement technologies that relay real-time information from ITS infrastructure to connected vehicles.	○	○	○	Not at this time
Dynamic Curve Speed Warning Signs	Install dynamic feedback signs that measure the speed of individual vehicles and display activated messages if motorist speed is over a designated threshold.	○	◓	○	Not at this time
Traffic Surveillance	Add cameras along I-90 to improve traffic monitoring capabilities, and connect to the traffic management center (TMC). This strategy could be used in conjunction with providing real time information for both traveler information and incident management.	●	◒	◒	YES – include with ATM
Off-Ramp Traffic Signal Coordination	Improve signal timing at select off-ramps and surrounding traffic signals to prevent vehicle queues from extending onto the freeway mainline.	○	○	●	Ongoing
	Maintenance and Construction Management Strategies				
Work Zone Management	Address work zone policies and management for both daily (temporary) maintenance activities and longer term construction activities to improve the safety of both the workers and travelers. Strategies include: speed control, use of portable VMS, coordination with law enforcement, communicating delays, detours, and lane configuration changes to travelers.	◒	◉	○	YES
Telematics Technology on Fleet Vehicles	Add telematics capabilities on fleet vehicles that can be used to track vehicle performance, vehicle maintenance, and vehicle activities in real-time.	◓	◒	○	YES
Asset Management Software	Install software that enables automated maintenance logs and proactive management of system health (notifications of equipment failure) for ITS infrastructure.	◓	◒	◓	Ongoing – some capabilities included with new ATMS software
Corridor Operations Team	Implement a corridor operations team that coordinates between all agencies that operate roadway facilities or transit along the I-90 corridor.	◓	◒	◓	Not at this time
Transportation Management Center Enhancements	The purpose of a Transportation Management Center is to integrate various departments and offices of transportation and emergency agencies into a unified communications center.	◓	◒	◓	Not at this time

Strategy	Description	How well does the strategy meet each goal?			Recommend Strategy for Further Screening?
		1	2	3	
Emergency and Incident Management Strategies					
Traffic Incident Management Strategies	Pursue TIM strategies that include: **TIM team development**, expanding the **Dedicated Roving Patrol program**, and establishing **instant tow contracts**.				YES
Traffic Incident Management Strategic Plan	Develop a region-specific traffic incident management strategic plan that prioritizes future projects and investments related to traffic incident management. The plan can also help formalize relationships and agreements between responders and agencies.				Not at this time
9-1-1 Dispatch Integration	Connect the 9-1-1 dispatch center with SRTMC. Currently when a call comes into the 9-1-1 dispatch center that effects a state highway, WSP manually calls the TMC to relay the issue. Connecting SRTMC directly to the 9-1-1 dispatch center allows for the transportation agencies to be automatically notified when an event on a state facility occurs. Currently WSDOT has view-only access to events on the WSP computer aided dispatch screen, with some information scrubbed.				YES
Hourly Towing Contract	Initiate an hourly towing contract between WSDOT and towing companies during bad weather conditions or other necessary events. This contract enables WSDOT to dictate towing priorities and allocated towing resources as necessary.				Not at this time
Sharing On-Scene Photos and Video	Invest in technology that allows first responders to send and receive photos and video from an incident scene, including the tow partners.				Not at this time
Interoperable Communication Procedures	Implement standard protocols for using radios between agencies. This strategy could be a task for the TIM Team to develop.				Not at this time
Event Management	Event transportation management systems can help control the impact of congestion at stadiums, convention centers, fairgrounds, or other facilities that generate high traffic volumes for planned events.				Not at this time
Situational Software	Integrate Situational Awareness software during incident or emergency response. The software can track where each of the response agencies/vehicles is (en route, at the scene, and during clean up) and improve communication between responders.				Not at this time

Strategy	Description	How well does the strategy meet each goal?			Recommend Strategy for Further Screening?
		1	2	3	
Transit and Demand Management Strategies					
Real-Time Transit Information	Provide real-time transit information to transit riders including: vehicle location, estimated arrival time, trip duration, and possibly percent occupancy.	●	○	◉	Not at this time
Demand Management Strategies	Promote travel that reduces overall demand on the system such as: bus transit, carpool, and non-peak hour commuting.	◓	○	○	Not at this time
Active Demand Management Strategies	Active demand management strategies include using real-time information to dynamically adjust user demand. Strategies include dynamic pricing, on-demand transit, and dynamic ridesharing.	◓	○	○	Not at this time
Infrastructure Management Strategies					
Targeted Roadway Improvements	Construct targeted roadway improvements to meet current standards for acceleration and merge areas.	◒	○	●	YES
Targeted Shoulder Widening - Auxiliary Lane	Construct shoulder (right or left) to provide an extra travel lane during high demand or high congestion.	○	○	●	Not at this time

SECOND LEVEL SCREENING

For the ten strategies recommended for further evaluation, the project team applied a second level of screening criteria to narrow the strategies to 5 with the best potential to successfully improve safety and operations along the corridor.

Second Level Screening Criteria

The second round of screening focused on four criteria:

- Operational Benefits
- Influencing Factors (Physical Factors, Institutional Factors, Operational and Maintenance Factors)
- Implementation Cost
- Annual Operations and Maintenance Cost

Operational Benefits

Operational benefits include the potential operational benefit of the strategy, and uses results from previously implemented projects and studies documented in the ITS Benefit-Cost Database (discussed in the "First Level Screening Criteria" section). This assessment identifies the level of potential operational benefits for each strategy as it applies to the I-90 corridor.

The project team applied the following ranking system to evaluate each strategy for operational benefits.

Icon	Meaning
	High operational benefits
	Moderate operational benefits
	Some operational benefits
	Limited operational benefits
	Minimal or no operational benefits

Influencing Factors

Influencing factors consider the physical, institutional, and operations and maintenance barriers that may affect the successful implementation of the strategy.

- **Physical Factors** include characteristics necessary to design and build the system such as field devices, central systems, firmware/software, communications, and power connections.

- **Institutional Factors** include characteristics related to the legal, organizational, and behavioral roles associated with operating and managing a transportation system. These include policies, regulations, intra- and inter-agency coordination, and public-private partnerships.
- **Operations and Maintenance Factors** include characteristics related to the processes and procedures needed for day-to-day operation such as agency roles and responsibilities, operating procedures, and performance measurement.

The project team applied the following ranking system to evaluate each strategy by the three feasibility factors independently.

Icon	Meaning
	Minimal or no factors complicating implementation
	Few factors complicating implementation
	Moderate factors complicating implementation
	Several factors complicating implementation
	Not feasible

Implementation and Annual Operations and Maintenance Costs

The costs of implementation and the on-going needs for operating and maintaining a strategy are important criteria to consider when determining whether to pursue a TSMO strategy. These management and operations strategies generally require ongoing staff involvement to make the best use of the strategy and to keep the technology functioning properly.

- **Implementation Cost** – the initial cost to construct a project or create a plan or policy
- **Annual Operations and Maintenance (O&M) Cost** – the ongoing annual cost to maintain and operate devices; fix or calibrate equipment; allocate staff time to implement strategies such as attend meetings or work in the field during a road closure event.

For a strategy to be successful, it is not enough to merely install devices or create a plan, WSDOT needs sufficient resources to support ongoing operations and maintenance of the strategy. Knowing that information before selecting a strategy is critical to success.

The project team applied the following ranking system to evaluate each strategy by implementation cost.

Icon	Implementation Cost
	less than $100,000
	between $100,000 and $500,000
	between $500,000 and $1,000,000
	between $1,000,000 and $5,000,000
	over $5,000,000

The project team applied the following ranking system to evaluate each strategy by annual O&M cost.

Icon	Annual Operations and Maintenance Cost
	less than $1,000 per year
	between $1,000 and $5,000 per year
	between $5,000 and $15,000 per year
	between $15,000 and $50,000 per year
	over $50,000 per year

Strategies Recommended for Advancement

Based on a cumulative evaluation of the first and second level of screening (as shown in Table 2), six strategies are recommended to advance for further evaluation:

- Active Traffic Management
- Ramp Metering
- Ramp Closures
- Wrong Way Driver Notification System
- Traffic Incident Management
- Work Zone Management

Table 2: Strategies Recommended for Advancement

Strategy	First Level Screening			Second Level Screening				Recommend Strategy for Further Study?
	Goal 1: Safety	Goal 2: Efficiency	Goal 3: Traveler Info	Operational Benefits	Influencing Factors[A]	Implementation Cost	Ongoing O&M Cost	
Traffic Operations and Management								
Active Traffic Management – variable speeds, queue warning, dynamic lane control, off-ramp signal coordination	●	●	●	●	○	●[B]	●	YES
Ramp Metering	●	●	●	●	◒	◓	◓	YES
Ramp Closures (Permanent or Time of Day)	●	◒	●	●	◓	◓	●	YES
Integrated Corridor Management	◓	●	○	◒	◒	◓	◓	Not at this time
Expand Real-Time Traveler Information	◓	○	●	○	◒	○	○	Ongoing
Wrong Way Driver Notification System	◒	○	○	◒	●	◓	○	YES
Maintenance and Construction Management								
Work Zone Management	◒	●	○	◒	●	○	●	YES
Telematics Technology on Fleet Vehicles	◓	◒	○	◓	◒	◒	◓	Not at this time
Emergency and Incident Management								
Traffic Incident Management Strategies – TIM Team Development, Expand Roving Patrol, and Establish Instant Tow Contracts	◒	●	○	●	●	◒	●	YES
9-1-1 Dispatch Integration	◓	●	○	○	○	○	◒	Not at this time

Strategy	First Level Screening			Second Level Screening				Recommend Strategy for Further Study?
	Goal 1: Safety	Goal 2: Efficiency	Goal 3: Traveler Info	Operational Benefits	Influencing Factors[A]	Implementation Cost	Ongoing O&M Cost	
Transit and Demand Management								
none	--	--	--	--	--	--	--	--
Infrastructure Management								
Targeted Roadway Improvements – Weave and Merge Areas								Not at this time

Notes:
A – Four influencing factors: physical, institutional, and operations and maintenance
B – The high implementation cost for ATM represents a system wide installation. Smaller segments could be implemented for a lower cost.

RECOMMENDED STRATEGIES AND LOCATIONS

This section describes the five high priority strategies that are recommended for further study and evaluation. These strategies best meet the project goals, and pass the second level screening to confirm feasibility. In general, these strategies can all work in combination. The one exception is permanent ramp closures, which if implemented, would physically close the ramp and eliminate the merge area. If a ramp is closed on a time-of-day basis, the ramp could also operate ramp metering and the other two strategies.

Active Traffic Management

Active Traffic Management uses a combination of operational strategies to optimize the existing infrastructure and improve safety. On I-90 the primary strategies include a variable speed system, queue warning, travel times, and dynamic lane control. The speed and lane control information would be conveyed to travelers using signs installed over each lane. The system could also provide weather, travel time, and queue warning information to travelers based on real-time measured conditions using full matrix DMS.

Locations

The extent of the active traffic management system should extend between approximately mileposts 277 and 287 in both directions, as shown in Figure 1. In the eastbound direction, installing at least one (possibly two) gantries east of the interchange with US 195 could reduce crashes at the US 195 merge by directing through traffic to use the left lane. Specific locations for speed, lane control, and queue warning signs will be determined in the next analysis phase.

Recommended spacing is approximately 1,500 feet downstream of interchange entrances, or every ½ to 1 mile along an urban freeway system. Specific segments and sign locations will be addressed during the operational concept phase.

Ramp Metering

Traffic signals on freeway ramp meters alternate between red and green to control the flow of vehicles entering the freeway. Metering rates can be altered adaptively based on freeway and on-ramp traffic conditions.

Locations

Ramp metering can either be applied at an individual interchange or corridor-wide. Corridor-wide ramp metering is recommended when[4]:

- Crashes are not clustered at isolated locations, but rather extended along a facility throughout a corridor
- Multiple bottlenecks or locations of recurring congestion are observed

Based on these criteria and existing conditions along the I-90 corridor, ramp metering is recommended on a **corridor-wide** basis. In both the eastbound and westbound directions the potential extents include all the on-ramps from US 195 to the Liberty Lake interchange as shown in Figure 2. The ramp meters could be installed in phases, as indicated by the priorities shown in the figure.

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[4] FHWA. Active Traffic Management Feasibility and Screening Guide. May 2015. Section 5.6

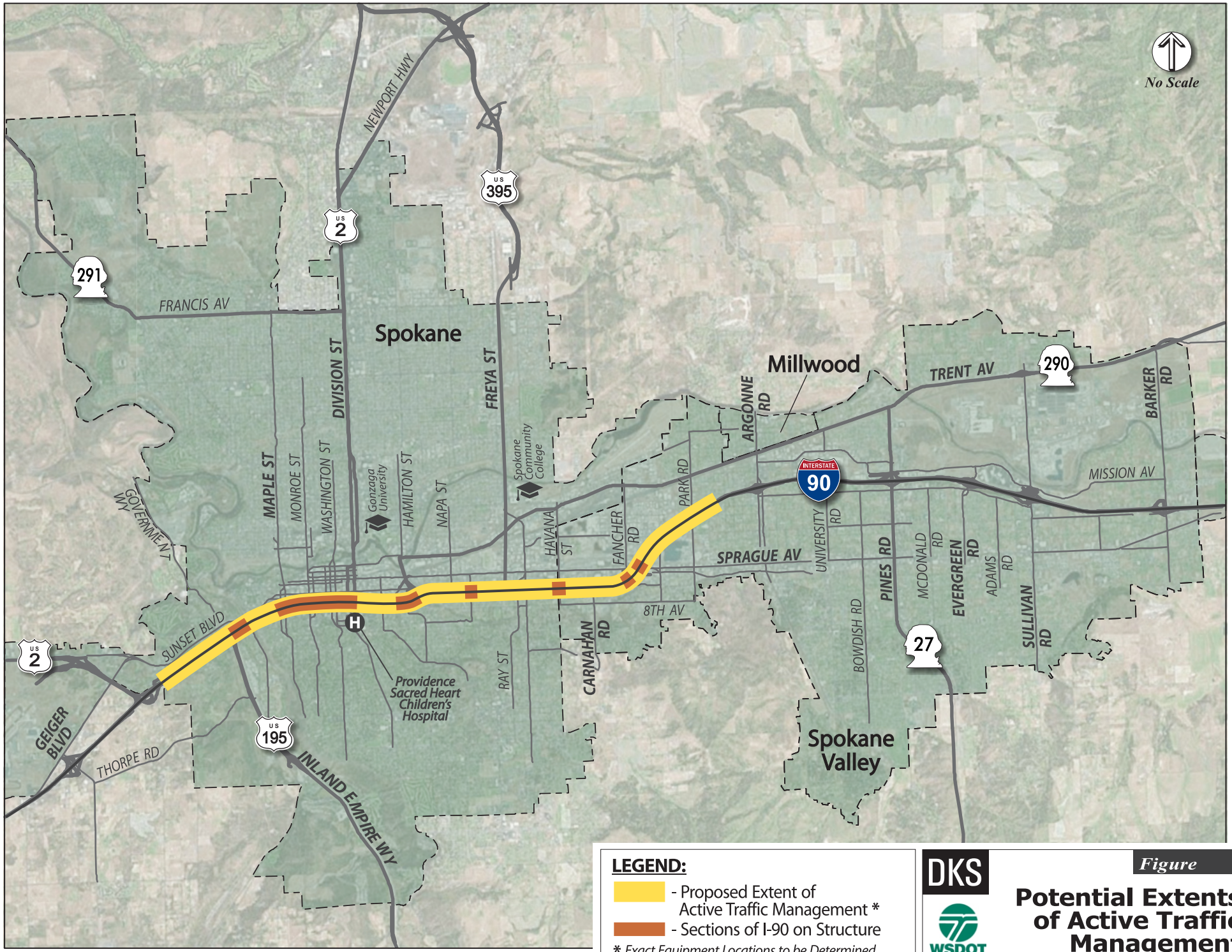
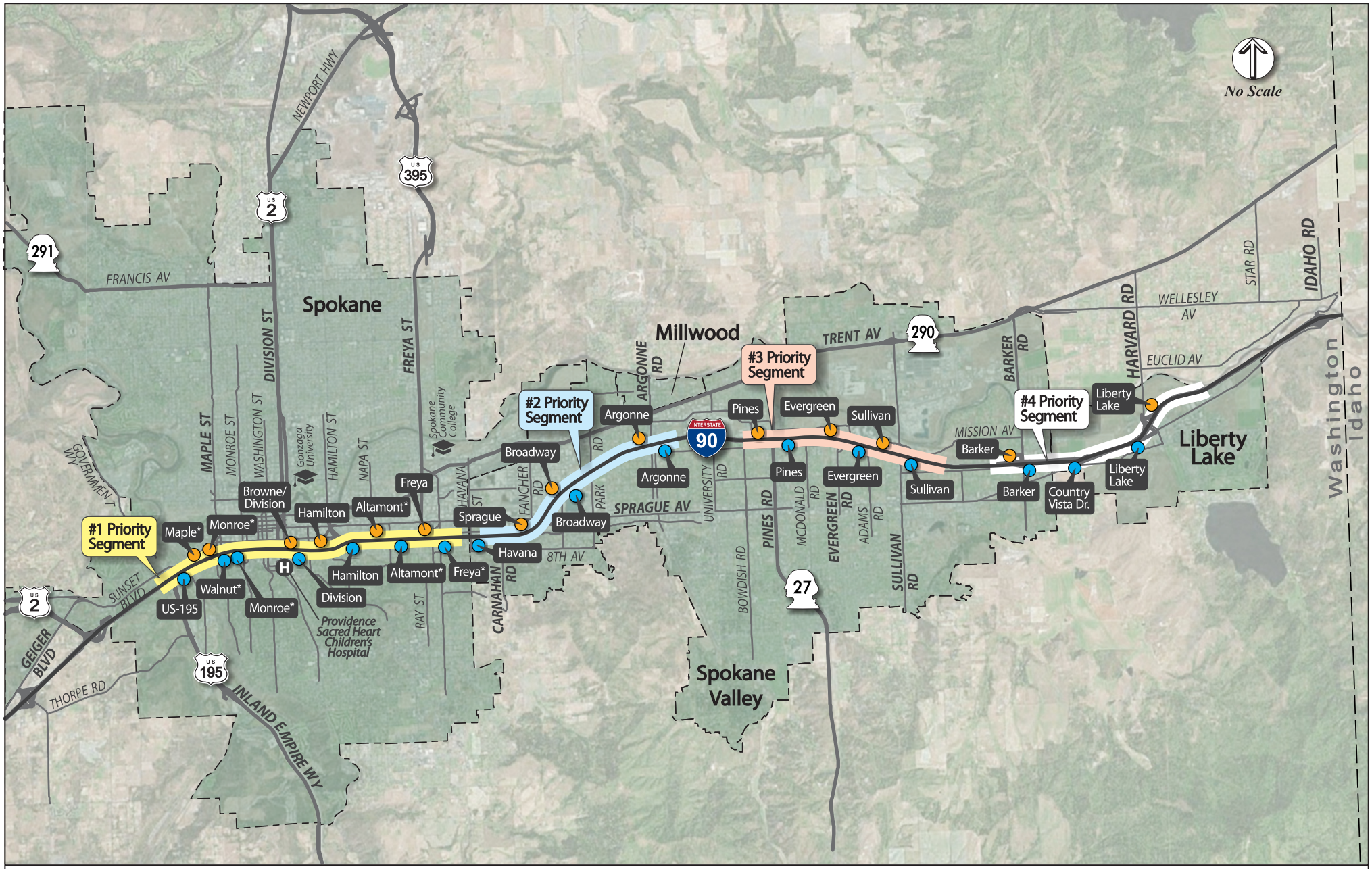


Figure 1

Potential Extents of Active Traffic Management



LEGEND:

- Eastbound On-Ramp
- Westbound On-Ramp

* Ramp is also recommended for further evaluation of ramp closure strategy

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Figure 2

Potential Ramp Meter Locations

Ramp Closures

Closing ramps can improve safety by eliminating hazardous weave and merge areas and by improving interchange spacing to achieve best practices. In general, a ramp closure strategy should only be considered when closing a ramp does not present a more severe problem than already exists. Guidance for ramp closure strategies are outline in the Ramp Management and Control Handbook, published by FHWA.[5]

Ramps can be closed by time-of-day, permanently, or on a temporary basis during specific events. Each type of ramp closure has different advantages and disadvantages, as show in Table 3.

Table 3: Advantages and Disadvantages of Ramp Closure Types

Closure Method	Advantages	Disadvantages
Permanent	• One time cost (no on-going operation cost) • Improves safety and operations permanently	• Impact on existing travel patterns (biggest potential to increase emissions and fuel consumption due to diverted trips) • Potential socio-economic impacts
Temporary (During construction)	• Impacts are temporary • Significantly reduces conflicts during construction or maintenance near the ramp	• Moderate impact on existing travel patterns
Time-of-day	• Closures are restricted to times of day when crashes are likely. Maintains access during all other times of day. • Improves safety and operations during peak hours	• Moderate impact on existing travel patterns • On-going operations and maintenance cost necessary, as well as advanced traveler information signs

Potential Ramp Closure Locations

The locations for potential ramp closures are described below and shown in Figure 3. In addition, ramp volumes are shown in Figure 4 to get a better understanding of the impact a closure may have. Further traffic analysis is necessary before advancing any of the potential ramp closure options. The next phase will analyze and evaluate the traffic impacts of potential ramp closures.

Potential Eastbound Ramp Closures

- Permanent closure of **either** the eastbound **Monroe or Walnut on-ramp**. These two on-ramps are closely spaced and contribute to a high crash frequency (higher than expected based on the predictive crash analysis[6]). Further investigation is necessary to determine traffic diversion impacts, and whether the Monroe or Walnut eastbound on-ramp provides the optimal closure location.

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[5] Ramp Management and Control Handbook. FHWA. January 2006. Chapters 5 and 6.
[6] Existing Conditions Report. I-90 to Idaho State Line Operations Study. March 2017. Prepared for WSDOT by DKS Associates.

- Permanent closure of the eastbound **Freya on-ramp**. Eliminates a short acceleration/merge area and a high crash area. Analysis of this potential ramp closure must consider the current North Spokane Corridor (NSC) Plan, which currently assumes the Freya on-ramp remains open. The next phase of this evaluation will consider the value of a Freya on-ramp closure for safety and operations on I-90 while consider the local access traffic impacts and the NSC plan.
- Time-of-day or permanent closure of the eastbound **Altamont off-ramp**. Eliminates a short weave area between the Hamilton eastbound on-ramp and the Altamont eastbound off-ramp.
- Time-of-day or permanent closure of the eastbound **Altamont on-ramp**. Addresses a short weave area between the Altamont on-ramp and the Freya off-ramp.

Note that if both the eastbound Altamont and Freya on-ramps are closed, traffic can proceed on 3rd Avenue and access I-90 east of Havana Street, an extra 0.5 miles east of Freya or 1.25 miles east of the Altamont on-ramp.

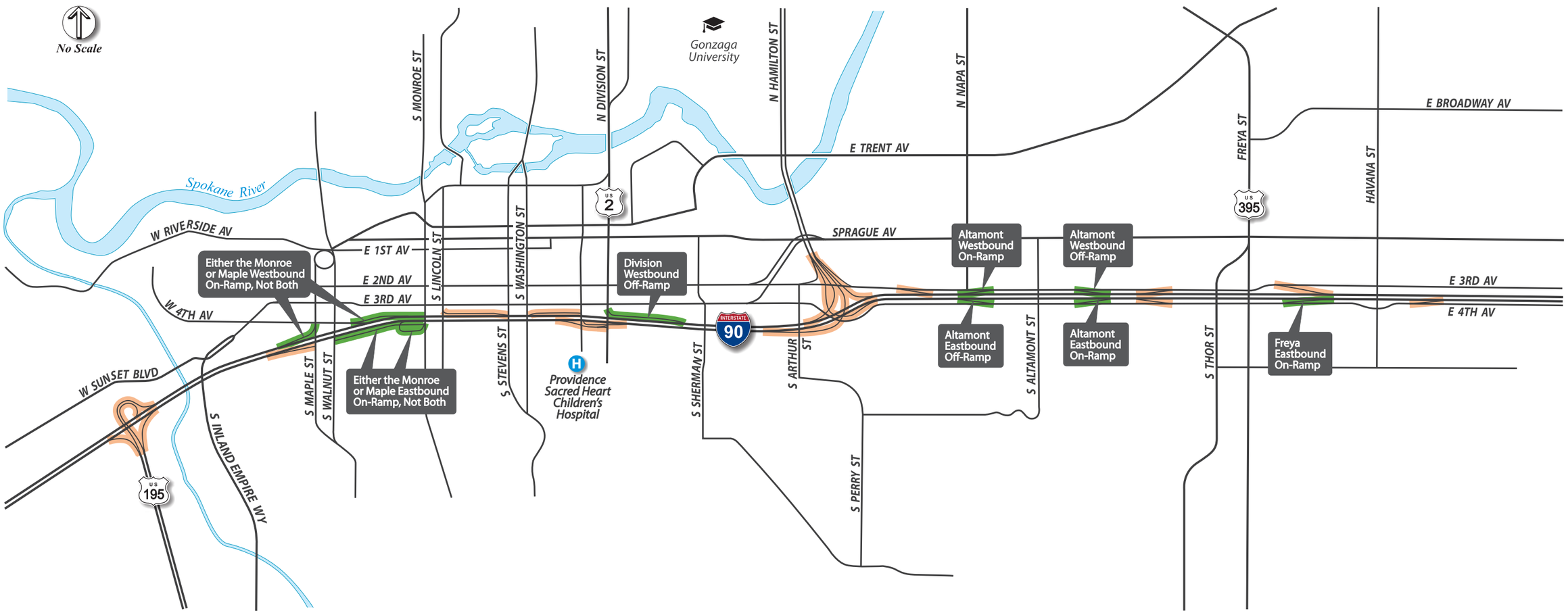
Potential Westbound Ramp Closures

- Permanent closure of westbound **Altamont on-ramp**. Eliminates a short weave segment between the Altamont on-ramp and 2nd Avenue/Hamilton off-ramp.
- Time-of-day or permanent closure of the westbound **Altamont off-ramp**. Eliminates a short weave segment between the westbound Freya on-ramp and the Altamont off-ramp.
- Time-of-day or permanent closure of the westbound **Division off-ramp**. Queues regularly back up onto I-90 during peak commute hours. Option to divert traffic to exit at the 2nd Avenue/Hamilton off-ramp or proceed to the Lincoln off-ramp.
- Time-of-day or permanent closure of **either** the westbound **Monroe or Maple on-ramp**. These two on-ramps are closely spaced and contribute to a high crash frequency (higher than expected based on the predictive crash analysis[6]). Further investigation is necessary to determine traffic diversion impact and whether the Monroe or Maple westbound on-ramp provides the optimal closure location.

Wrong Way Driver Notification System

While wrong way driving (WWD) crashes are infrequent, accounting for less than one percent of the crashes on I-90, when they do occur the results are severe. Data shows that wrong way collisions have a 12 to 27 times higher fatality rate than other types of crashes. During the five years of crash data analyzed for I-90, there were nine fatalities, three of which were due to wrong way drivers. Washington State Patrol (WSP) data from 2017 indicates that far more WWD events occur than are reported in the crash database, since not all WWD events result in a crash. In 2017 WSP reported 21 WWD incidents, one of which resulted in a fatality. The other 20 WWD incidents resolved without a crash.

The wrong way driver notification system likely applies systematically throughout the I-90 corridor. During the next phase of the project, the project team will evaluate previous wrong way crashes to try to identify whether there are specific off-ramps with repeated problems. However, while crash data identifies the location of the wrong way crash, it may not be possible to trace each wrong way crash to determine from which ramp the wrong way driver accessed the freeway. If specific ramps cannot be identified as repeated problem locations, the strategy should be applied at off-ramps throughout the I-90 study corridor.



LEGEND

- Ramps Recommended for Further Evaluation for Potential Closure
- Other I-90 On-Ramps & Off-Ramps

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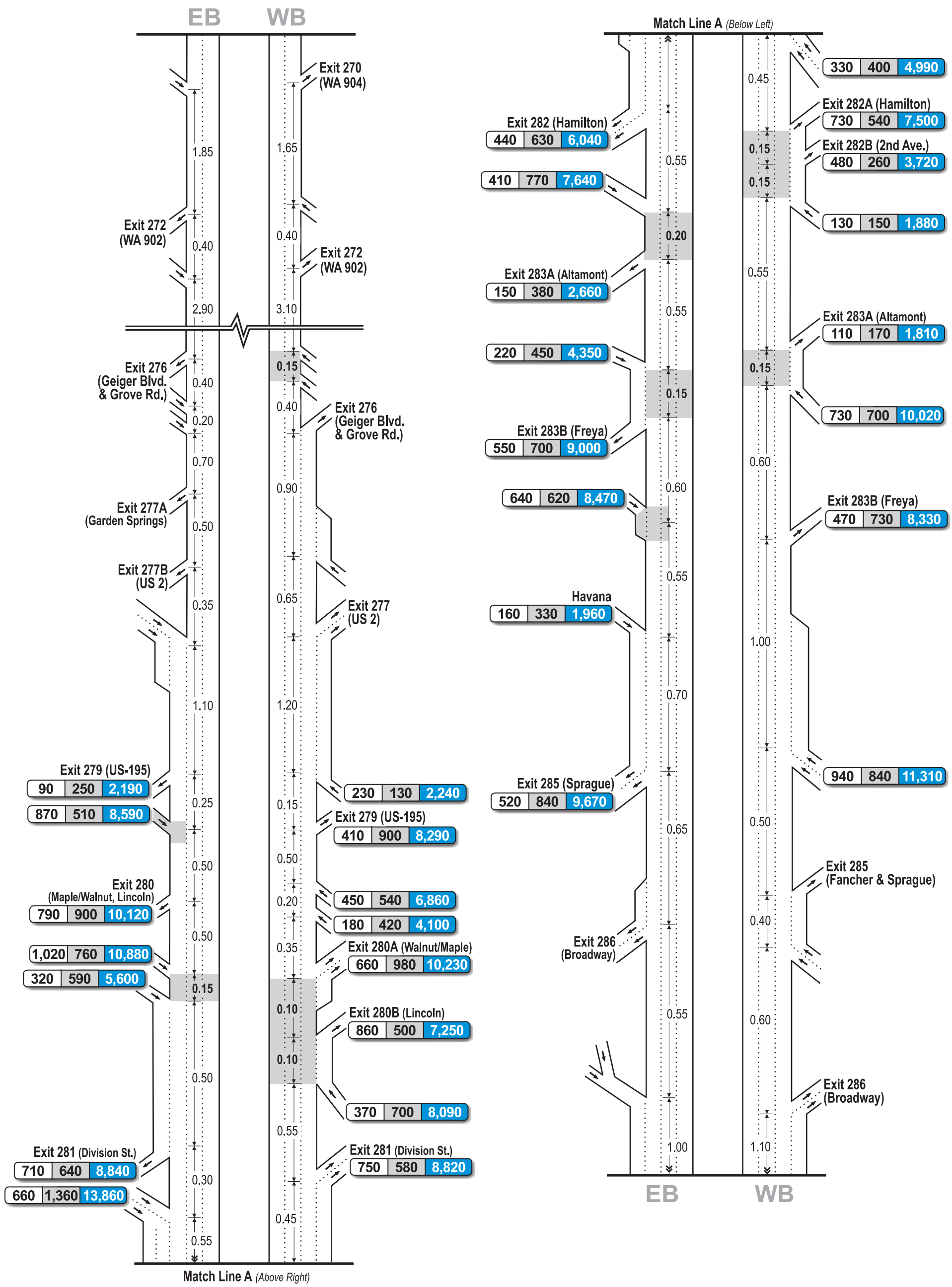
Figure 3

Potential Ramp Closure Locations



NOT TO SCALE

LEGEND

Traffic Volumes - 0,000 (AM) 0,000 (PM) 00,000 (ADT)

Note: AM & PM traffic volumes were measured in June 2015 and averaged across a Tuesday, Wednesday, and Thursday. Seasonal factor & axle adjustments were applied.

0.00 - Distance In Miles Between Interchange Gore Areas (Rounded to Nearest 0.05)

0.00 - Merge or Weave Areas That Do Not Meet Current Performance Expectations

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Figure 4

I-90 Lane Geometry & Interchange Spacing

Traffic Incident Management

Traffic incident management systems can reduce the effects of incident-related congestion, reduce secondary crashes, and keep first responders safe, by decreasing the time to detect incidents, the time for responding vehicles to arrive and clear the incident, inform approaching drivers, and provide a safe scene. Ultimately, clearing incidents faster reduces secondary crashes, and the time required for traffic to return to normal conditions. For I-90 the traffic incident management strategies will likely include **developing a traffic incident management (TIM) team** for the region, **expanding the dedicated incident responder program** (called Dedicated Roving Patrols), and **establishing instant tow contracts**.

Location

Traffic incident management should be implemented on a region-wide basis with focus on I-90 and other key state routes.

Work Zone Management

Work zone management includes both long-term stationary construction projects and all other short term maintenance operations including mobile work zones. ITS strategies for work zone management include variable speeds, dynamic lane merging, traveler information providing real-time information about delay and alternate routes, real-time locations of vehicles and workers, real-time locations of lane closures, and automated speed enforcement. Depending on the duration and location of the work zone, different work zone strategies apply. The potential for driverless vehicles further increases the need to digitally share real-time work zone, worker, and vehicle locations so that driverless vehicles safely navigate the temporary and changing conditions within the roadway.

Location

Work zone management strategies should be used for all long-term stationary, short-term temporary, and mobile maintenance operations anywhere within the I-90 corridor.

LESSONS LEARNED FROM PAST IMPLEMENTATIONS

This section presents lessons learned from implementations of the top five strategies in other parts of the country, including the benefits achieved and challenges that had to be overcome.

Active Traffic Management

For I-90, the active traffic management strategy encompasses a combination of variable speed, queue warning, travel times, and dynamic lane control using overhead signs installed on gantries. In cases where the added benefits of dynamic lane control are not warranted, using post-mounted variable speed signs is a lower cost option. However, driver compliance with post-mounted signs may be lower than compared to overhead signs, and experience suggests the post-mounted signs are not as effective. Cases where post-mounted signs might be appropriate include areas where side swipe crashes are not an issue, and where variations in speed are caused by recurring weather conditions. [7]

The following case studies describe benefits and challenges at three different locations:

- In Seattle, Washington[8] an ATM system was installed on I-5, I-90 and SR 520 in 2010 and 2011. The system installed gantries over the freeway at ¼ to ½ mile spacing with variable speed signs, lane control signs, and variable message signs. In total the system covered 23 miles and included 276 signs (multiple signs per gantry). After five years of operations, results on I-5 northbound showed a 4.1 percent crash reduction, while on other similar corridors the region experiences a 2 to 4 percent increase in crashes. Weekend crashes (infrequent drivers) decreased most significantly by 14 percent.

ATM strategies can reduce injury crashes by up to 30%, reduce property damage only crashes by up to 25%, improve throughput and reduce speed variance.

- In Minneapolis, Minnesota[9] the DOT completed an ATM system along 28 miles of freeways by 2012. Results showed a positive impact during the most severe congestion (speeds below 15 mph) and reduced property damage only crashes by 25 percent, a statistically significant amount. However, the annual operations and maintenance cost is about $300,000, plus an additional $60,000 for utilities. Based on the high annual maintenance and operations costs, Minneapolis has taken a more minimal sign approach on future projects.
- In Portland, Oregon[10] an ATM system was installed along OR 217 for 7.5 miles in 2014. The system included variable advisory speed signs, variable message signs, curve and queue warning signs, and adaptive ramp metering. Aside from the ramp meters, most of the components are mounted on gantries that extend over the freeway lanes. Initial results include an 18 percent reduction in crashes, a

[7] FHWA. Active Traffic Management Feasibility and Screening Guide. May 2015
[8] ATDM Operations and Implementation, WSDOT, Morgan Balogh, April 2015.
[9] Urban Partnership Agreement: Minnesota Evaluation Report, US DOT, FHWA-JPO-13-048, January 2013
[10] Dennis Mitchell. OR 217 Active Traffic Management. ODOT.

9 percent decrease in travel times during the a.m. and p.m. peak commute hours and a 50 percent reduction in travel time variability.

- A group of studies in the US, Germany, Finland, and the UK showed that variable speed systems can reduce overall crashes by up to 15 percent, reduce injury crashes by up to 30 percent, improve throughput by up to seven percent, and reduce speed variance.

Ramp Metering

Ramp metering, when implemented at warranted locations, provides safety and operational benefits that range from improved vehicle throughput and speeds, to reduced crashes in the merge zone and upstream of the merge zone, as well as reduced vehicle emissions and fuel consumption.

The following case studies and results highlight the safety and operational benefits of ramp meters:

- A collection of studies from Minneapolis (MN), Seattle (WA), Denver (CO), Detriot (MI), Portland (OR), Long Island (NY), and Kansas City (KA) all point to a crash reduction ranging from 15 to 64 percent. In Kansas City, a ramp metering system installed at a total of seven interchanges in 2010, reduced the number of crashes attributed to merging by 81 percent.[11]
- A study in Minneapolis showed that when ramp metering was reduced, it resulted increased vehicle emissions, and a seven percent reduction in vehicle speeds. The benefit cost ratio for the Minneapolis-St Paul ramp meter system was 15:1.
- A second simulation study in Minneapolis-St Paul found that ramp metering decreased system travel time by 6 to 16 percent; increased mainline speeds by 13 to 26 percent; and reduced stops on the mainline by 90 percent.[12]
- In Salt Lake City a study showed that with an eight second metering cycle, mainline peak period delay decreased by 36 percent.[13]

For actuated ramp meter systems, expected crash reduction ranges from 20% to 50%, and freeway capacity can increase by 7% to 20%.

One concern in implementing ramp meters is the perception that traffic wanting to access the freeway will divert to local roads to avoid waiting at a ramp meter. In Portland, Oregon, a before and after study observed the impact to traffic volumes on adjacent streets after ramp meters were installed on I-5.[14] The goal was to ensure that the volume increase on local roads did not exceed 25 percent. If so, the ramp meters would need to be adjusted or removed. After the ramp meters were installed, the traffic volume increase on adjacent roads

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[11] Kansas City Scout Program. Ramp Metering Evaluation 2011. Kansas DOT and Missouri DOT. 2012.
[12] ITS database: Evaluation of Ramp Meter Control Effectiveness in Two Twin City Freeways. John Hourdakis and Panos Michalopoulos. January 2002.
[13] ITS database: Utah DOT. March 2004.
[14] Piotrowicz, G. and J. Robinson. Ramp Metering Status in North America; 1995 Update. Publication DOT-T-95-17. Federal Highway Administration (FHWA), U.S. Department of Transportation. June 1995.

was determined "not substantial". Which meant there was little indication that drivers altered their route to avoid the ramp meters.

Ramp Closures

As discussed in the previous section, ramps can close by time-of-day, permanently, or on a temporary basis during specific events.

Permanent Ramp Closures

Permanent ramp closures are infrequent and often face public controversy. There are few examples of permanently closing a ramp, that don't involve construction of a new ramp providing similar access as the closed ramp.

In California, there was once such permanent ramp closure in 2015. In October 2015, California DOT permanently closed an off-ramp in Los Angeles in the direct vicinity of Universal Studios. The closure of the off-ramp from 101 to Barham Road was part of NBCUniversal's Evolution Plan to expand the theme park, which was approved by the LA City Council and LA County Board of Supervisors. The plan included construction of a new on-ramp, which when completed would be too close to the Barham off-ramp, creating weaving and safety issues. In addition, the area suffered from a higher than average collision rate. Based on this information, and acknowledging public concern, Caltrans determined a permanent closure was necessary.

Ramp closures can be a controversial topic. If implemented appropriately, it can decrease crashes and improve freeway throughput.

The closure was not without controversy. An advocacy group filed a lawsuit (which was later dismissed) to keep the ramp open. The lawsuit claimed that Caltrans broke state laws by failing to fully study the potential environmental impacts of the ramp closure and the adverse traffic effects for the surrounding neighborhoods.

Time-of-Day Ramp Closure

Time-of-day ramp closures are not common, but there is some research supporting specific findings. In Detroit, a three-mile section of the John C Lodge Freeway experimented with time-of-day closures and found the following results[15]:

- Freeway volumes increased 3.5 to 13.7 percent.
- Average freeway speed (averages over all periods and locations) increased from 27 to 37 mph in the a.m. peak period and from 25 to 39 mph in the p.m. peak period.

[15] Prevedouros, P.D. H-1 Freeway Ramp Closure: Simulation and Real-world Experiment. Transportation Research Board 78th Annual Meeting. January 1999.

Wrong Way Driver Notification System

Several states including Texas, Rhode Island, and Florida have all installed various wrong way driver notification systems and reported a reduction in wrong way driving incidents following the installations.

- In Texas, a task force identified a section of US-281 near San Antonio as having the largest concentration of wrong way crashes and a pilot study began targeting that section. The pilot study installed radars to detect wrong way drivers and then automatically turn on LED "wrong way" notification signs to warn on coming drivers. After a 14-month pilot study (July 2012 through August 2013) results showed a 30 percent decrease in wrong way driver incidents.[16]

Wrong way driver notification systems can reduce wrong way incidents by 30%

- A system installed at 25 locations in Rhode Island included an early warning system to detect wrong way drivers. During the five years prior to installation 16 crashes were reported, resulting in eight fatalities. In the first 18 months after the system was installed there were zero crashes.[17] The system was activated 66 times, and resulted in the drivers turning around without incident.

Traffic Incident Management

Case studies showing the benefits of implementing traffic incident management programs are abundant. The following list describes a few of the documented benefits:

- In Maryland, the CHART highway incident management system led to almost a 30 percent reduction in average incident duration, which resulted in an estimated 377 fewer secondary incidents. At the time of the report, CHART included: traffic monitoring, incident response, traffic management, and traveler information. [18]

- In Florida, the Miami-Date TIM Team reduced average roadway clearance by 11 percent from the previous year (2008/2009).

- In Georgia, a study determined that when a dedicated incident responder, or Highway Emergency Response Operator (HERO), responded to an incident, the average incident duration was reduced by 69 percent (from 67 minutes to 21 minutes). Other environmental benefits included reduced fuel consumption and emissions.

Dedicated responders can reduce incident duration by 17% to 70%.

- Following a contracted towing strategy that was implemented in Houston, Texas, as part of the SafeClear program, there was a significant reduction in collisions and 90.5 percent of the incidents were cleared in less than 20 minutes. The final evaluation showed that the SafeClear program was responsible

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[16] ITS International. Cutting the cost of wrong way driving. May/June 2014
[17] Interview with Peter Alviti. Website: http://www.wbur.org/hereandnow/2016/10/27/wrong-way-accidents
[18] Performance Evaluation of CHART. Dr. Gang-Len Chang, University of Maryland. November 2003.

for a reduction of approximately 1,440 incidents per year, resulting in an economic savings of $49 million per year.[19]

- In Portland, Oregon, two towing strategies were tested as pilots: instant tow and staged towing. The instant tow decreased tow response times by 30 percent with a minimal annual cost. The study concluded that instant tow dispatch was 50 times cheaper than staged towing. [20]

Work Zone Management

Work zone management has the potential to improve safety for both travelers and workers, and reduce delay through work zones.

- In Northern Virginia along a 7.5-mile stretch of I-495 a variable speed system was implemented to harmonize upstream and downstream traffic around several work zones. Leading up to each work zone were tapered lane closures that reduced travel lanes from four to two or one. The study[21] found that in the case of the four to two lane closure, the VSL produced a mean savings of almost 270 vehicle hours of delay per day (equivalent to about $12,300 per day in user delay savings). When the lane closure went from four lanes to one lane, the VSL did not produce any savings.

- In Washington DC a system posting real-time delay information and a suggestion to use an alternate route during work on I-295 effectively diverted traffic and reduced delay by an average of 52 percent during the construction hours. Using before and after data, the study[22] showed a 3 to 89 percent decrease in mainline volumes.

- In Michigan a dynamic lane merge system was installed on US-131 prior to a construction zone approximately 11 miles long. Based on field observations, the system reduced the number of forced merges seven fold, and reduced the number of dangerous merges three fold.

ITS work zone strategies can reduce crashes, speeds, and traveler delay

- In Oregon in 2010 a section of US 30 in the Portland area was under construction. A photo radar enforcement van was stationed at the work zone temporarily during construction. While the van was stationed at the work zone, speeding was reduced by an average of 23.7 percent. After the van departed, the speed reduction did not continue. [23]

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[19] Best Practices in Traffic Incident Management. FHWA. 2010.
[20] Tow Truck Response Strategy Evaluation. Prepared for ODOT by Kittelson and Associates. November 2012.
[21] Fudala, Nicholas J., Michael Fontaine. Work Zone Variable Speed Limit Systems: Effectiveness and System Design Issues. Virginia Department Research Council. Final Report VTRC 10-R20. March 2010.
[22] FHWA Comparative Analysis Report: The Benefits of Using Intelligent Transportation System Work Zones. Report Number FHWA-HOP-09-002. October 2008.
[23] Joerger, Mark. Photo Radar Speed Enforcement in a State Highway Work Zone: Demonstration Project Yeon Avenue – Final Report. ODOT. April 2010.

- In Illinois in 2011, portable variable message signs were used to warn motorists about vehicle queues well in advance of a work zone at the I-79/I-57 interchange in Effingham. Portable VMS were located 10 to 12 miles upstream of the work zone, providing drivers with information about the work zone and opportunities about alternate routes. Reviewing the before and after data, researchers found that the system reduced queueing crashes by 14 percent, and reduced injury crashes by 11 percent, despite a 52 percent increase in the number of days when temporary lane closures were implanted during the evaluation.

As part of the studies mentioned above, key lessons learned were identified in the FHWA Comparative Analysis Report:

- Coordinate with neighboring agencies
- Allow time for obtaining right of way use permits to place equipment (portable VMS)
- In the design of ITS for work zone applications, involve the construction contractor as early as possible
- Ensure that the managing agency has real-time access to archived system data

NEXT STEPS

During the next phase of the project, more detailed analysis of each of the recommended strategies will be conducted to assess the potential effectiveness of the strategies, consider challenges, impacts, and costs.

The project team will include the following elements for each strategy in the Implementation Plan:

- Provide an overview of the system
- Refine the project costs and benefits
- Create a map indicating locations for the proposed field equipment
- Identify resources and partnerships necessary for successful operations of each strategy
- Refine cost estimates to show design, construction, and annual operations and maintenance costs
- Describe system software enhancements if necessary
- Develop a phased implementation plan

Attachment A

Toolbox of Strategies

Strategy	Description	Benefits	Estimated Cost	Influencing Factors
Traffic Operations and Management				
Active Traffic Management **(Includes: Variable Speed System, Queue Warning, Dynamic Lane Control, added surveillance)**	Active traffic management consists of a combination of operational strategies that, when implemented in concert, fully optimize the existing infrastructure and provide measurable benefits to the transportation network and the motoring public. The strategies would all use variable message signs mounted on gantries over the travel lanes. On I-90 the strategies include: **Variable Speed System -** enables adjustments to the posted speed (regulatory or advisory) based on real time congestion and weather conditions. If weather conditions are incorporated, **RWIS stations** are necessary. The primary purpose of a variable speed system is to provide better information about current conditions and reduce crashes. The variable speeds would be displayed on dynamic message signs on overhead gantries with the potential for a dynamic message sign over each lane. **Queue Warning System** - the overhead dynamic message signs could also display messages that alert drivers about downstream slowing so that drivers are aware of an upcoming change in speed due to unexpected congestion. **Dynamic Lane Control -** using dynamic signs over lanes, enables operators to close lanes or shift traffic to improve safety and operations during a variety of scenarios (closing a lane in advance of a high volume on-ramp that requires an extra lane, closing a lane and merging traffic in advance of an incident that blocked a lane, other special events).	Reduces crashes - VSL can reduce crashes by 8% (CMF ID: 3340). In particular VSL can target rear-end crashes. - Queue Warning can reduce injury crashes by 16% to 44% (CMF ID: 75 and 76) - Reduces fixed object and side-swipe crashes - Reduces weather related crashes Improves Commuter Mobility: - Makes travel times more reliable during peak hours	Cost ranges depending on corridor length, sign type, sign frequency, and available utilities. Range $5,000,000 to $10,000,000 for a 20 mile urban segment. Typical cost for each gantry installation is approximately $500,000. Based on past project in Seattle, Portland, and the Bay Area, the average cost per lane mile of an ATM System is $500,000	Physical Factors - Available ROW for sign structures; structural sections of I-90 may be challenging to construct gantries; connection to utilities and communications network; maintenance access; integration of various ITS components. Institutional Factors - Coordination with local law enforcement. Public perception and potential resistance. Public education necessary; train staff to operate new system. Operational and Maintenance Factors - Ensure detection is accurate and maintained providing real-time data; ongoing operations and maintenance requirements; developing procedures for system failures; understand technical capabilities and limitations of equipment; periodic software updates.
Road Weather Information Systems/Weather Responsive Systems **Note - option to include with ATM System**	Install Road Weather Information Systems (RWIS) with ice detection at key locations. Surveillance, monitoring, and prediction of weather and roadway conditions enable the appropriate management actions to mitigate the impacts of any adverse conditions. Install sensors that detect conditions such as pavement grip factor and visibility. Then use the information to alert travelers of hazardous conditions either via electronic roadside signs or other means. This strategy can also be used to manage a variable speed system.	- Travelers perceive enhanced safety by being better prepared for roadway conditions - Lower traveler frustrations due to better real-time information - Expected B:C ratios 2:1 to 10:1 - Improved weather information leads to more efficient application of anti-icing chemicals, reduced maintenance costs, reduced delay, and increases safety (US DOT) - Improved safety by reducing crashes - Reduced vehicle speed during adverse weather - Improved information for agency decision-makers and travelers - Reduces weather related crashes	Cost varies which can range from $20,000 for a sensor unit to over $3 million for a weather management system. Weather station ($20-50k capital, $1.5-4k operations and maintenance), CCTV-surveillance ($25k-40k capital, $1.0k-2.5k operations and maintenance), Highway Advisory Radio ($16-32k capital, $500-1,000 operations and maintenance), variable message signs ($50k-120k capital, $2.5k-6k operations and maintenance), and variable speed limit display ($3-5k capital).	Physical Factors - Available ROW for RWIS structures, connection to utilities and communications network; maintenance access; integration of various ITS components. Institutional Factors - Optimize operations by interagency cooperation between weather systems. Operational and Maintenance Factors - Ensure RWIS sensors are accurate and maintained providing real-time data; ongoing operations and maintenance requirements; understand technical capabilities and limitations of equipment; periodic software updates.
Ice Warning Signs **Note - option to include with ATM System**	Install activated ice warning signs at key locations that notify drivers (via VMS, flashing beacons, or other means) when roadway conditions are icy. For optimal benefit, detection segments should be short and warning systems frequent. Ice detection could use an existing or proposed RWIS station, or a grip factor sensor at the sign location.	- Ice Curve Warning System reduced ice-related crashes by 18% (CMF ID: 4114, 2 star)	$5,000 to $45,000 (cost does NOT include power or communications) $5,000 annual operations and maintenance cost	Physical Factors - Available ROW for sign structures; connection to utilities and communications network; maintenance access; integration of various ITS components. Institutional Factors - Educate travelers; liability concerns if a crash occurs during a sign failure; train staff to operate new system. Operational and Maintenance Factors - Ensure signs and sensors are accurate and maintained providing real-time activated warning messages; developing procedures for system failures; ongoing operations and maintenance requirements; understand technical capabilities and limitations of equipment; periodic software updates.

Strategy	Description	Benefits	Estimated Cost	Influencing Factors
Ramp Metering	Traffic signals on freeway ramp meters alternate between red and green signals to control the flow of vehicles entering the freeway. Metering rates can be altered based on freeway and on-ramp traffic conditions.	Reduces crashes - Reduces crashes by 36% on roadways with 50K to 200K AADT (CMF ID: 5436) Reduces mainline peak period delay - Increases freeway speed - Improves freeway capacity - Reduced duration of congestion - Reduces mainline stops	$25,000 - $66,000 per site; $6,500 for detection components per site; $1,000-$3,000 per site for annual operation and maintenance	Physical Factors - Ensure infrastructure and timing plans allow green time to meet demand. Avoid queue spillback to adjacent intersections. Institutional Factors - Agency coordination on operations to ensure ramp queues don't impact surface street operations; public perception that ramp meters may increase delay accessing freeway and potential resistance Operational and Maintenance Factors - Ongoing operations and maintenance requirements.
Ramp Closures (Permanent or Time of Day)	Close an on or off ramp at an interchange to achieve standard interchange spacing and reduce congestion and collisions resulting from substandard interchange spacing.	- Improves safety - Reduces fixed object and side-swipe crashes - Increases freeway vehicle throughput and speeds - Improves commuter mobility - Makes travel time more reliable during peak hours - Reduces non-recurring delay for planned events - Improves freight mobility - Makes travel time more reliable during non-peak hours	Highly variable.	Physical Factors - ROW necessary for infrastructure connections and enhancements to combine ramps or physically close ramps. Support diverted traffic. Institutional Factors - Public perception and potential resistance. Creates confusion to travelers if closures are by time of day; potential to move congestion to surface streets. Operational and Maintenance Factors - Ongoing O&M required. Need to providing adequate traveler information in the short term about route change. If time of day closures are implemented, an advance traveler information system would be necessary.
Integrated Corridor Management	With integrated corridor management, the various institutional partner agencies manage the transportation corridor as a system, rather than the more traditional approach of managing individual assets. Travelers could receive information that encompasses the entire transportation network including parallel facilities that may provide faster travel times. They could dynamically shift to alternative transportation options, even during a trip, in response to changing traffic conditions.	- Reduced travel time and delays - Increased reliability and predictability of travel	$2,000 - $3,000 per intersection for signal retiming (additional cost if new detection is necessary). Approximately $500,000 per variable message sign (includes sign, support, controller, and installation) Annual O&M dependent on which strategies are installed.	Physical Factors - utilizing existing ITS devices and communications; expanding communications. Institutional Factors = Interagency cooperation and implementation is key to project success. Operational and Maintenance Factors - staff training; on-going O&M to ensure field devices and communications are properly functioning.
Expand Real-Time Traveler Information	Advanced communications have improved the dissemination of information to the traveling public. Motorists are now able to receive relevant information on location-specific traffic conditions in a number of ways, including dynamic message signs (DMS), onboard GPS devices, and 3rd party apps such as Inrix, HERE or WAZE. May include 511 systems. Provide predictive travel times using algorithms that combine existing data with future weather/event information.	- Reduced delay and number of stops - Reduced gas emissions Improves Commuter Mobility: - Makes travel times more reliable during peak hours - Reduces non-recurring delay for planned events Improves Freight Mobility: - Makes travel times more reliable during peak hours - Makes travel times more reliable during non-peak hours	Cost per VMS installation approximately $500,000 which includes the sign, support, foundation, controller, and installation. Typical O&M cost of 3% of installation cost. Other methods such as partnerships with private information service providers will have variable costs.	Physical Factors - Constantly evolving technology. Institutional Factors = Agency partnership and data/resource sharing to create a robust system; educating the public and explaining the benefits of an ITS solution versus expanding roadway infrastructure. Operational and Maintenance Factors - staff training and ongoing O&M to ensure field devices are functioning and accurate.
Connected Vehicle Strategy	Deliver real-time roadway information to connected vehicles. Ensure that roadway related communications systems are connected vehicle ready. Delivery of roadside infrastructure information to vehicles may use a combination of cellular networks and short range communication radios dedicated for connected vehicles. When implementing new roadside devices, Agency should support sharing standard message sets from roadside devices such as DMS through a central application programming interface (API) or including extra conduit and pole capacity to accommodate roadside dedicated short range communications (DSRC) radios. The system could deliver road conditions, current speeds, incident notification from the roadside to the vehicle.	- Improves safety - Improves commuter mobility - Improves freight mobility - Reduces rear end crashes - Reduces fixed object and side-swipe crashes - Reduces weather related crashes - Makes travel times more reliable during peak hours - Makes travel times more reliable during non-peak hours - Reduces freight related crashes	variable	Physical Factors - Available room in device cabinets and conduit; quickly evolving technology is changing quickly. Institutional Factors - Sharing resources across agencies and creating public-private partnerships; education of public; understanding what connected vehicle readiness means. Operational and Maintenance Factors - educating staff about policy

Strategy	Description	Benefits	Estimated Cost	Influencing Factors
Increase Traffic Surveillance	Monitor traffic operations in real-time using video cameras along the corridor that are controlled from a traffic management center (TMC). This strategy could be used in conjunction with providing real time information for both traveler information and incident management.	- Improved incident response times and accuracy - Real-time and historic system operations information - Improved visual information for decision-makers and the public - Clears lane blocking incidents faster - Makes travel time more reliable during peak hours - Makes travel time more reliable during non-peak hours	$25,000 - $40,000 per CCTV (camera + pole) detection unit, $1 - 2 million for central system integration and firmware upgrade if run through a TMC	Physical Factors - Connection to utilities and communications network; determining communication requirements if live streaming and pan tilt zoom capabilities are necessary; integration of various ITS components Institutional Factors - Public perception of "big brother" surveillance and invasion of privacy; establish policies to share images with other agencies. Operational and Maintenance Factors - Ensure cameras are maintained providing real-time images; ongoing operations and maintenance requirements.
Dynamic Curve Speed Warning Signs	Dynamic feedback signs can measure the speed of individual vehicles and post messages such as "SLOW DOWN. YOUR SPEED IS OVER 60 MPH. CURVE AHEAD" Note - if an Active Traffic Management System is installed, this component could be incorporated.	- Crash reduction of 2% to 50% for beacons (CMF Clearinghouse) - Speed reduction in 68% of drivers (rural CA, 2000) - Ice Curve Warning System reduced ice-related crashes by 18% (CMF ID: 4114, 2 star)	$15,000 (basic sign with beacons) $100,000+ (overhead mounted feedback message sign)	Physical Factors - Available ROW for sign structures; connection to utilities and communications network; maintenance access; integration of various ITS components; determining criteria that activates the warning. Institutional Factors - Educate travelers; liability concerns if a crash occurs during a sign failure; potential for non-compliance. Operational and Maintenance Factors - Ensure signs and sensors are accurate and maintained providing real-time activated warning messages; developing procedures for system failures; ongoing operations and maintenance requirements; understand technical capabilities and limitations of equipment; periodic software updates; train staff to operate new system.
Off-Ramp Traffic Signal Coordination (Mainline Vehicle Queue Prevention)	Improve signal timing at select off-ramps and surrounding traffic signals to prevent vehicle queues from extending onto the freeway mainline.	Improves Safety: - Reduce queues on mainline and resulting rear end crashes	$4,000 - $7,000 per intersection for signal retiming and ramp detection. Cost increases if new traffic signal controller or other intersection improvements are necessary.	Physical Factors - Reliable and accurate vehicle detection must be maintained. Institutional Factors - Coordinating between multiple agencies Operational and Maintenance Factors - ongoing retiming and coordination
Wrong Way Driver Notification System	Install a wrong way driver alert system on off-ramps that can detect wrong way drivers, activate signs to help deter the wrong way driver, send a notification to the TMC, and automate messages to VMS or on-board systems to notify drivers.	- Reduce fatal and severe injury crashes - TxDOT implemented a wrong way driver notification system which decrease wrong way events up to 30% - ITS Database	Approximately $25,000 to $150,000 per off-ramp depending on the extent of new detection and activated signs. Additional VMS approximately $300,000 each. Low end includes activated "wrong way" signs to notify the wrong way driver. Higher cost includes those signs plus a system to notify on-coming traffic, law enforcement, and traffic operation centers.	Physical Factors - Communication between ITS devices, locating equipment. Institutional Factors - Coordinating with WSP. Operational and Maintenance Factors - Ongoing O&M required; detection accuracy critical.
Red Light Running Cameras	Install cameras at select intersections that can automatically detect when a vehicle runs a red light, take a picture, and issue a ticket.	- Reduce fatal red light running crashes by 24% - ITS Database - Reduce all fatal crashes at signalized intersections by 17% - ITS Database	Approximately $70,000 to $90,000 which includes: camera, detectors, and related wiring and housing.	Physical Factors - Placement of equipment in ROW. Institutional Factors - Public acceptance; coordination with local agency depending on who owns, operates, and maintains the traffic signal. Operational and Maintenance Factors - Ongoing O&M and calibration required.

Strategy	Description	Benefits	Estimated Cost	Influencing Factors
Maintenance and Construction Management				
Work Zone Management **(Includes both construction long term work zone management and daily maintenance work zone activities)**	Implement work zone management strategies to reduce the duration of the construction activity and safety impacts to travelers and workers. ITS applications in work zones include the temporary implementation of traffic management such as variable speeds, automated enforcement, portable VMS to control lane use in advance of the work zone, as well as other applications. Other management strategies may include limiting lane closures during daytime hours, incentivizing contractors to reduce the duration of the activity, and using demand management programs to reduce traffic volumes through work zones.	- Reduced traveling speed across work zone by 9mph and reduced speed variability by 70% in a Minneapolis/St. Paul study - Improved safety with reduced travel speed - Reduced delay and travel time - Using portable VMS: - driver speeds reduced by 3.6 mph upstream of work zones (study in rural Missouri) - When used in conjunction with radar, a study in Virginia found a 50% reduction in speeding vehicles through work zones, with a decrease in vehicle speeds of up to 9 mph within a work zone	$150 - 800k for a work zone management system, which commonly includes variable message signs ($50k-120k capital, $2.5k-6k operations and maintenance), CCTV-surveillance ($25k-40k capital, $1.0k-2.5k operations and maintenance), Highway Advisory Radio ($16-32k capital, $500-1,000 operations and maintenance), traffic detectors ($3k-13k capital, $100-1,000 operations and maintenance) and variable speed limit display (varies, $75k+ for full matrix with controller, less for LED panel within regular speed sign), etc. Costs are dependent on agency leasing or purchasing, and portable versus permanent components.	Physical Factors - Available ROW to set up system and provide through movement for travelers. Institutional Factors - Coordinating across agencies and with the WSP for enforcement; public outreach and education Operational and Maintenance Factors - Staff training
Telematics Technology on Fleet Vehicles	Telematics capabilities that can be used to track vehicle performance and vehicle maintenance. Telematics technology has a range of capabilities. For maintenance vehicles some of the key features to implement are tracking performance and fuel use, automatic notifications when vehicle maintenance is necessary, and improve routing efficiency.	- Reduces fuel costs - Improves vehicle maintenance - Reduces idle time	$5,000 to $15,000 per vehicle (assumes some retrofitting necessary). If implemented with AVL there are cost savings $1,000 per vehicle annual operations and maintenance cost	Physical Factors - Ensure vehicles are properly equipped; establish communications system to collect and process the data. Institutional Factors - Fleet operators may be hesitant to track all activity and locations; coordination across agencies. Operational and Maintenance Factors - Regular software updates and device maintenance; staff training.
Asset Management Tool	Install software that enables automated maintenance logs and proactive management of system health (notifications of equipment failure) for ITS infrastructure: • Traffic signal controllers • Street lights • Cameras • VMS • RWIS	- Improves operational efficiency	Varies based on system	Physical Factors = Determining the optimal software platform and integrating all ITS components Institutional Factors - Implementation could be more of a statewide initiative than a regional approach. Operational and Maintenance Factors - staff training and regular software updates.
Corridor Operations Team	Implement a corridor operations team that meets regularly to coordinate operations within the corridor. Specific activities the corridor operations team could be responsible for could include: Planning management and operations (M&O) for special events, coordinate incident response, review performance, allocate resources for active corridor operations.	- Improves safety - Clears lane blocking incidents faster - Improves commuter mobility - Makes travel times more reliable during peak hours - Reduces non-recurring delay for planned events - Improves freight mobility - Makes travel times more reliable during peak hours	Cost is mostly staff time (variable)	Physical Factors = Providing communication between agencies Institutional Factors - Coordinating between agencies and creating dedicated staff roles. Operational and Maintenance Factors - staff time.
Transportation Management Center Enhancements	The purpose of a Transportation Management Center is to integrate various departments and offices of transportation and emergency agencies into a unified communications center. The integration provides the communications and computer infrastructure necessary for coordinated transportation management on roadways during normal commuting periods, as well as during special events and major incidents.	- More efficient coordination and operation of various transportation systems - Better data collection for decision-making and future planning purposes - Co-locate and collaborate with traffic, transit, fire, emergency, police, etc.	Varies depending on specific enhancements.	Physical Factors - Available space at TMC for expansion or additional communication connections. Institutional Factors - Communication and interoperability issues may exist among agencies. Changing agency culture to operate differently. Potential collaboration with transportation, emergency, police, fire, etc. Operational and Maintenance Factors - added staff time and training

Strategy	Description	Benefits	Estimated Cost	Influencing Factors
Emergency and Incident Management				
Traffic Incident Management Strategies **(Includes TIM Team Development and Dedicated Incident Responders and Instant Towing)**	Incident management systems and planning reduce the effects of incident-related congestion by decreasing the time to detect incidents, the time for responding vehicles to arrive, and the time required for traffic to return to normal conditions. Incident management systems make use of a variety of surveillance technologies as well as enhanced communications and other technologies that facilitate coordinated response to incidents. Other incident response element include: **- TIM Team Developmen**t - develop and operate a TIM team for the Spokane region that includes responders from DOT, Fire, Tow, Law Enforcement, County, Cities, and 911 dispatch. Establish regular meetings and communication with the TIM Team. **- Dedicated Incident Response Vehicles** - expanding the current Dedicated Roving Patrol program, especially during peak travel periods to assist disabled vehicles, respond to incidents and reduce clearance times. **- Establishing Instant Tow Contracts** - the purpose of instant tow contracts is to deploy a tow truck to a scene as soon as the incident is reported, rather than waiting for on-scene confirmation. This strategy can greatly reduce clearance times and secondary crashes.	- Reduced average incident duration (studies cite a range of 10% up to 70% reduction in incident durations) - Decreased secondary crashes - Reduced delay due to quicker incident clearance - Improve coordination between responder partners - Improve understanding of partner roles	Variable - Cost dependent on which strategies are implemented: TIM Team - cost is mostly staff time Dedicated Roving Patrol program - estimate $55 per vehicle hour for patrolling vehicle plus cost of additional vehicles if necessary. Instant Tow Contracts - variable	Physical Factors - Reliable communication system with wide coverage; interoperability issue among different agencies Institutional Factors - Coordination between multiple responder agencies. WSDOT already has a Dedicated Roving Patrol on staff. Operational and Maintenance Factors - staff time and training.
Traffic Incident Management (TIM) Strategic Plan	Develop a region specific traffic incident management strategic plan that prioritizes future projects and investments related to traffic incident management. The plan can also help formalize relationships and agreements between responders and agencies.	- Improve coordination between responder partners - Improve understanding of partner roles - Improve management's understanding of TIM roles and responsibilities	Staff time to prepare plan. If developed by a consultant, estimated cost is $100,000	Physical Factors - n/a Institutional Factors - Coordination between multiple responder agencies. Operational and Maintenance Factors - staff time to maintain and update plan.
9-1-1 Dispatch Integration	Connect the 9-1-1 dispatch center with SRTMC. Currently when a call comes into the 9-1-1 dispatch center that effects a state highway, WSP manually calls the TMC to relay the issue. Connecting SRTMC directly to the 9-1-1 dispatch center allows for the transportation agencies to be automatically notified when an event on a state facility occurs. Currently WSDOT has view-only access to events on the WSP computer aided dispatch screen, with some information scrubbed.	- Reduce incident response time - Shorten incident duration - Reduce dispatch response time - Reduce interagency calls Results from Deschutes County in Oregon: - reduced interagency calls by 60% - reduced response time by 25 minutes		Physical Factors - communication links between WSDOT, WSP, and other local agencies. Institutional Factors - Coordinating between multiple agencies; processing sensitive information. Operational and Maintenance Factors - staff time; staff training; periodic software updates.
Hourly Towing Contract (during severe weather or specific events)	Initiate an hourly towing contract between DOT and towing companies during bad weather conditions or other necessary events. This contract enables DOT to dictate towing priorities and allocated towing resources as necessary.	- Improves safety - Reduces rear end crashes - Reduces fixed object and side-swipe crashes - Clears lane blocking incidents faster - Improves commuter mobility - Makes travel times more reliable during peak hours - Improves freight mobility - Makes travel times more reliable during non-peak hours - Reduces freight related crashes	Variable	Physical Factors - Communication interface with tow companies Institutional Factors - Developing a contract and partnerships between DOT and tow companies. Operational and Maintenance Factors - On-going verification that tow companies are in compliance with WSDOT standards

Strategy	Description	Benefits	Estimated Cost	Influencing Factors
Sharing On-Scene Photos and Video	Invest in technology that allows first responders to send and receive photos and video from an incident scene, including the tow partners.	- Increase the percent of time tow companies arrive with correct equipment - Faster incident clearance	$200 to $1,000 per vehicle	Technical Factors - Implemented software that operates on current responder vehicles or systems. Institutional Factors = Developing protocol for sending photos and video with sensitive information; perception that media may be shared inappropriately; privacy concerns. Operational and Maintenance Factors - staff training and education about sending sensitive images.
Interoperable Communication Procedures	Implement standard protocols for using radios between agencies. This strategy could be a task for the TIM Team to develop.	- Faster incident clearance, gets responders to the scene and where they are needed at the scene faster - Improve on-scene communication	Staff time to prepare protocol and provide training. Ongoing staff time for training and updating	Physical Factors - Selecting communication technology and software. Institutional Factors - Coordination across multiple agencies. Operational and Maintenance Factors - staff training and periodic software updates.
Event Management	Event transportation management systems can help control the impact of congestion at stadiums or convention centers. In areas with frequent events, large changeable destination signs or other lane control equipment can be installed. In areas with occasional or one-time events, portable equipment can help smooth traffic flow.	- Reduced delay amidst heavy demand during special events - Reduced crash rates due to reduced conflicts - Increased attractiveness of event attendance, particularly repeat attendees	(System components are similar to Incident Management, which gives similar cost as that) $2,000 - $3,000 per intersection for specialized event timing plan; $20-$50 per hour per officer for manual traffic control; $2,000 - $3,000 per lane control display; $300K - $450K per lane control system including software, integration and other hardware costs	Physical Factors - Available ROW to place equipment; available power and communications to equipment; Institutional Factors - Coordination with various event organizers and agencies; concern from residents about detours through local roadways. Operational and Maintenance Factors - maintaining a current contact list for event sites and agencies; developing procedures; ensuring detour routes have adequate capacity.
Situational Software	Integrate the Situational Awareness, such as Intterra, software during incident or emergency response. The software can track where each of the response agencies/vehicles is (en route, at the scene, and during clean up) and improve communication between responders.	- Faster incident clearance - Improve on-scene communication - Improve incident scene management	Annual license fee (based on a system used by Keno Fire Dept. in Oregon the annual fee of $56K for Intterra software)	Physical Factors - Enable all response/fleet vehicles with software. Institutional Factors - Coordination across multiple responder and traffic management agencies; privacy concerns. Operational and Maintenance Factors - staff training; regular software upgrades.

Strategy	Description	Benefits	Estimated Cost	Influencing Factors
Transit and Demand Management Strategies				
Real-Time Transit Information	Transit agencies can disseminate both schedule and system performance information to travelers through a variety of applications, in-vehicle, wayside, or in-terminal dynamic messages signs, as well as the internet or wireless devices. Coordination with regional or multimodal traveler information efforts can also increase the availability of this transit schedule and system performance information.	- Enhanced passenger convenience - Increased attractiveness of transit - Improve travel experience for transit user - Potential for increased ridership and revenue - Improve schedule adherence by 9 to 23% using AVL/CAD systems (study based on information from Portland, Milwaukie, and Baltimore)	$1 - 4 million for a real-time transit information system $7,000 per "next stop" annunciator	Physical Factors - Provide system interface and GPS equipment on all transit vehicles. Ensure wireless communication capabilities. Institutional Factors - Coordination and integration between agencies (providing transit signs on agency owned ROW). Operational and Maintenance Factors - Maintaining accurate and reliable GPS equipment; regular software updates; staff training.
Support Transportation Demand Management (TDM) Strategies	Promote travel that reduces overall demand on the system such as: bus transit, carpool, and non-peak hour commuting.	- Improves commuter mobility - Makes travel times more reliable during peak hours - Reduces non-recurring delay for planned events - Improves freight mobility - Makes travel times more reliable during non-peak hours	Variable	Physical Factors - n/a Institutional Factors - Coordinate with employers and event managers to promote TDM strategies; public education. Operational and Maintenance Factors - staff time for public outreach.
Support Active Demand Management Strategies	Active demand management strategies include using real-time information to dynamically adjust user demand. Strategies include dynamic pricing, on-demand transit, and dynamic ridesharing.	- Improves commuter mobility - Makes travel times more reliable during peak hours - Reduces non-recurring delay for planned events - Makes travel times more reliable during non-peak hours	Variable	Physical Factors - Communication interface between agencies; real-time data collection; modeling capabilities; integration of various ITS components across agencies. Institutional Factors - Coordinate agreements and policies across agencies (state, local, transit); decision matrix. Operational and Maintenance Factors - staff management of system and training.
Infrastructure Management Strategies				
Targeted Roadway Improvements/Widening (Increasing the length of merge areas and acceleration lanes)	Construct targeted roadway improvements to meet current standards for acceleration and merge areas.	- Improves safety - Improves commuter mobility - Makes travel time more reliable during peak hours - Improves freight mobility - Makes travel time more reliable during non-peak hours	Cost is over $10,000,000	Physical Factors - Limited widening options on I-90 due to structural constraints. Institutional Factors - Possible ROW agreements with other agencies; funding. Operational and Maintenance Factors - regular roadway maintenance once constructed.
Targeted Shoulder Widening - Auxiliary Lane	Construct shoulder (right or left) to provide an extra travel lane during high demand or high congestion. The shoulder needs to meet roadway construction standards for a regular freeway traffic lane.	- Improves safety - Clears lane blocking incidents faster - Improves commuter mobility - Makes travel time more reliable during peak hours - Reduces non-recurring delay for planned events - Improves freight mobility - Makes travel time more reliable during non-peak hours	Cost is over $10,000,000	Physical Factors - Limited widening options on I-90 due to structural constraints. Institutional Factors - Possible ROW agreements with other agencies; funding. Operational and Maintenance Factors - regular roadway maintenance once constructed.

FINAL REPORT

I-90 Operations Study

May 2018

Appendix D

Implementation Plan

DKS

IMPLEMENTATION PLAN MEMORANDUM

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DATE: May 1, 2018

TO: Mike Bjordahl (WSDOT)
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FROM: Jim Peters, P.E., Principal, Project Manager
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Dennis Mitchell, P.E.

PROJECT: I-90: Four Lakes to Stateline Operations Study P16159-000

This memorandum documents the benefit cost analysis methodology, results, and recommended implementation phasing for the six strategies identified in the *Evaluation and Screening Memorandum*[1] as having the best potential to meet the needs, goals, and operation objectives of the I-90 corridor operations study.

This project seeks to find transportation system management and operations (TSMO) solutions to improve safety along the I-90 corridor between Four Lakes and the Idaho Stateline (as shown in Figure 1). TSMO strategies target improving existing infrastructure rather than building additional capacity and tend to be lower cost than larger infrastructure projects. For example, instead of building an additional lane along I-90, a TSMO-type solution might use variable speed control or a queue warning system to help improve safety and mobility.

Figure 1: I-90 Corridor Study Area

1 "Evaluation and Screening Memorandum #4, I-90: Four Lakes to Stateline Operations Study". March 24, 2017. Prepared for WSDOT by DKS Associates.

SUMMARY OF RECOMMENDED STRATEGIES

The table below summarizes the six strategies evaluated during this part of the study and the resulting benefit cost (B/C) ratio ranges of each. A benefit cost ratio greater than 1.0 indicates that the overall benefits are greater than the overall cost of the strategy. The analysis process is discussed in more detail in the *Analysis Methodology* section of this memorandum.

	Active Traffic Management Install variable message signs (VMS) and weather sensors along the freeway to provide variable speeds notifications, queue warnings, and dynamic lane management.	**4.2 to 6.3** Variable Speed System
	Ramp Metering Install ramp meters at on-ramps to manage the flow of entering vehicles, reduce crashes at merge areas, and minimize congestion on the mainline.	**5.6 to 7.9** Full System – 13 ramps
	Wrong Way Driver Notification System Install sensors on off-ramps that can detect wrong-way drivers and alert the traffic management center and travelers using VMS or, when possible, on-board navigation systems.	**1.6 to 2.8** Depending on Segment
	Traffic Incident Management (TIM) Strategies Enhance existing traffic incident management strategies by further developing TIM Teams, expanding the Incident Response, and establishing instant tow contracts.	**4.4 to 15.4** Instant Tow **3.9 to 9.1** Dedicated Responder
	Work Zone Management Implement work zone management strategies that improve safety in work zones. These strategies apply safety measures that inform drivers of work zone and worker locations, limit work zone hours, and support a range of work zone durations from long-term stationary projects to short duration or even mobile projects.	n/a
	Ramp Closures Close on-ramps or off-ramps either permanently or by time of day to reduce crashes where ramp spacing does not meet performance expectations. This study only evaluates ramp closures from the perspective of reducing crashes. ***Further evaluation in the form of an Interchange Justification Report (IJR) is necessary before proceeding with this strategy.*** An IJR would explore the traffic operational impacts, socio-economic impacts, and political factors associated with a closure. This initial evaluation is intended to determine whether further study at a location may be warranted.	**1.3 to 8.3** Permanent

ANALYSIS PROCESS AND METHODOLOGY

This section provides an overview of the analysis process and methodology that the project team used to narrow the full toolbox of strategies and then to determine the benefit cost ratios of the six strategies with the strongest potential to improve safety along the I-90 corridor.

Throughout this process, the project team held two public open houses and two stakeholder workshops seeking input. The public open houses were open to all and advertised through media sources. The two workshops targeted select stakeholders from local agencies, local businesses, and neighborhood organizations.

In addition, WSDOT held meetings with neighborhood organizations and conducted other public outreach to inform community members about this project and potential strategies, including ramp closures. For a full list of public outreach meetings, see Attachment B.

SCREENING LEVELS 1 AND 2

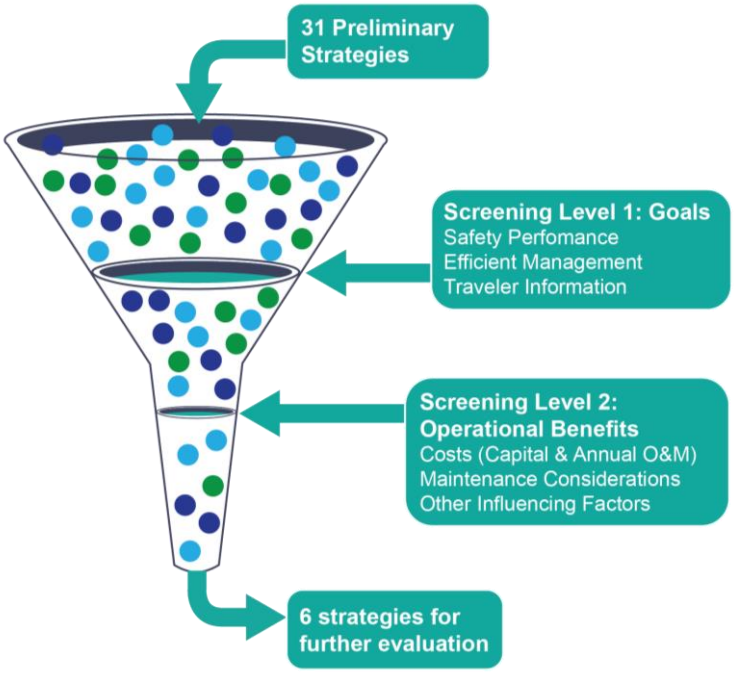
Based on the needs identified by agency staff and the study advisory group, the project team developed a toolbox of strategies to address the needs. Applying a two-level screening process, the project team then narrowed the full list of 31 strategies in the toolbox to six strategies to advance through a more in-depth benefit cost analysis.

Level 1 screening compared the strategies to the three project goals:

- Improve safety performance for all I-90 corridor users.
- Enable efficient management and operations of the I-90 corridor.
- Enhance traveler information along the I-90 corridor.

Level 2 screening focused on four additional criteria:

- Operational Benefits
- Influencing Factors (Physical Factors, Institutional Factors, Operational Factors, and Maintenance Factors)
- Implementation Cost
- Annual Operations and Maintenance Cost



The Level 1 and 2 screening processes are more fully detailed in the *Evaluation and Screening Memorandum*.[1]

BENEFIT COST ANALYSIS

This study uses a benefit cost analysis approach to compare the strategies. These next sections describe the tools and methods used to calculate annual benefits and annual costs for each of the strategies. In general, the higher the benefit cost ratio, the better. A benefit cost ratio greater than 1.0 indicates that the benefits outweigh the costs over the expected lifespan of the strategy.

Cost Components

To arrive at an annualized cost for each strategy, the project team considered three cost components:

- **Initial capital investment** – the initial cost to construct a project. This includes the equipment and software costs, as well as design and construction engineering.
- **Annual maintenance and operations** – the ongoing annual cost to maintain and operate devices, fix or calibrate equipment, allocate staff time to implement strategies such as attend meetings or work in the field during a road closure event.
- **Equipment service life** – certain components of a project may require replacement within a 25-year period. For example, detection may need to be replaced every ten years. Over 25 years, the cost of detection devices is incurred 2.5 times.

Tools for Determining Benefits

This section provides an overview of three key resources used for determining the benefits of each strategy.

Crash Modification Factors

Crash modification factors (CMFs) are used to determine the effect a specific countermeasure will have on future crashes at a given location or along a corridor. The CMF Clearinghouse is an online searchable database of CMFs and can be accessed here: http://www.cmfclearinghouse.org/index.cfm. The CMF Clearinghouse uses a five-star rating system to indicate a level of confidence in the study that produced the CMF. The star rating is based on study design, sample size, standard error, potential bias, and data source. CMFs used in this analysis were all rated three-stars, or better.

In many cases the CMF targets a specific type of crash, severity, or type of facility. When calculating benefits for a strategy at a specific location, it is important to ensure that the CMF is applied to those same types of crashes and severity categories. For example, if a countermeasure has a CMF that reduces fatal crashes by 20 percent, and the location where it is being applied had an annual average of five fatal crashes and 15 non-fatal injury crashes, the benefit from that CMF would be the reduction of one fatal crash per year. That CMF would not apply to the non-fatal crashes.

In general, when two countermeasures are being applied to a location, the CMFs are not additive. For example, if both variable speeds and ramp metering are installed along a freeway segment, either the CMF

related to variable speeds or the CMF related to ramp meters should be used, but not both. The only condition in which two (or more) CMFs might be used for combined countermeasures is when the CMFs each target different types of crashes or severity of crashes at a given location. Even then, however, judgement should be applied to minimize any sort of exaggerated additive benefit from using more than one CMF.

Benefits Associated with Crash Reduction

WSDOT associates a specific cost with each type of crash severity (see Table 1). By combining the cost associated with crash severities with the ability for each strategy to uniquely reduce crashes (such as the crash modification factors described in the previous section), the project team calculated benefits for each strategy.

Table 1: WSDOT Crash Severity Costs

Crash Severity	Associated Cost (WSDOT)
Fatal	$2,900,000
Disability Injury	$2,900,000
Evident Injury	$155,000
Possible Injury	$60,000
Property Damage Only (PDO)	$10,000

These crash costs are applied to the crashes that each strategy can reduce. In some cases, the same number of crashes are reduced, but the value of the benefit is different. This difference in benefits is due to the actual severity distribution of crashes at a given location. For example, a strategy might reduce 10 percent of all crashes at a location. In location A, there are 50 crashes that resulted in PDO, whereas in location B there were 50 crashes that resulted in fatalities. This is an extreme example, but demonstrates the difference in calculated benefit when crash severity is considered. In both cases the strategy reduces 5 crashes (a 10 percent reduction from 50), but the calculated benefit for each location is significantly different:

- Location A: 5 x $10,000 = $50,000
- Location B: 5 x $2.9 million = $14.5 million

Again, this is a simplified example. Some strategies may only target certain types or severities of crashes. For example, a queue warning system reduces the more severe rear end crashes that result in an injury, however, the same strategy may increase rear end crashes that result in property damage only. The benefits calculated in this report represent the actual allocation of crashes on a segment of I-90 and how the strategy could help reduce those crashes.

Tool for Operations Benefit Cost Analysis (TOPS-BC)

The Tool for Operations Benefit Cost Analysis (TOPS-BC) was created by the FHWA Office of Operations as a sketch-planning analysis tool for TSMO related strategies. It is meant to provide preliminary screening and initial prioritization of TSMO strategies. The TOPS-BC tool provides four key functions:

1. Allows users to look up the expected range of TSMO strategy impacts based on a database of observed impacts in other areas nationally and internationally.

2. Provides guidance and a selection tool for users to identify appropriate benefit/cost methods and tools based on the input needs of their analysis.
3. Provides the ability to estimate life-cycle costs of a wide range of TSMO strategies.
4. Allows for the estimation of benefits using a spreadsheet-based sketch-planning approach and comparison with estimated strategy costs.

As a sketch-planning-level tool, TOPS-BC allows users to quickly understand typical benefits for a range of TSMO strategies and then estimate the benefit-cost ratio of those TSMO strategies. The tool also provides a suggested list of analysis tools for TSMO strategies depending on user-selected criteria such as the level of confidence required, which TSMO strategies are being investigated, key measures of effectiveness, and a few other filters.

Traffic Incident Management Benefit-Cost Tool

The Federal Highway Administration Office of Operations Research and Development also created a benefit cost estimation tool for traffic incident management (TIM) strategies.[2] The tool incorporates benefits derived from reduced delay, reduced emissions, and reduced secondary crashes. This analysis used Version 2, which focuses on eight of the most cost effective and commonly used TIM strategies. For the I-90 corridor, the project team used this tool to evaluate the first two strategies, **indicated in bold**:

- **Safety Service Patrols (Dedicated Incident Responder)**
- **Pre-established Towing Service Agreements (Instant Tow)**
- Driver Removal Laws
- Authority Removal Laws
- Shared Quick-Clearance Goals
- Dispatch Collocation
- TIM Task-Forces
- SHRP2 Training

ANALYSIS METHODOLOGY FOR EACH STRATEGY

This section provides an overview of how the project team calculated benefits for each of the six strategies.

Ramp Metering

Crash Reduction Benefits

For ramp metering, the project team applied a crash reduction factor of 36 percent[3] to all crashes near the on-ramp location. For each on-ramp analyzed, the crashes were mapped in GIS. The study that identified the 36 percent reduction defined the ramp functional area as 525 feet upstream and downstream from the ramp entry point and looked at all crash types within that physical area (mainline only). The study also suggests using site-specific information to determine analysis extents in lieu of the 525-foot blanket. For the I-90 study, the 525-foot extents were used at most locations, while crash patterns and roadway characteristics where used to determine the extents at locations where the 525-foot blanket did not accurately capture the situation.

[2] TIM BC Tool website: https://www.fhwa.dot.gov/software/research/operations/timbc/
[3] CMF ID = 5436 (three star). Liu, C. and Wang, Z. “Ramp Metering Influence on Freeway Operational Safety near On-Ramp Exits”. June 2013.

The project team analyzed hourly volume data by lane to determine how many hours the ramp metering system would operate on a typical weekday. While occupancy data is typically used to determine when ramp metering is appropriate, occupancy data was not available for I-90. Instead, volume data was roughly correlated to occupancy data. A volume threshold on I-90 of 1,400 vehicles per hour per lane was used as an indicator to determine which hours of the day may warrant ramp metering. Based on that threshold, the system may operate six hours (or more) during a typical weekday.[4]

The benefits analysis incorporated the volume data by filtering the crashes to those during the peak six hours of daily operations. A 36 percent reduction factor was then applied across all the crashes in the ramp vicinity.

Additional Ramp Metering Benefits

In addition to crash reduction benefits, when ramp metering is installed along consecutive ramps there are also fuel savings and reduced delay benefits. Three of the four options (A, B, and D) included a section of consecutive ramp meters. For these three options, the project team estimated the reduction in delay and fuel savings using the TOPS-BC tool. The TOPS-BC tool used a default of 8 percent reduction in delay and a 10 percent reduction in fuel use. While that level of benefit is likely along corridors that begin with high levels of congestion, a more moderate improvement is likely achieved along this segment of I-90. To provide a conservative estimate of benefits, those values were modified to a 4 percent reduction in delay and a 3 percent reduction in fuel use.

Active Traffic Management (ATM)

Crash Reduction Benefits – Variable Speeds

For active traffic management, the focus of the crash reduction evaluation was the variable speed component. Based on a four-star study in the CMF Clearinghouse[5], a variable speed system along an urban freeway can reduce all crashes by 8 percent. The variable speed component focused on the section of I-90 east of the US-2 interchange to Broadway interchange. An 8 percent reduction was applied to all crashes through this section.

Crash Reduction Benefits – Queue Warning and Dynamic Lane Management

In addition to variable speeds, an ATM structure can also be used for dynamic lane management, queue warning, and general traveler information using variable message signs (VMS).

In the case of a queue warning system, the CMF Clearinghouse provides two studies that document benefits. One study identifies a 16 percent decrease in rear-end crashes that result in serious or minor injuries. The second study notes a 16 percent *increase* in rear-end crashes that result in property damage only.[6] These studies provide some insight that a queue warning system helps reduce higher severity rear-end crashes, but may increase the lower severity rear-end crashes.

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[4] Six hours of operation is based on volumes during summer months in 2016, which is when volumes peak. During other times of the year the ramp meters may be activated for shorter periods.

[5] CMF ID= 3340 (four star). Bham, G. H., Long, S., Baik, H., Ryan, T., Gentry, L., Lall, K., Arezoumandi, M., Liu, D., Li, T., and Schaeffer, B., "Evaluation of Variable Speed Limits on I-270/I-255 in St. Louis." RI08-025, Missouri University of Science and Technology, Rolla, MO., (2010).

6 CMF IDs = 76 and 77. Study: Elvik. R, and Vaa, T. Handbook of Road Safety Measures. 2004.

For dynamic lane management, there are no established CMFs for this application. Based on an implementation in California from SR-110 to I-5, there was an overall reduction in crashes, but also some challenges to consider[7]:

- Compliance with dynamic lane closure ranged from 15–38 percent.
- California project used in-pavement lighting system which did not work properly.

The benefits documented in this I-90 study focused solely the queue warning system. If dynamic lane management is added in the future, benefits could increase.

Wrong Way Notification System

Crash Reduction Benefits

There is no established CMF for the wrong way notification system. Several studies document benefits for specific installations. In San Antonio Texas, a recent study identified a 30 percent reduction in wrong way crashes, and in Rhode Island a recently installed wrong way notification system provided a 100 percent reduction (it was activated 66 times, but not a single crash resulted, indicating that drivers could turn around after the notification system activated). Based on this information as well as successful implementations in other states, a 30 percent reduction factor was applied to the wrong way crashes on this corridor.

Traffic Incident Management

For the traffic incident management strategies, the project team used the FHWA web-based TIM BC tool for the evaluation. For this analysis, the project team reviewed incident data from 2011 to 2015 (five years) to determine the overall frequency and proportion of lane blocking incidents and clearance times.

For both the instant tow and additional dedicated responder strategies, the following assumptions apply:

- Operating area = full length of the study area (30 miles)
- Allocation of incident duration by blockage type:
  - Shoulder blockage duration = 10 minutes
  - One lane blockage = 15 minutes
  - Two lane blockage = 35 minutes
- Strategy applies during weekdays and weekends, peak and non-peak hours
- Percent of estimated secondary incidents[8] = 10 percent

Instant Tow Assumptions

For the instant tow analysis, the project team used the following assumptions:

[7] Presentation by Marco Ruano. Active Traffic Management in Los Angeles. January 15, 2014

[8] Note: Study showed that for every minute a primary incident continues to be a hazard, the likelihood of a secondary incident increases by 2.7% - Karlaftis et al Study, 1999.

- Proportion of all lane blocking incidents that could be improved by instant tow = 90 percent (suggested default is 100 percent)
- Compliance rate = 90 percent (suggested default is 100 percent)
- Average shortened incident duration = 2 to 5 minutes (suggested default is 10 percent)

Additional Dedicated Responder Assumptions

For the additional dedicated responder analysis, the project team used the following assumption:

- Average incident duration savings (suggested default is 20 minutes) = 3 to 5 minutes (range). Since WSDOT already has two dedicated responders, the benefit of adding a third is incremental and would not reduce incidents by the full suggested 20 minutes. A conservative estimate of 3 to 5 minutes still provides a benefit cost ratio well above 1.0.

Ramp Closures

The ramp closure analysis focused solely on the ability to reduce crashes at select ramps and weave or merge areas. There is no documented crash reduction factor for a ramp closure. To evaluate this strategy, the project team first determined the baseline crash rate on I-90 along segments with spacing between ramps that better meet performance expectations (i.e., longer spacing between interchanges). The three segments with longer spacing used to calculate this baseline crash rate for the mainline included:

- US 2 interchange to US 195 interchange
- Argonne interchange to Pines interchange
- Sullivan interchange to Barker interchange

Using GIS software, crashes near the analyzed ramps were categorized as occurring on either a ramp or the I-90 mainline. The project team then developed crash rates for the mainline crashes. If a ramp is closed, the crashes that occur on the ramp itself are eliminated. For mainline crashes at a potential ramp closure, the crashes were compared to the baseline crash rate (based on the three segments listed above) and reduced to that rate if it was less than the existing crash rate.

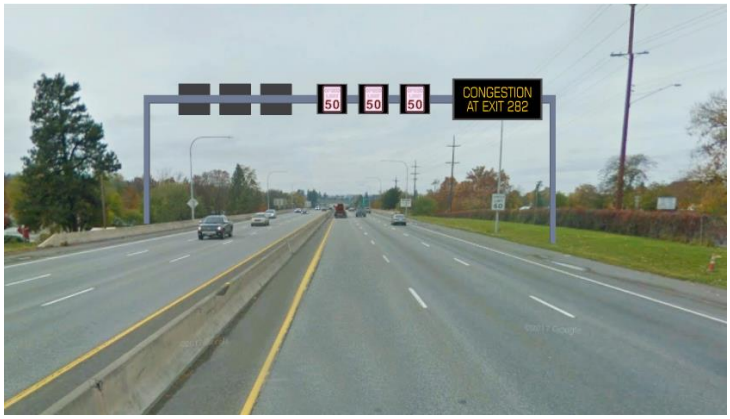
The crash reduction benefits were calculated based on the actual severity distribution of crashes reduced at each potential ramp closure location.

This methodology does not account for the potential to increase crashes elsewhere due to redistributed traffic or other economic impacts of closing ramps.

ANALYSIS RESULTS

This section documents the benefit cost results for each of the strategies. Most of these strategies can be deployed together for added benefits. If strategies are applied collectively, the overall benefits will likely increase, but benefits are not cumulative. Similarly, costs may decrease due to shared infrastructure and resources. For a detailed list of benefits and cost results for each strategy, see Attachment A.

ACTIVE TRAFFIC MANAGEMENT (ATM)



Active Traffic Management (ATM) uses a combination of operational strategies to optimize the existing infrastructure and improve safety. On I-90 the primary strategies include a variable speed system, queue warning, travel times, and dynamic lane control.

Speed and lane control information are conveyed to travelers using signs installed over each lane. The system could also provide weather, travel time, and queue warning information to travelers based on real-time measured conditions using full matrix Variable Message Signs (VMS).

Analysis Results and Summary

<table>
<tr><th colspan="2">Average Annual Benefit</th><th colspan="2">Average Annual Cost</th><th>B/C Range</th></tr>
<tr><td colspan="2">$6,000,000
(variable speed system benefits only))</td><td colspan="2">$1,200,000</td><td rowspan="4">4.2 to 6.3*
(Benefits due to the Variable Speed System)

*Additional benefits possible if the system is also used for queue warning or traveler information</td></tr>
<tr><td colspan="2" rowspan="3">Crash Reduction
Variable Speed System = 8% crash reduction, potential to reduce approximately 100 crashes per year through the proposed project limits, see Figure 2 (CMF ID 3340).

Queue Warning System = 16% rear-end crash reduction resulting in injuries (CMF ID 76).

16% increase in rear-end crashes resulting in PDO (CMF ID 77)

Dynamic Lane Management = no established CMFs.</td><td colspan="2">Capital cost elements include infrastructure, detection, communications, and software enhancements</td></tr>
<tr><td>Initial Capital Cost
$24,000,000
(full system – 10 gantries)

$1,000,000 to $2,500,000 per gantry if installed individually</td><td>Annual O&M
$105,000</td></tr>
<tr></tr>
</table>

Other Considerations

While the full cost of the ATM strategy is greater than available funds, it may be constructed in phases with a focus on addressing the most critical areas first. In cases where the added benefits of dynamic lane control are not warranted, using post-mounted variable speed signs is a lower cost option. However, driver compliance with post-mounted signs may be lower than with overhead signs. The costs in this study assume gantry style structures with signs over each lane.

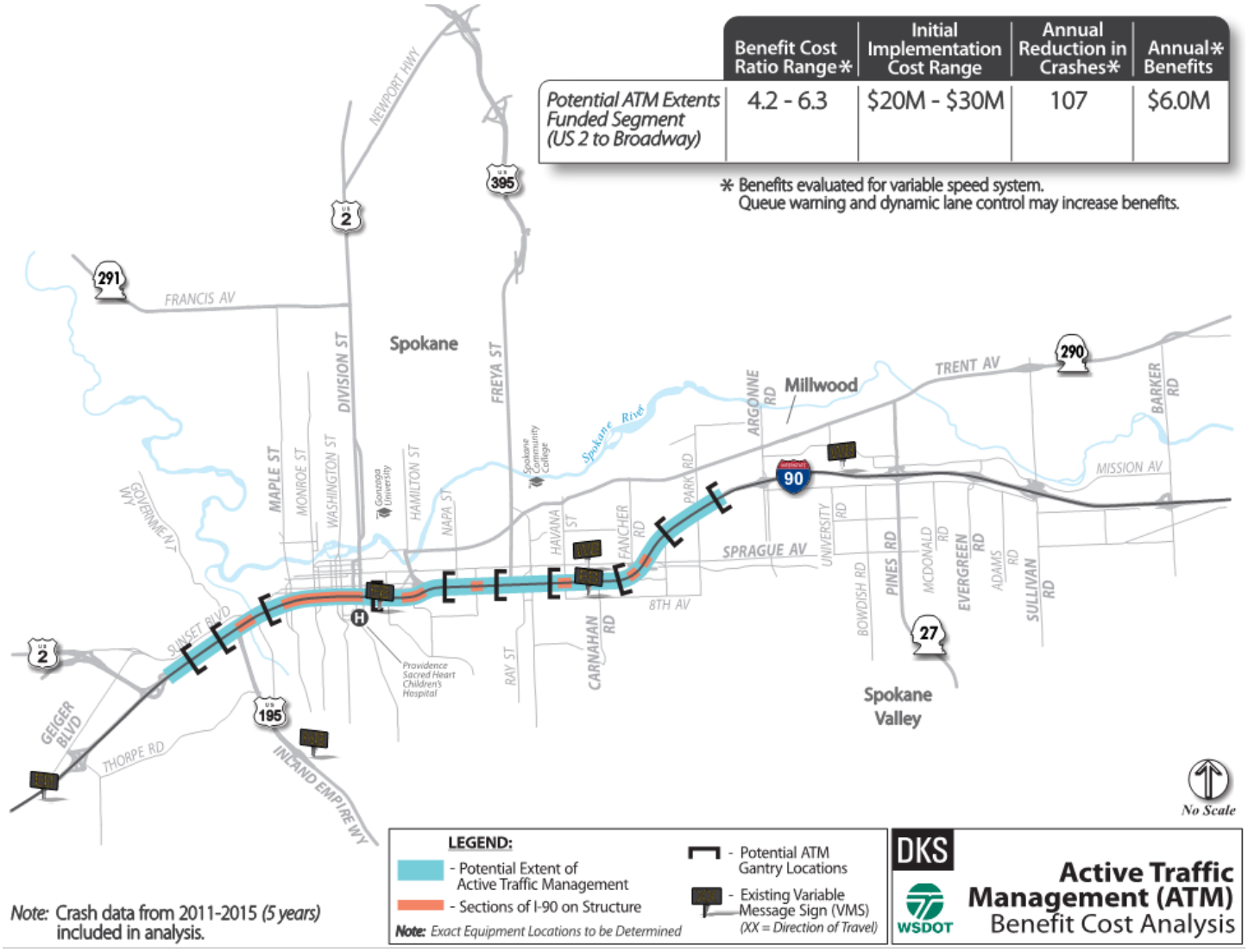


Figure 2: Proposed ATM System

I-90 and US-195 Merge Area

The merge from US-195 northbound to I-90 eastbound is short, creating a safety and operational hazard for travelers through this area. Currently, there is a guide sign about a ¼ mile in advance of the merge and a static warning sign with flashing beacons just prior to the merge that is activated by traffic on the on-ramp. Both signs are intended to alert motorists and encourage use of the left lane for through traffic. See pictures in Figure 3.

Figure 3: Existing Merge Area Treatment

To improve the safety and operations through this merge area, different components of an ATM system could be implemented:

- Improved variable message signs
- Dynamic lane management

Improved Variable Message Signs

In advance of the US-195 merge with eastbound I-90, variable message signs (VMS) could be used to actively warn through travelers to move to the left lane when there is traffic on the US-195 on-ramp. These VMS could be placed upstream of the merge either on their own sign structure or on existing overpasses, which may reduce the construction cost. Instead of the current static signs, these VMS could activate based on the US-195 on-ramp volumes. VMS, compared to the current static signs, could better catch the attention of drivers and more effectively encourage drivers to use the left lanes through the merge area, leaving the right lane open for traffic from US-195.

Dynamic Lane Management

Dynamic lane management is another option for improving safety and operations at the merge area. The VMS in the previous option encourages drivers to move left, while dynamic lane use would ***require*** drivers to use the lanes as directed.

In addition to using ATM structures for variable speeds, the structures could also be used for dynamic lane management and queue warning. At the I-90 and US-195 merge area, dynamic lane management and ramp metering could work in conjunction to reduce crashes during both peak and non-peak hours. Ramp metering could operate during peak hours. During non-peak hours, dynamic lane management could close the right-most traffic lane on I-90, providing a dedicated entry lane for traffic from US-195 as depicted in Figure 4.

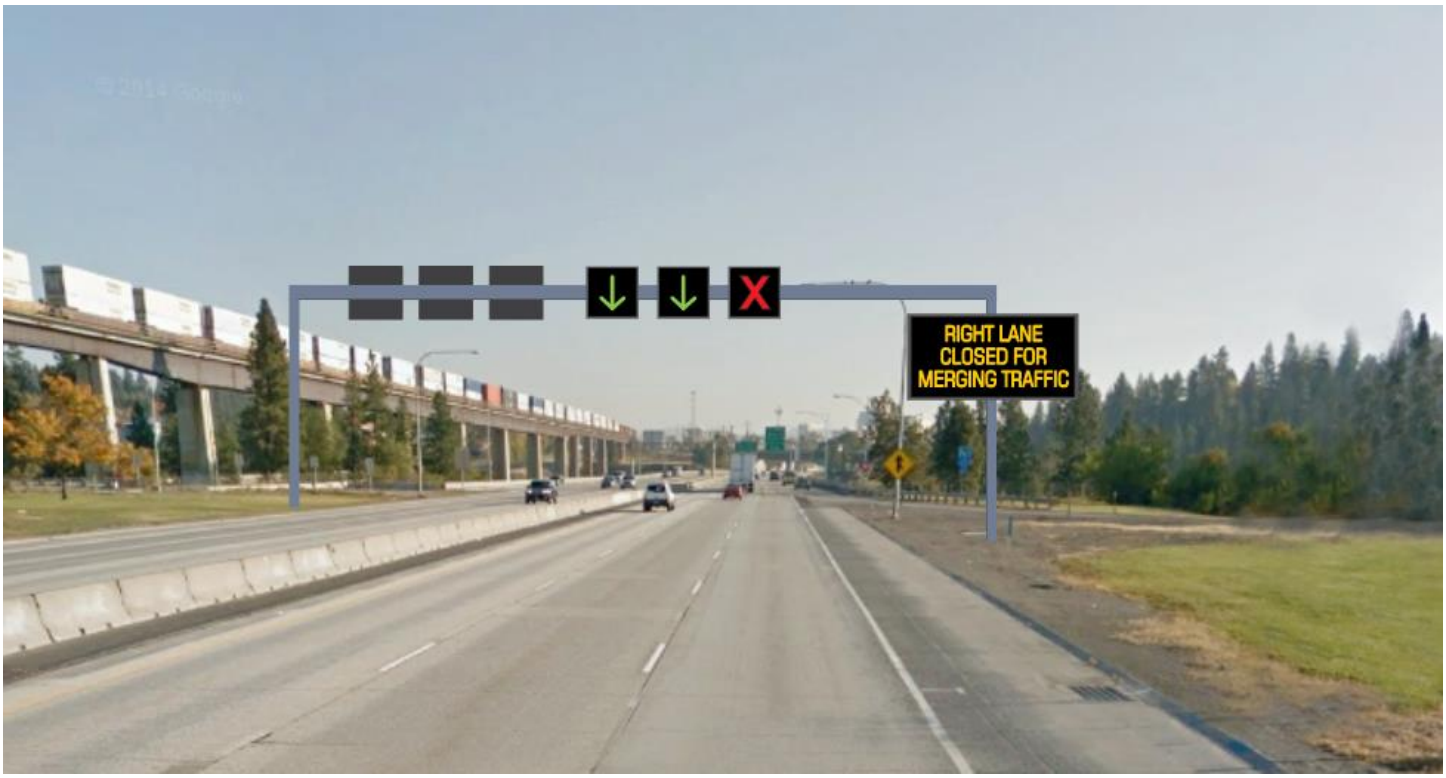


Figure 4: Picture depicting potential dynamic lane management at the I-90 and US-195 merge area

At this location, 44 percent of the crashes occur during non-peak hours and may be reduced using dynamic lane management as shown in Figure 4. During peak hour traffic volumes, the ramp meter would likely operate and could target a reduction in the remaining 56 percent of crashes.

In Figure 5, the crashes associated with the merge area and the US-195 on-ramp are graphed by time of day and overlaid with the average hourly traffic volume per two lanes. At this location, there are three lanes of eastbound traffic. However, to show when two eastbound lanes are adequate, the figure displays vehicles per lane assuming two instead of three lanes (the total volume is divided by two instead of three). Traffic volumes approaching 1,400 vehicles per lane per hour represent congested conditions and indicate that a third lane is necessary to handle the volume. The highlighted segments on the graph indicate when the dynamic lane management could close the right-most lane without adversely affecting upstream traffic.

Based on volume data collected at a permanent traffic recording station just west of the US-195 merge on I-90, the right-most lane could be closed during non-peak hours, as shown in Figure **5**, without negatively impacting upstream traffic.[9] Three lanes are necessary during peak hours.

The volumes graphed in Figure 5 are an average of weekdays during the summer of 2016. Based on annual traffic counts, as shown in Figure 6, traffic volumes are highest in the summer. Summer traffic volumes are roughly eight percent higher than the average daily traffic volumes throughout a year, indicating that the

[9] PTR Station 118. Weekday traffic volumes from June-Aug 2016.

volumes shown in Figure 5 are representative of the highest volumes throughout the year. During other times of the year, it's possible the right lane could be closed for more hours during the day.

With dynamic lane management, it is important to understand the traffic volumes. While this strategy may work under current traffic volume conditions, growth may limit the ability to close a lane in the future.

If dynamic lane management is selected, a series of dynamic lane use signs would need to be installed, both upstream as well as one downstream of the I-195 merge. In the future, if volumes grow to the point where a lane closure is not feasible, the ATM structures could be used for variable speed system signs, which become more relevant as congestion increases. The same ATM structure could be used for either the dynamic lane use strategy or the variable speed system. Depending on VMS design preference, it is feasible for the two systems to use the same VMS.

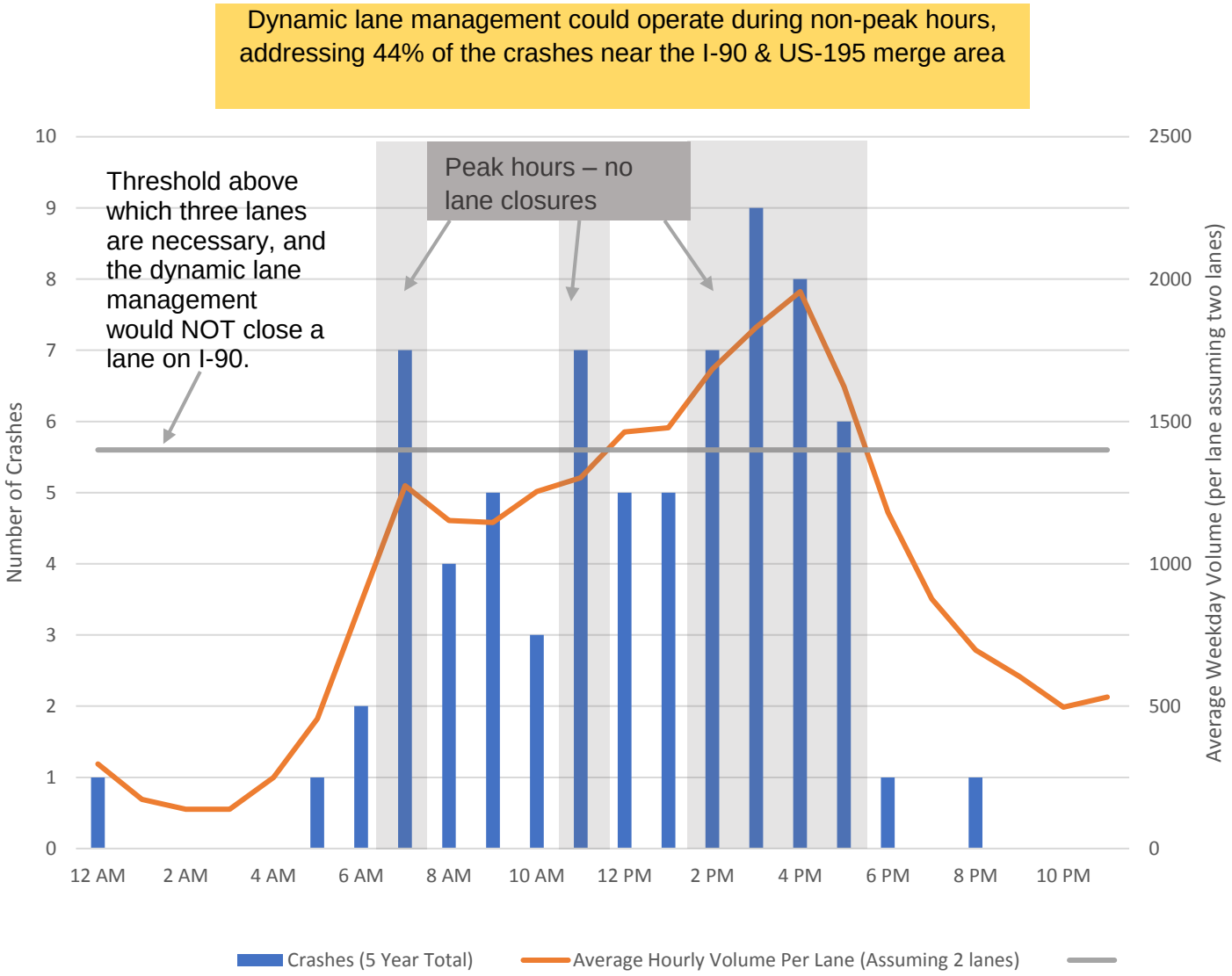


Figure 5**: Eastbound Traffic Volumes on I-90 West of the US-195 Merge Area and Eastbound Crashes in the I-90/US-915 Merge Vicinity** (Crash data: 2011-2015, ADT: 2016 June-Aug)

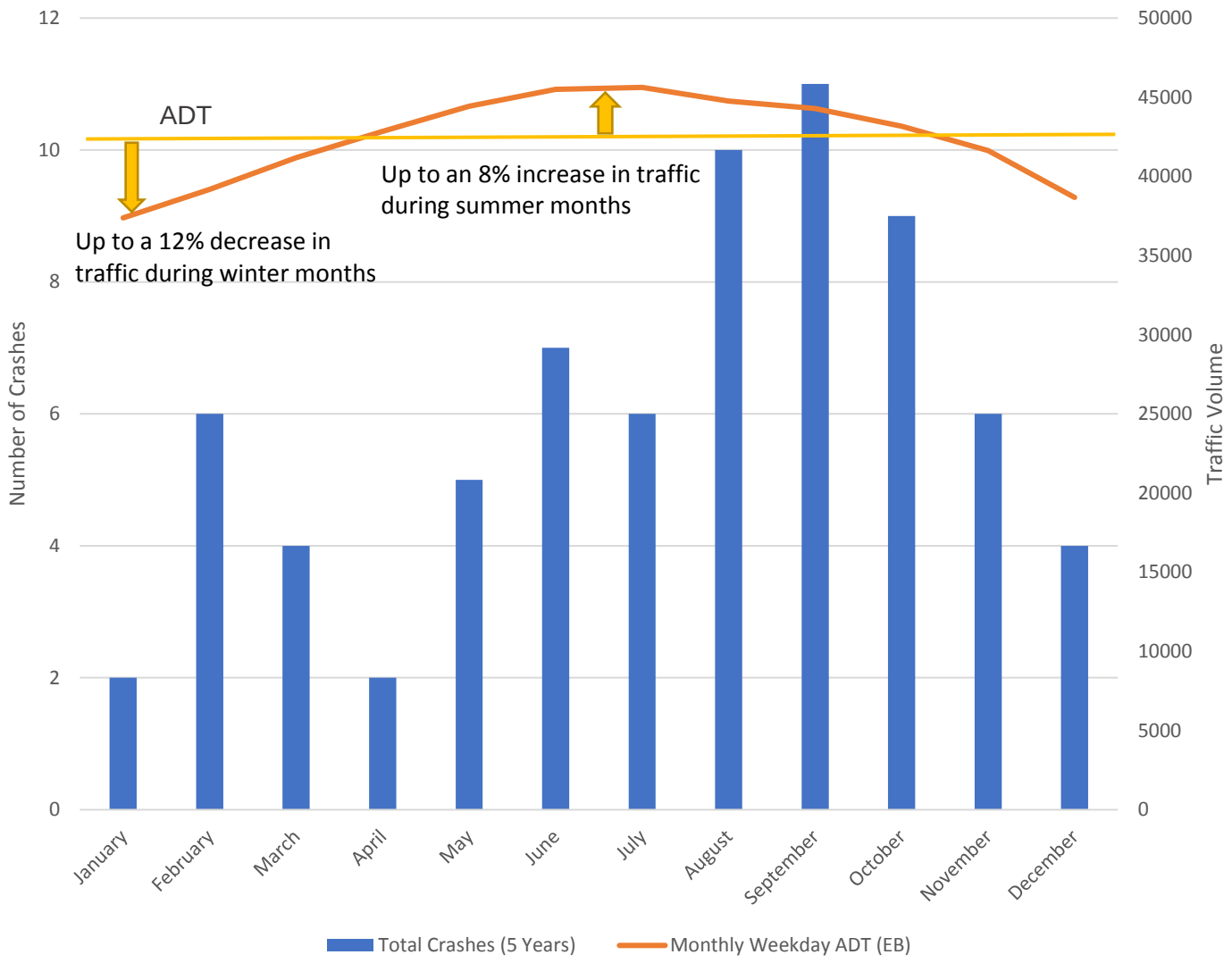


Figure 6: Eastbound Crashes and Average Weekday Traffic Volumes on I-90 near the US-195 Merge Area by Time of Year (Crash data: 2011-2015, ADT: 2016)

RAMP METERS

System overview

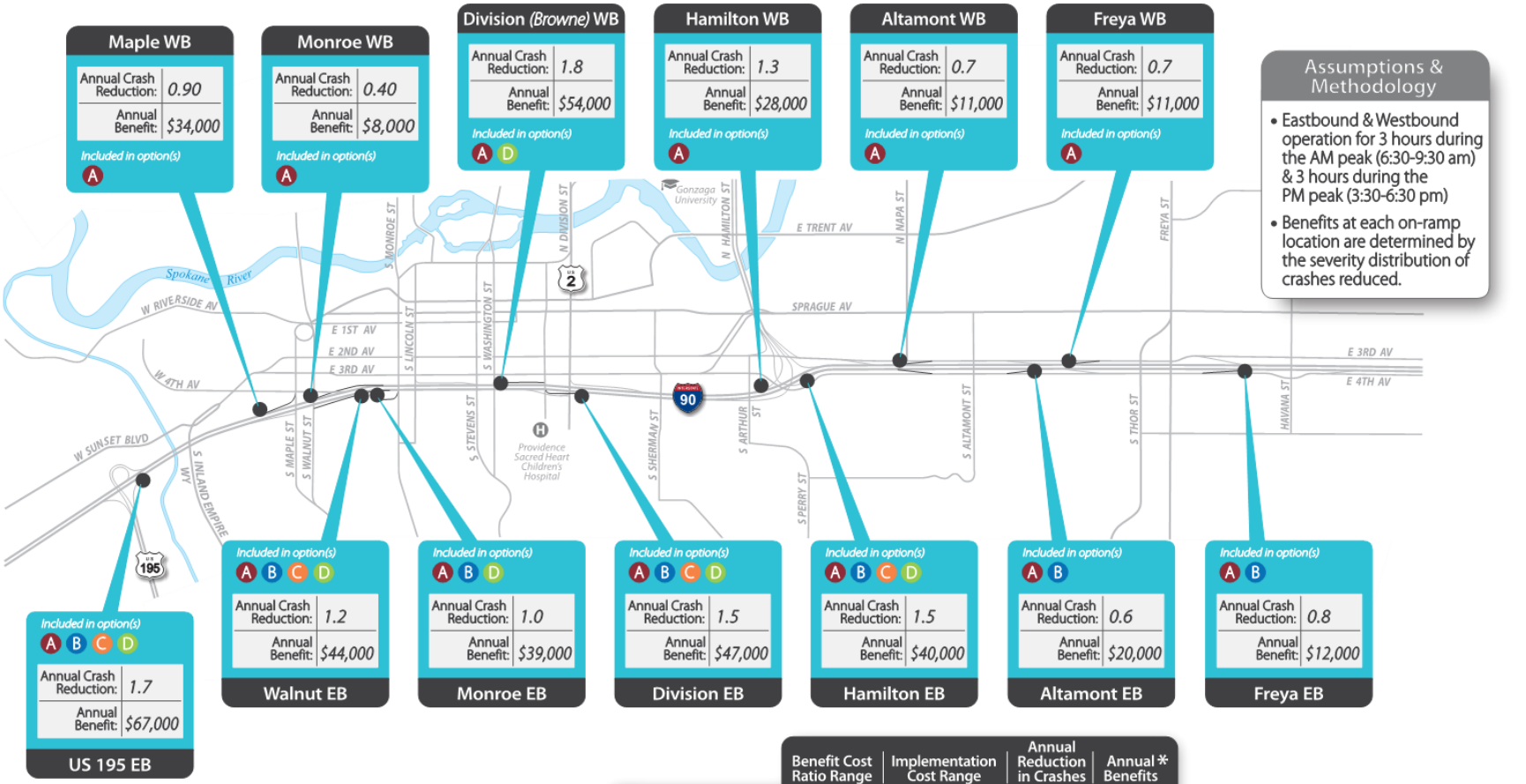
Traffic signals on freeway ramp meters alternate between red and green to control the flow of vehicles entering the freeway. Metering rates can be adaptively altered based on freeway and on-ramp traffic conditions. Since benefits are increased when installed in groups rather than in isolated installations, ramp metering is recommended on a corridor-wide basis. Ramp metering, when implemented at warranted locations, provides safety and operational benefits that range from improved vehicle throughput and speeds to reduced crashes in the merge zone and upstream of the merge zone, and reduced vehicle emissions and fuel consumption. This strategy evaluated ramp meters at 13 locations as shown in Figure 7. The options listed in that figure show some potential implementation phasing and associated costs and benefits.

Analysis Results and Summary – Option A (all 13 on-ramps)

Average Annual Benefit	Average Annual Cost		B/C Range
$1,775,000	$270,000		**5.6 to 7.9** (13 on-ramps through downtown core)
Crash Reduction: Applying a CRF of 36% (CMF ID 5436), ramp meters installed at all 13 locations shown in Figure 7, have the potential to reduce 14 crashes per year. Additional benefits include reduced delay and fuel use.	Capital cost elements include comm./power, controller/cabinet, ramp meter signal, detection, advance signs, and ATMS software upgrade		
	Initial Capital Cost $3,500,000	**Annual O&M** $55,000	

Other considerations

Benefits are likely underestimated, as ramp meters can work in conjunction with other strategies, including ATM and a Wrong Way Notification System. The benefits calculated for this study assume ramp meters are active during peak hours. If ramp meters are activated during other incidents or events, the scale of benefits will increase.



OPTIONS	Benefit Cost Ratio Range	Implementation Cost Range	Annual Reduction in Crashes	Annual * Benefits
A All Ramps	5.6 - 7.9	$2.8M - $4.4M	14.0	$1.8M
B All EB Ramps	4.5 - 6.1	$1.8M - $2.8M	8.3	$980,000
C Select EB Ramps with Greatest Benefit	1.7 - 2.2	$1.3M - $2.0M	5.9	$285,000
D Ramps Selected for Phase 1 Implementation	2.1 - 2.9	$1.5M - $2.3M	8.7	$400,000

* Annual Benefits include reduced crashes as noted for individual ramps as well as system-wide benefits from reduced delay and reduced fuel use.

Note: Crash data from 2011-2015 *(5 years)* included in analysis.

No Scale

DKS WSDOT **Ramp Meters** Benefit Cost Analysis

Figure 7: Ramp Meter Benefit Cost Results

Ramp Queueing

Vehicle queuing from on-ramps to adjacent roadway faciltities is another consideration. The project team conducted a preliminary analysis of vehicle queuing to determine if adequate storage is an issue at any of the potential ramp meter locaitons. Using peak hour volumes, maximum ramp metering rates, and assuming a steady flow of traffic (not fluctuations over the peak hour), all of the evaluated ramps provide adequate storage.

However, ramp metering rates are intended to vary based on traffic volumes on I-90. As traffic volumes on I-90 increase, the metering rate at on-ramps can decrease, slowing the rate in which vehicles are added to the freeway system. At the eastbound Division on-ramp location, which has two storage lanes, there is little flexibility in the ramp metering rate before the vehicle queue begins to spill back onto local roadways. At locations with potential to queue, there are different ways to approach the issue which will be further explored in the operational concept. Some options to consider include flushing the vehicle queue before it spills onto local roadways, limiting the minimum ramp metering rate at the location, or creating additional storage space.

Table 2 shows the on-ramps with the highest concern of vehicle queues spilling back to local roadways. Maximum remcommended metering rates are 1400 vehicles per hour for a dual lane on-ramp (alternating lanes), and 900 vehicles per hour for a single lane on-ramp. Most of the ramps have a degree of flexibility in decreasing metering rates without concern for vehicle queue spillback. The eastbound Division on-ramp has the least amount of flexibility, and measures to address this issues will be explored during the Operational Concept phase of the project.

Table 2: Evaluation of On-Ramps with Highest Vehicle Queuing Concerns

On-Ramp	Hour	Volume	Storage Length*	Number of Lanes	Maximum Meter Rate (vehicles per hour)	Vehicle Queuing?	Minimum Meter Rate Without Exceeding Available Storage (vehicles per hour)
EB Walnut	AM	1020	900	2	1400	No	1000
WB Freya	PM	700	175	1	900	No	700
WB Freya	AM	730	175	1	900	No	725
EB Freya	AM	640	175	1	900	No	650
EB Altamont	PM	450	175	1	900	No	450
WB Division	PM	700	700	1	900	No	700
EB Division	PM	1360	1650	2	1400	No	1350

*Total linear length available for vehicle storage

At the EB Division on-ramp, the difference between the maximum metering rate and the minimum rate is only 50 vehicles per hour. The operations of this ramp will need to be explored during the Operational Concept phase prior to installing.

WRONG WAY DRIVER NOTIFICATION

System overview

While wrong way driving (WWD) crashes are infrequent, accounting for less than one percent of the crashes on I-90 (nine crashes total between 2011 and 2015), when wrong way crashes do occur, the results are severe. Data shows that wrong way collisions have a 12 to 27 percent higher fatality rate than other types of crashes.[10] Wrong way driver crashes on I-90 resulted in three fatalities, or 38 percent of the total fatalities along the corridor. All nine of the wrong way crashes on I-90 over the study period are shown in Figure 9.

Looking closer at data from the Washington State Patrol (WSP) system, data from 2017 indicates that far more WWD events occur than are reported in the crash database, since not all WWD events result in a crash.[11] In 2017, 21 WWD events were reported to WSP within the I-90 study area. One of which resulted in a fatality, while the other 20 WWD incidents resolved without a crash. The higher than reported number of WWD events in the crash database, combined with the potential to result in severe crashes, reinforce the need to address this issue.

Installing a wrong way driver alert system on off-ramps can detect wrong way drivers, activate signs to help deter the wrong way driver, and send a notification to the TMC and law enforcement. By notifying the TMC and law enforcement, operators and police officers can monitor the car's movement using cameras, send messages to VMS or drivers with on-board systems, and close the facility for right way drivers downstream.

Figure 8 shows some examples of the WWD detection and notifications options. The top image is a prototyped from the Arizona DOT and shows how the system can interact with VMS, other ramp meters, and notifying law enforcement and traffic operators. The bottom image depicts a few options to deter a wrong way driver: different activated wrong way signs, and even in-pavement illumination (Option C in the figure).

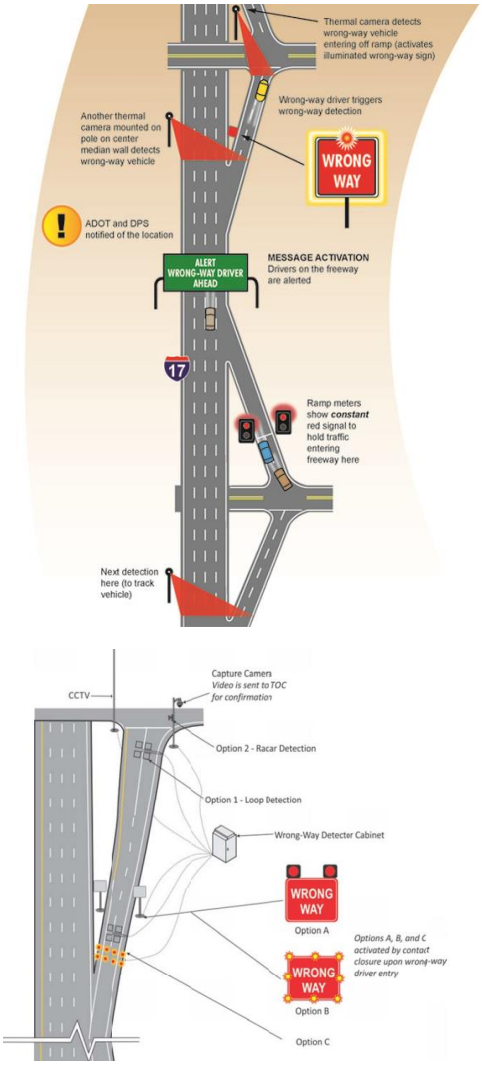


Figure 8: Examples of WWD Solutions

[10] Highway Special Investigation Report: Wrong-Way Driving. National Transportation Safety Board. NTSB/SIR-12/01. PB2012-917003. Adopted Dec 11, 2012.

[11] Washington State Patrol, Research, Analysis, and Mapping (RAM). APA 19: 2017 Wrong Way Incidents on I-90 (MP 279-299). Prepared Jan 8, 2018.

Analysis Results and Summary

<table>
<tr><th>Average Annual Benefit</th><th colspan="2">Average Annual Cost</th><th rowspan="2">B/C Range</th></tr>
<tr><td>$890,000 (full corridor)
$350,000 (funded segment)</td><td colspan="2">$410,000 (full corridor)
$180,000 (funded segment)</td></tr>
<tr><td rowspan="2">Crash Reduction: Applying a CRF of 30%, wrong way driver notification reduces wrong way incidents, which tend to be high severity, by 0.5 crashes per year.

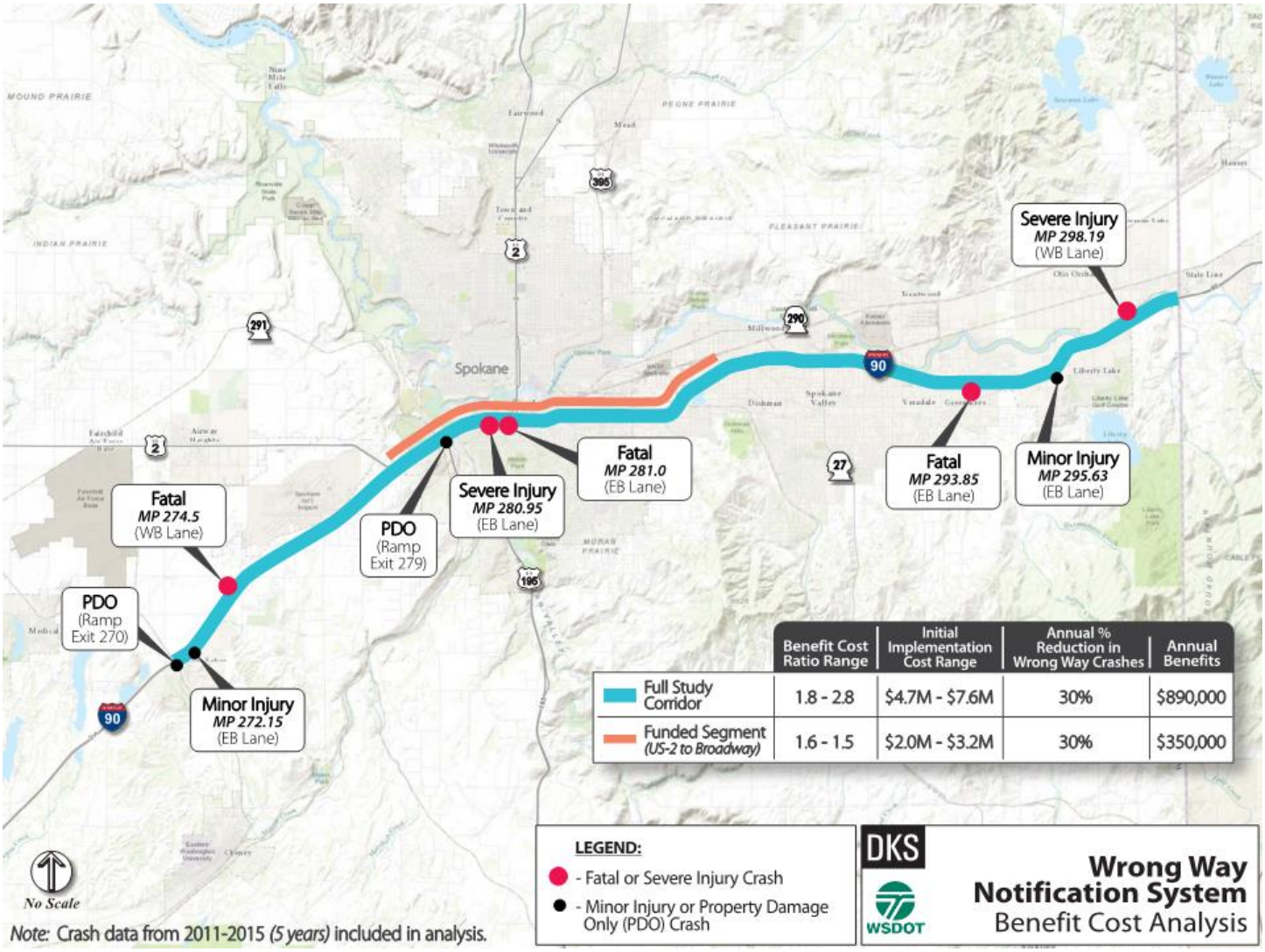
Historically, wrong way crashes comprise 38% of all fatal crashes on I-90.</td><td colspan="2">Capital cost elements include communication, power, off-ramp detectors, mainline detection, activation signs, additional VMS, and software enhancements to the ATMS.</td><td rowspan="2">1.8 to 2.8
(full corridor)

1.6 to 2.5
(funded segment)</td></tr>
<tr><td>Initial Capital Cost
$6,200,000 (full corridor)
$2,600,000 (funded segment)</td><td>Annual O&M
$10,000 to $20,000</td></tr>
</table>

Other Considerations

The wrong way notification system works in conjunction with ATM by providing the ability to post messages alerting travelers if a wrong way driver is present, as well as linking to ramp meters and turning upstream ramp meters red preventing drivers from entering the freeway. Addtionally, the geometry of each interchange should be reviewed to determine if some off-ramps have design elements that make drivers more prone to entering the freeway traveling the wrong direction.

One challenge to installing a wrong way notication system is determining where drivers are accessing the freeway the wrong way. To address this challenge, wrong way notification treatement could be incorporated in the design of off-ramps moving forward and applied systemically. Crash data reports where the crash occurred, not where the driver accessed the freeway. In some cases the crashes are reported in the news and there may be further investigation or documentation about where the driver accessed the system, but more commonly that information is lacking. Without knowing where vehicles are accessing the system the wrong way, it is difficult to prioritize installation. One option is to install the wrong way system in phases, with the first phase focused on detection and collecting data on where wrong way drivers access I-90. Then the detection data can be reviewed and more advanced wrong way notification equipment and systems installed at targeted locations.



	Benefit Cost Ratio Range	Initial Implementation Cost Range	Annual % Reduction in Wrong Way Crashes	Annual Benefits
Full Study Corridor	1.8 - 2.8	$4.7M - $7.6M	30%	$890,000
Funded Segment (US-2 to Broadway)	1.6 - 1.5	$2.0M - $3.2M	30%	$350,000

Figure 9: Wrong Way Notification System Benefit Cost Analysis

TRAFFIC INCIDENT MANAGEMENT (TIM) ENHANCEMENTS

System overview

Traffic incident management (TIM) systems can reduce the effects of incident-related congestion, reduce secondary crashes, and keep first responders safe by decreasing the time to detect incidents, the time for responding vehicles to arrive and clear the incident, informing approaching drivers, and providing a safe scene. Ultimately, clearing incidents faster reduces secondary crashes and the time required for traffic to return to normal conditions.

For I-90, the TIM strategies evaluated include expanding the dedicated incident responder program (called Dedicated Roving Patrols), establishing instant tow contracts, and developing a TIM team for the region. TIM should be implemented on a region-wide basis with focus on I-90 and other key state routes.

Since WSDOT already employs two full-time dedicated responders, this strategy evaluates adding a third dedicated responder. A dedicated responder is often the first to arrive at a reported incident, whether the incident is a crash or simply debris reported on the shoulder. WSDOT dedicated responders have specially equipped vehicles with signs on the back that can be used to help alert and inform other travelers of the incident. The reponders can also help clear and secure an incident area.

An instant tow contract is an agreement between the agency and tow companies with the intention of clearing incidents faster. Under an instant tow contract, a tow company is dispatched as soon as an incident is called in, instead of waiting for WSDOT or law enforcement to verify that a tow is in fact necessary. If the tow company shows up and the tow is not needed, the tow company is paid an agreed-upon fee. If they proceed with the tow, then the owner of the towed vehicle pays the full towing fee. This strategy reduces the incident duration by expediting the tow response.

Analysis Results and Summary (Instant Tow / Additional Dedicated Responder)

<table>
<tr><th colspan="2">Average Annual Benefit
$200,000 (Instant Tow)
$800,000 (Dedicated Responder)</th><th colspan="2">Average Annual Cost
$24,000 (Instant Tow)
$135,000 (Dedicated Responder)</th><th>B/C Range</th></tr>
<tr><td colspan="2" rowspan="2">Crash and Travel Delay Reduction:
Applying FHWA TOPS BC methodology,
• Passenger vehicle delay reduction:
○ 7,000 / 28,000 vehicle hours per year
• Truck vehicle delay reduction:
○ 500 / 2,100 vehicle hours per year
• Secondary incident reduction:
○ 2.4 / 9.0 fewer crashes per year</td><td colspan="2">No capital costs required; all costs associated with annual operations and maintenance of the tow and incident responder vehicles</td><td rowspan="2">4.4 to 15.4
(Instant Tow)

3.9 to 9.1
(Dedicated Responder)</td></tr>
<tr><td>Initial Capital Cost*
$0 / $0</td><td>Annual O&M
$24,000 (Instant Tow)
$135,000 (Dedicated Responder)</td></tr>
<tr><td colspan="5">*No capital cost because the Eastern Region has an available incident response truck.</td></tr>
</table>

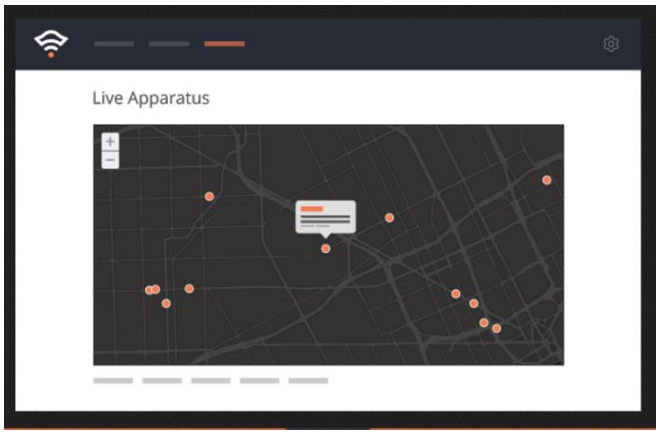
WORK ZONE MANAGEMENT

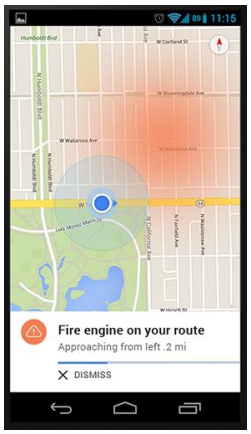
System overview

Work zone management addresses work zone policies and management for both daily (temporary) maintenance activities and longer term construction activities to improve the safety of both the workers and travelers. While WSDOT already follows standard work zone procedures, additional work zone strategies can further improve safety for both travelers and workers:

- Implement speed control through work zones with the option of automated enforcement.
- Use portable VMS to warn drivers of upcoming work zones or to provide vehicle queue warnings caused by work zones.
- Install wireless PCMS for dynamic notification when static signs are not available.

- Coordinate with law enforcement to ensure drivers comply with work zone traffic management.
- Coordinate work zones between WSDOT maintenance and utility work or other construction activities.
- Communicate delays, detours, lane configuration changes to travelers.
- Restrict lane closure and work hours to off-peak times.
- Advance connected vehicle applications used in work zones.
- Employ sensors that detect when a vehicle's trajectory could harm a worker and automatically notify the worker.
- Use automated attenuator trucks and mobile barriers to follow construction and maintenance crews in work zones.
- Implement third party applications to provide travelers with notifications about upcoming work zones or emergency vehicles, as well as providing incident managers with improved ways to manage fleets in real-time. Example images from Haas Alert[12]:





[12] Website: http://haasalert.com

RAMP CLOSURES

System overview

Ramp closures involve closing an on-ramp or off-ramp at an interchange with the intent of improving safety by improving interchange spacing. Closing a ramp can eliminate hazardous weave and merge areas and reduce congestion and collisions resulting from interchange spacing that does not meet performance expectations. Ramps can be closed by time of day (TOD), temporarily for an event, or permanently. If operated by TOD, ramp closure can work in conjunction with the ramp metering and ATM strategies. However, permanent closure would physically close the ramp and permanently eliminate the merge area.

Due to the extensive impacts of a ramp closure, WSDOT will pursue an Interchange Justification Report (IJR) to investigate all the challenges that a closure presents. Ramp closures will not move forward as part of this project. Therefore, ramp closures are not suggested as part of the Phase 1 projects listed in Table 5 (page 35).The analysis and results reported in this section focus only on the potential for a closure (either permanently or by time of day) to reduce crashes and improve safety.

Ramp closures will not be implemented with the currently available project funds.

WSDOT determined that a full Interchange Justification Report (IJR) will be necessary to further explore the impacts and benefits associated with a modification to an existing freeway access. An IJR is necessary when seeking to modify access to a freeway. Access revisions need to be approved by the Federal Highway Administration (FHWA) when an interstate facility is impacted.

The analysis reported in this memorandum seeks only to understand whether a ramp closure (either permanently or by time of day) has potential to improve traveler safety.

Other considerations

Closing a ramp does not eliminate traffic, but routes it elsewhere in the system. This analysis does not account for the possibly of increasing crashes elsewhere in the system due to rerouted traffic.

Further investigation for ramp closure strategies will include a full IJR and address socio-economic considerations, traffic impacts to local streets and other ramps, alternate access (all modes), and political considerations.

Analysis Results and Summary

The project team began by identifying ten on-ramps and off-ramps to evaluate for potential closure, based on known performance issues such as short spacing between ramps or short weave and merge areas. The analysis focused solely on the potential to reduce crashes to determine whether further evaluation is warranted for any of the locations.

Analysis reviewed potential costs and benefits of closing the ramps permanently and by time of day during peak hours. Preliminary results for permanent closure of all ten ramps are shown in Figure 10. Potential closures at four ramps, highlighted in Figure 10, stood out as having the most potential to improve corridor safety:

- Walnut EB On-Ramp or Monroe EB On-Ramp (only one of these ramps would be selected, not both)
- Division WB Off-Ramp
- Maple WB On-Ramp

Table 3 summarizes the results of permanently closing the four ramps identified as having the greatest potential benefits. Permanent ramp closures offer a higher benefit cost ratio than a time of day closure, but also result in the most impact to traffic flow. The high costs associated with the permanent ramp closures assume additional civil improvements to nearby intersections to handle the change in traffic flow, as well as demolition of the existing ramp and conversion to a non-ramp facility.

Table 4 summarizes the results of closing the same four ramps during peak hours only. Time of day closures assume the installation of remotely operated gates and signs, but few other civil and structural improvements. The Division WB Off-Ramp time of day closure is an exception. Closing an off-ramp on the freeway by time of day would require substantial improvements to advanced variable message signing to ensure travelers are aware of the closure and reroute accordingly.

In general, the benefit cost ratios are higher for the permanent closure option and less than 1.0 for the time of day closures.

The Walnut EB On-Ramp is an exception to that trend, showing time of day closures with a benefit cost ratio greater than 1.0. Here are a few things to keep in mind:

- The Walnut and Monroe EB On-Ramps are in close proximity. The crash data provides the location of the crash, but not whether it's due to a queue downstream or is specific to the Walnut EB On-Ramp merge area. Some of the crashes attributed to the Walnut EB On-Ramp may be due to the Monroe EB On-Ramp, artificially increasing the benefit of closing Walnut and decreasing the benefit of closing Monroe (as captured under Table 3).
- Full closure of the Walnut EB On-Ramp would push traffic volumes to the Monroe EB On-Ramp throughout the day. The cost assumes about $2 million in improvements to several surrounding intersections (see Figure 12), increasing the cost for the permanent closure. For the time of day closure, fewer improvements to nearby intersection would likely be implemented, lowering the cost.
- The spread of crashes at the Walnut EB On-Ramp is more pronounced over the PM peak hour than the other on-ramp peak hours (as shown in Figure 11), which increases the benefit for the time of day closure.

Table 3: Permanent Ramp Closure Analysis Results

Ramp	Average Annual Benefit	Average Annual Cost	Annual Crash Reduction	B/C Range
Walnut EB On-Ramp	$1,050,000	$360,000	19.5	2.5 to 3.7
Monroe EB On-Ramp	$140,000	$590,000	5.3	0.2 to 0.3
Division WB Off-Ramp	$1,870,000	$290,000	3.6	5.3 to 8.3
Maple WB On-Ramp	$780,000	$510,000	5.2	1.3 to 2.0

Note – There are about six times more crashes on the ramp portion of the Walnut EB On-Ramp than the ramp portion of the Monroe EB On-Ramp. While the crashes on the ramps themselves would be eliminated by closing each on-ramp, the remaining distribution of crashes reduced on I-90 may differ slightly than the indicated values. Due to the close spacing between these two ramps, some of the crashes on the mainline portion closer in proximity to the Walnut EB On-Ramp may be attributed to the downstream weaving and merging issues at the Monroe EB On-Ramp. Closing the Monroe EB On-Ramp may decrease crashes more than indicated, and likewise, closing the Walnut EB On-Ramp may decrease crashes less than indicated in Table 3.

Table 4: Time of Day (Peak Hour) Ramp Closure Analysis Results

Ramp	Average Annual Benefit	Average Annual Cost	Annual Crash Reduction	B/C Range
Walnut EB On-Ramp *(PM peak)*	$200,000	$170,000	5.3	1.4 to 2.1
Monroe EB On-Ramp *(PM peak)*	$5,000	$80,000	0.5	0.1 to 0.1
Division WB Off-Ramp *(AM peak)*	$50,000	$700,000	0.8	0.1 to 0.1
Maple WB On-Ramp *(AM peak)*	$5,000	$80,000	0.5	0.1 to 0.1

In Figure 11, the crashes for each of these four ramps are graphed by time of day to better understand when the crashes are occurring and whether a peak hour closure would address safety concerns. At each of the locations, there is an increase in crashes during the AM and PM peak hours, but there is also a consistent spread of crashes over other hours of the day. The crashes are categorized as occurring on either the I-90 mainline or on the ramp. At the Walnut EB On-Ramp, a majority of the crashes occur on the ramp, but for the other three locations the majority of crashes occur on the mainline.

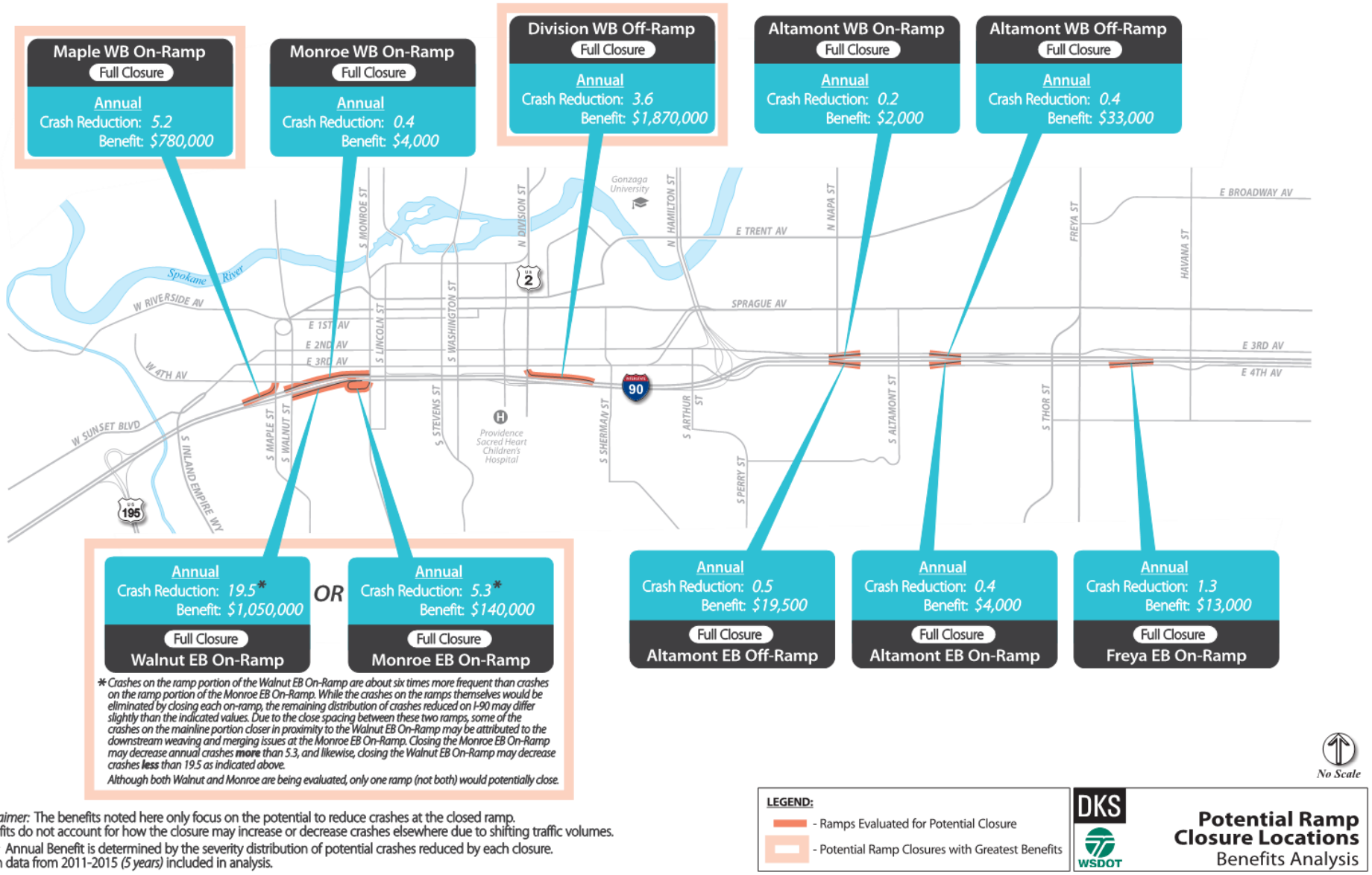


Figure 10: Potential Ramp Closure Locations

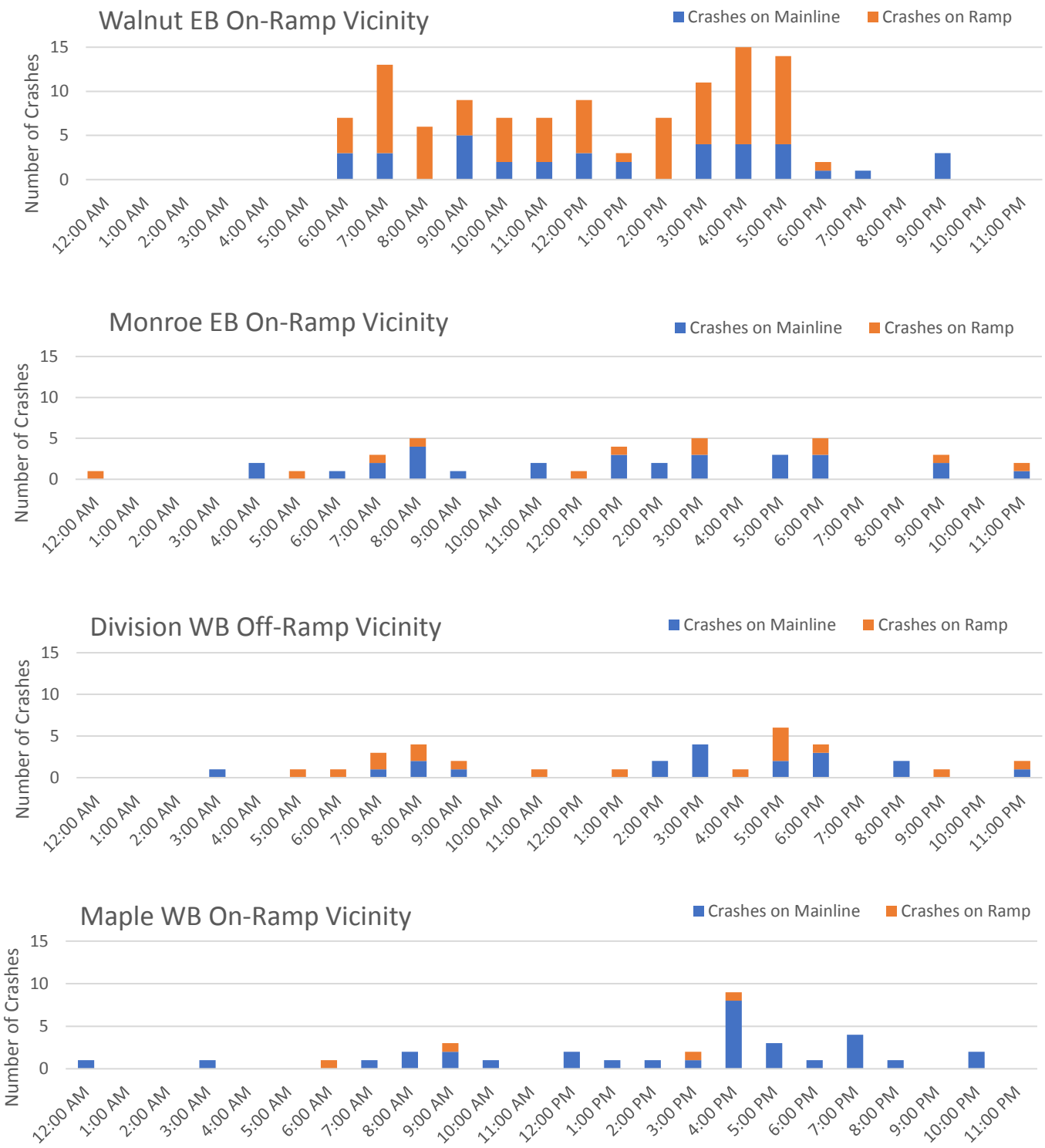


Figure 11: Crashes by Time of Day at Ramps Considered for Closure (Crash Data: 2011-2015)

Key Ramp Closure Impacts

The following figures (Figure 12 through Figure 15) show some assumptions associated with the cost of **permanently** closing each of the four ramps as well as the assumed re-routing options. In general, a permanent closure consists of installing barrier, roadway demolition, and targeted intersection improvements to facilitate the rerouting of vehicles to other ramps. In some cases, roadway demolition may be optional, especially if there are any plans to re-open the ramp in the future.

Walnut EB On-Ramp Closure

Closing the Walnut EB On-Ramp would reroute travelers to the Monroe EB On-Ramp, with minimal out-of-direction travel.

Monroe EB On-Ramp Closure

In the case of the Monroe EB On-Ramp closure, there is a significant structural component, upwards of $12 million, to extend the on-ramp from Walnut to the existing auxiliary lane for the Monroe EB On-Ramp. Widening this structure would provide a dedicated auxiliary lane for the Walnut EB On-Ramp traffic, eliminating the existing short merge area. Closing the Monroe EB On-Ramp would route traffic out of the downtown core to either the Walnut or Division EB On-Ramps.

Division WB Off-Ramp

Closing the Division WB Off-Ramp impacts traffic flow into the downtown core of Spokane. Traffic would use either the westbound exit to 2nd Avenue, east of downtown, or continue to the Lincoln Street exit.

Maple WB On-Ramp

Closing the Maple EB On-Ramp could require significant rerouting or out-of-direction travel.

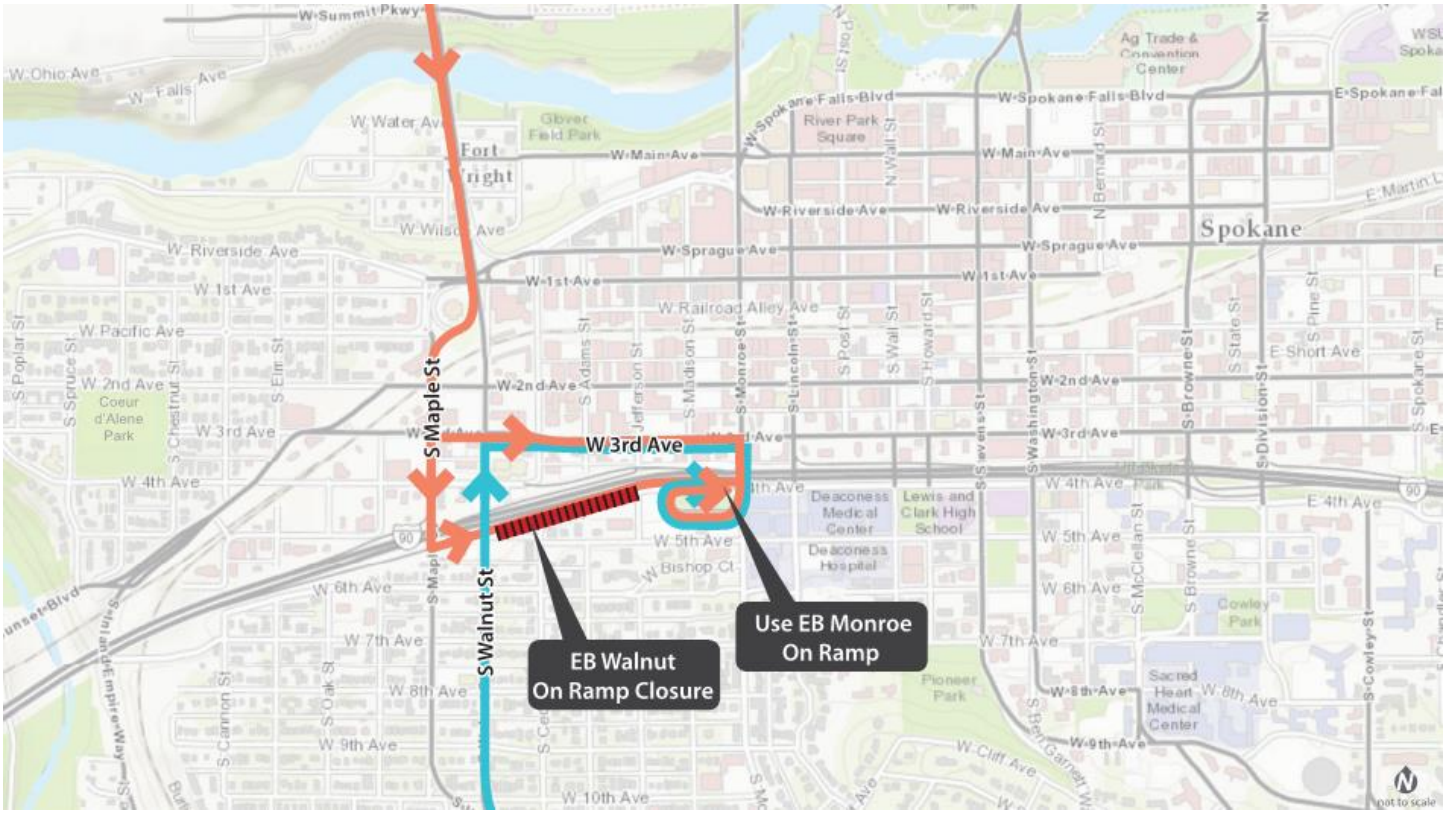


Figure 12: Walnut EB On-Ramp Potential Closure Improvements and Alternate Access

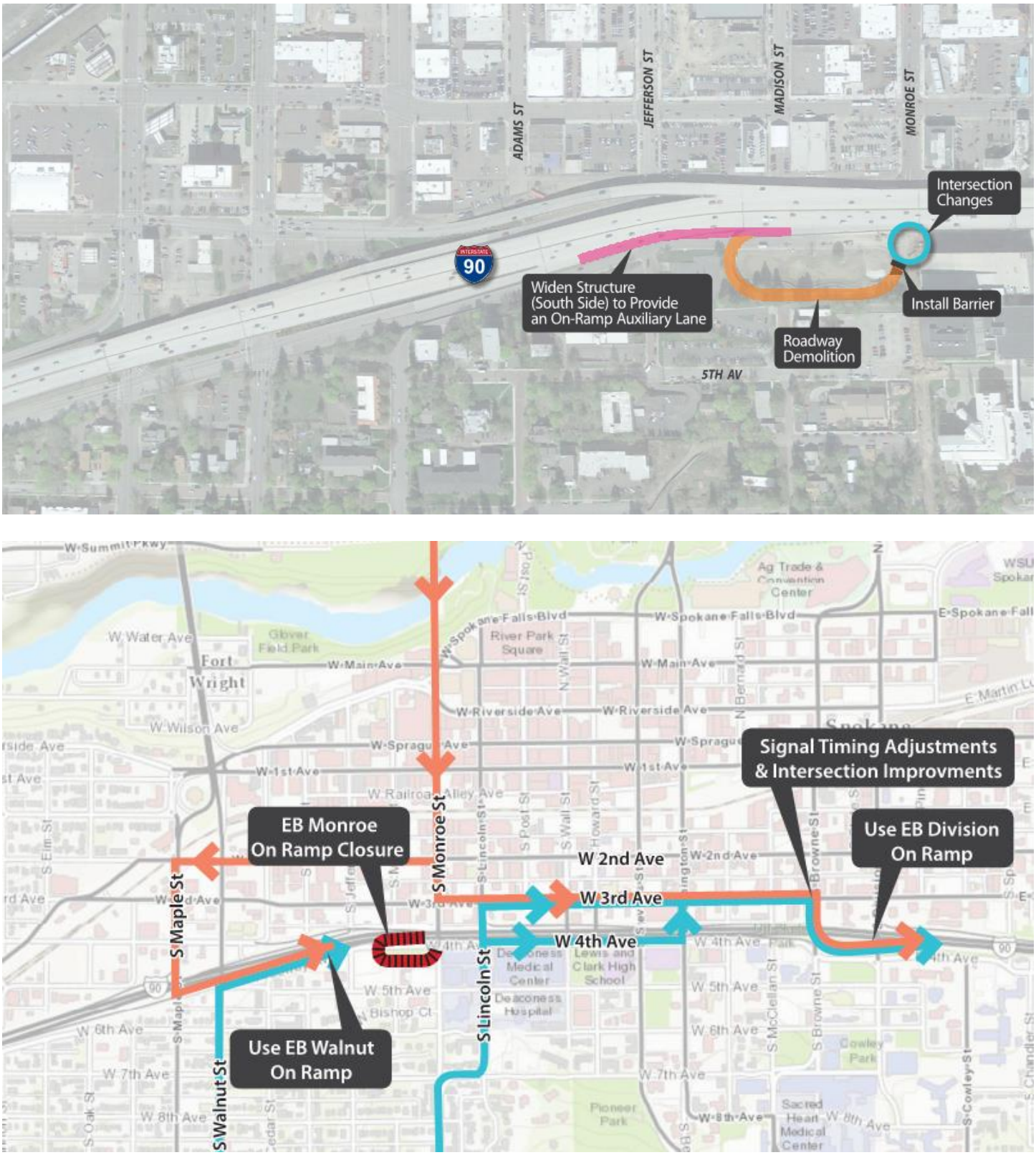


Figure 13: Monroe EB On-Ramp Potential Closure Improvements and Alternate Access

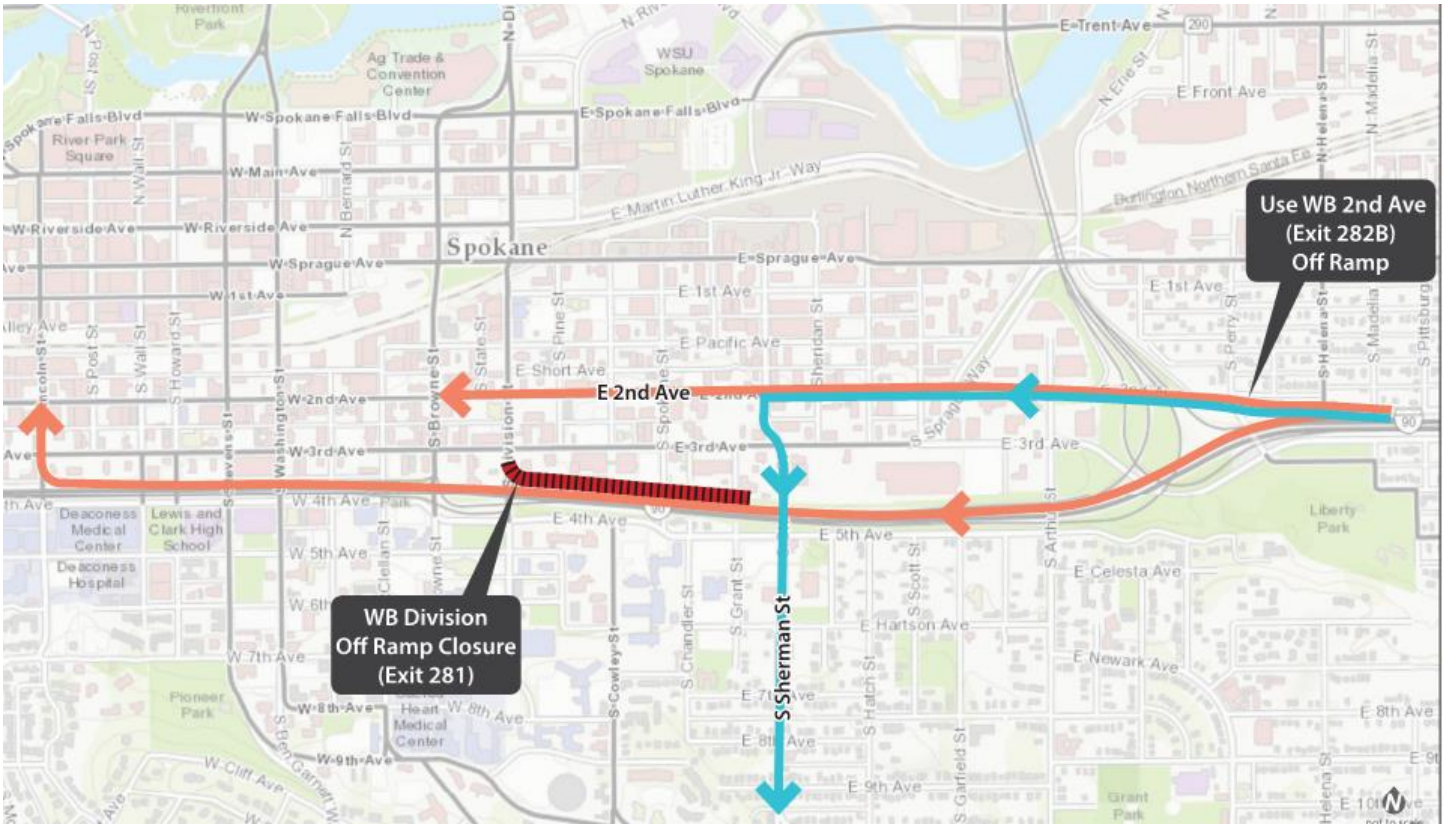


Figure 14: Division WB Off-Ramp Potential Closure Improvements and Alternate Access

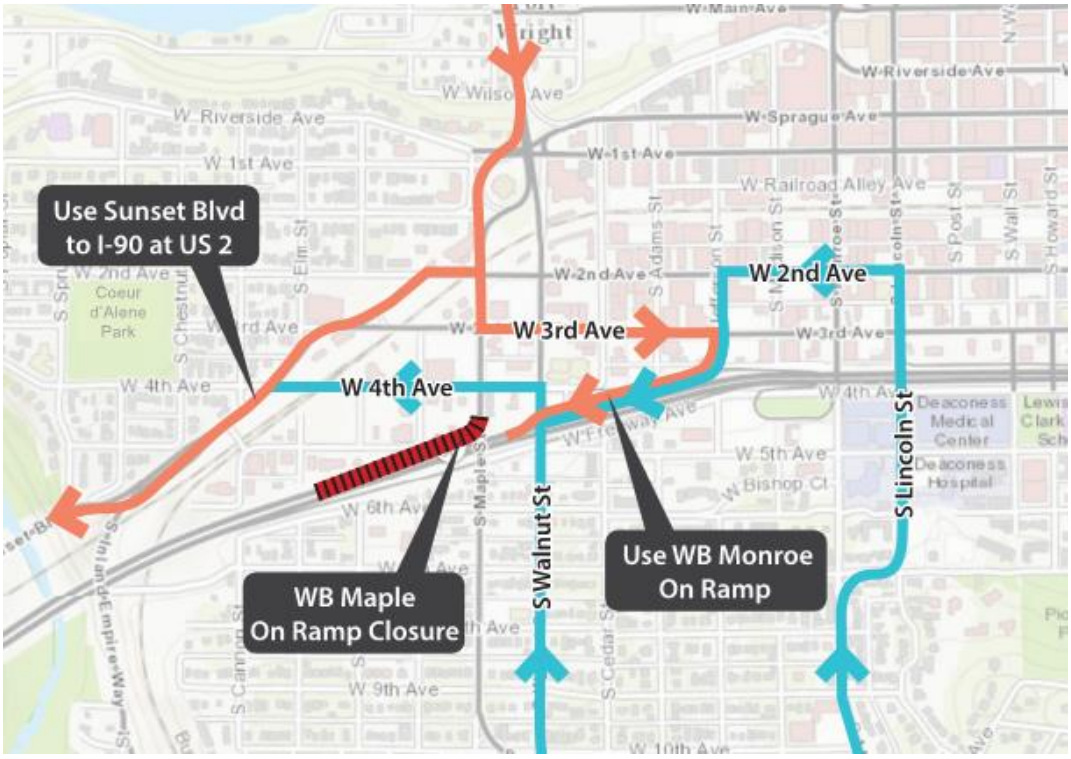


Figure 15: Maple WB On-Ramp Potential Closure Improvements and Alternate Access

PHASED IMPLEMENTATION PLAN

After extensive evaluation and input from stakeholders, WSDOT plans to move forward with the projects shown in Table 5 as Phase 1 implementation projects. Ramp meters, wrong way notification, and merge and queue warning systems were selected as the priority strategies to implement. These projects will serve as building blocks to continue improving ITS operations the I-90 corridor. Once ATMS software is upgraded to accommodate ramp meters and the wrong way notification system, adding additional on and off-ramps to either system will be incremental.

In addition to the three projects listed above, WSDOT will continue to improve the Dedicated Responder program and will seek to Implement the Instant Tow program through funding outside this grant.

Table 5: Phase 1 Implementation Projects

Phase and Projects	Cost	B/C ratios	Annual Crash Reduction
Phase 1: Funded by Currently Programmed Funds			
Ramp meters – 6 Total EB: US-195, Walnut, Monroe, Division/Browne, Hamilton WB: Division/Browne	$2,000,000	2.1 to 2.9	9
Wrong Way Notification – 13 off-ramps	$2,500,000	1.6 to 2.5	<1
Improve signing near the I-90/US-195 EB Merge	$400,000 (could be significantly greater depending on selected solution)	Variable (depends on strategy)	Variable (depends on strategy)
Total	**$4,900,000**		**> 10**
Phase 1: Option to Substitute Above or Implement when Additional Funding is Available			
Queue Warning System upstream of Division westbound off-ramp	$2,500,000	1.6 to 2.4	4
Phase 1: Implement as Funding Becomes Available			
Dedicated Responder (already implemented)	$125,000	3.9 to 9.1	9
Instant Tow	20,000	11.0 to 15.4	3

As additional funding becomes available, strategies should be reevaluated for implementation to further enhance safety and operations along I-90:

- Expand ramp metering.
- Expand the wrong way notification system.
- Implement work zone management projects as feasible.
- Implement additional ATM structures. Once a segment is complete, the ATM could be used for variable speeds.
- Consider ramp closures
- Expand incident response to encompass Four Lakes to Idaho Stateline.

ATTACHMENT A – SUMMARY OF BENEFIT COST RESULTS FOR ALL STRATEGIES

Benefit Cost Evaluation Summary

Strategy	B:C Ratio Range		Benefits		Initial Capital Cost	
			Annual Reduction in Crashes	Annual Benefit	Low	High
ATM						
Active Traffic Management: MP 277 to 286 (variable speeds - crash reduction benefits)	4.2	6.3	107.3	$5,983,000	$18,705,000	$29,361,000
Queue Warning System - WB at Division	1.6	2.4	-2.72	$317,000	$2,269,000	$3,562,000
Wrong Way Notification System						
Wrong Way Notification System (Full Corridor)	1.8	2.8	0.5	$890,000	$4,728,000	$7,621,000
Wrong Way Notification System (funded area US-2 to Broadway)	1.6	2.5	0.2	$349,000	$1,997,000	$3,219,000
Traffic Incident Management (TIM)						
TIM Dedicated Responder (3 minute average savings)	3.9	5.4	6.8	$614,000	$0	$0
TIM Dedicated Responder (5 minute average savings)	6.5	9.1	11.3	$1,029,000	$0	$0
TIM - Instant Tow (5 minute reduction)	11.0	15.4	3.4	$308,000	$0	$0
TIM - Instant Tow (2 minute reduction)	4.4	6.1	0.00	$122,000	$0	$0
Ramp Metering Options						
Option A: Ramp Meter Summary (6 Hours) - All Ramps	5.6	7.9	14.0	$1,775,000	$2,789,000	$4,378,000
Option B: Ramp Meter Summary (6 Hours) - All Eastbound Ramps	4.5	6.1	8.3	$982,000	$1,799,000	$2,824,000
Option C: Ramp Meter Summary (6 Hours) - Select Eastbound Ramps	1.7	2.2	5.9	$285,900	$1,304,000	$2,047,000
Option D: Ramp Meter Summary (6 ramps for phase 1)	2.1	2.9	8.7	$399,000	$1,485,000	$2,331,000
Individual Ramps (Benefits based on Crash Reduction Only) AM and PM peak hours of operation						
1- Ramp Metering - at US 195 EB On-Ramp	4.2	6.1	1.7	$67,000	$174,000	$273,000
2 - Ramp Metering - at Walnut EB On-Ramp	2.8	4.0	1.2	$44,000	$174,000	$273,000
3 - Ramp Metering - at Monroe EB On-Ramp	2.4	3.5	1.0	$39,000	$174,000	$273,000
4 - Ramp Metering - at Division EB On-Ramp	2.9	4.3	1.5	$47,000	$174,000	$273,000
5 - Ramp Metering - at Hamilton EB On-Ramp	2.5	3.6	1.5	$40,000	$174,000	$273,000
6 - Ramp Metering - at Altamont EB On-Ramp	1.3	1.8	0.6	$20,000	$174,000	$273,000
7 - Ramp Metering - at Freya EB On-Ramp	0.8	1.1	0.8	$12,000	$174,000	$273,000
8 - Ramp Metering - at Maple WB On-Ramp	2.1	3.1	0.9	$34,000	$174,000	$273,000
9 - Ramp Metering - at Monroe WB On-Ramp	0.5	0.7	0.4	$8,000	$174,000	$273,000
10 - Ramp Metering - at Division WB On-Ramp	3.4	4.9	1.8	$54,000	$174,000	$273,000
11 - Ramp Metering - at Hamilton WB On-Ramp	1.8	2.5	1.3	$28,000	$174,000	$273,000
12 - Ramp Metering - at Altamont WB On-Ramp	0.7	1.0	0.6	$11,000	$174,000	$273,000
13 - Ramp Metering - at Freya WB On-Ramp	0.7	1.0	0.6	$11,000	$174,000	$273,000
Ramp Closures						
Full Closure - Top 4						
Ramp Closure - Walnut EB On-Ramp	2.5	3.7	19.5	$1,047,000	$3,960,000	$6,216,000
Ramp Closure - Monroe EB On-Ramp	0.2	0.3	5.3	$137,000	$10,725,000	$16,835,000
Ramp Closure - Division WB Off-Ramp	5.3	8.3	3.6	$1,867,000	$5,528,000	$8,677,000
Ramp Closure - Maple WB On-Ramp	1.3	2.0	5.2	$778,000	$9,900,000	$15,540,000
Full Closure - Remaining 6 considered						
Altamont Street, EB Off-Ramp	0.3	0.5	0.5	$19,500	$1,000,000	$1,400,000
Altamont Street, EB On-Ramp	0.2	0.3	0.4	$4,000	$300,000	$420,000
Freya Street, EB On-Ramp	0.8	1.1	1.3	$13,000	$300,000	$420,000
Monroe Street, WB On-Ramp	0.2	0.3	0.4	$4,000	$300,000	$420,000
Altamont Street, WB On-Ramp	0.1	0.2	0.2	$2,000	$300,000	$420,000
Altamont Street, WB Off-Ramp	0.6	0.8	0.4	$33,000	$1,000,000	$1,400,000
Time of Day Closure						
TOD Ramp Closure - Walnut EB On-Ramp (PM Peak)	1.4	2.1	5.3	$202,000	$2,063,000	$3,238,000
TOD Ramp Closure - Monroe On-Ramp (PM Peak)	0.1	0.1	0.5	$5,000	$1,238,000	$1,943,000
TOD Ramp Closure - Division WB Off-Ramp (AM Peak)	0.1	0.1	0.8	$52,000	$12,705,000	$19,943,000
TOD Ramp Closure - Maple WB On-Ramp (AM Peak)	0.1	0.1	0.5	$5,000	$1,238,000	$1,943,000

ATTACHMENT B – LISTING OF COMMUNITY OUTREACH MEETINGS

Planned Outreach:

1. Meeting with Senator Michael Baumgartner, date, time and place TBD

2. West Hills Neighborhood Council Meeting, Tuesday, December 12, 6:30-8:00 PM, Finch Arboretum

Past Outreach:

1. Grandview/Thorpe Neighborhood Council Meeting June 14, 7:00 PM, Grandview Park

    a. Monica and I presented to about 15 in attendance. The proposed strategies were well received and there were many follow-up questions about ramp metering and active traffic management (ATM). Many had a concern about the 195 EB on-ramp so the ATM's ability to "close" the outside I-90 lane allowing free-flow from 195 sounded like a good concept to them. *There was mention that if Sunset Blvd was repaved it would be used as an alternative to I-90 for a person that works out at Airway Heights [added 6/16].*

2. Cliff/Canon Neighborhood Council Potluck, June 15, 5:30 PM, Polly Judd Park

    a. Larry, Monica, and I presented to about 15 people. There were comments about the lack of merge distance at the Walnut EB on-ramp and the closeness of the WB Division and Lincoln on-ramps. A comment that the closure of Walnut WB on-ramp would be an improvement for peds/bicyclists. There was mention, like the Grandview neighborhood, that if the local network was in better condition it would be a decent alternative to using I-90 for short distances.

3. City of Spokane Executives/Directors, June 16, 3:30 PM, City Conf Room 3B

    a. Presented our past and upcoming public outreach and the six strategies to Scott Simmons, Inga Note, Katherine Miller, Louis Meuler, Lisa Key, Bob Turner, Jonathan Mallahan, and Gary Kaesemeyer.

    b. WSDOT on hand: Glenn Wagemann, Char Kay, Monica Harwood, Larry Frostad, and Mike Bjordahl.

    c. Jen from DKS was present for this meeting.

4. SRTC TTC, June 28, 1:30-3:30 PM, SRTC Meeting Room

    a. Mike B, Larry, Glenn, and Monica presented to the committee.

5. Downtown Spokane Partnership Meeting #1, June 29, 11:00-1:00 PM, Convention Center Meeting Room

    a. Larry, Glenn, Char, and Mike B to a group of 15 members of the DSP

6. City of Spokane Council Study Session, June 29, 3:30 PM, Council Briefing Center

    a. Glenn presented to Ben Stuckart, Lori Kinnear, and Breean Beggs.

7. City of Spokane Plan Commission Transportation Subcommittee, July 11, 9:00 AM, City's Briefing Room

    a. Glenn presented to the subcommittee and Jim Peters of DKS was on hand for this meeting.

8. East Central Neighborhood Council Meeting, July 18, 6:00 PM, East Central Community Center

a. Glenn and Larry presented to the council.

9. City of Spokane Community Assembly, August 3.

a. Delivered pamphlets for handout at this meeting. We did not present to this group per their recommendation—they felt it best that we present to each neighborhood council individually.

10. Downtown Spokane Partnership Meeting #2, August 9 at Global Credit Union.

a. Glenn, Larry, Monica, and Mike Gribner presented.

11. The Community Assembly's Pedestrian, Transportation & Traffic (PeTT) Committee Meeting, August 22, West Central Community Center

a. Larry and Mike B presented to this group.

12. Meeting with City of Spokane Mayor David Condon, August 30.

a. Larry and Mike Gribner presented.

13. Meet with the ER Signals Shop, September 6.

a. Monica and Mike B presented.

14. SRTC Board Meeting, Thursday, September 14

a. Glenn presented.

15. Lincoln Heights Neighborhood Council Meeting, Tuesday, September 19, 6:30-8:00 PM Southside Senior Center

a. Larry and Mike presented.

16. Target Zero Task Force Meeting, Tuesday, October 3

a. Monica and Mike B presented.

FINAL REPORT

I-90 Operations Study

May 2018

Appendix E

Operational Concept Report

DKS

I-90: Four Lakes to Idaho Stateline

Operations Study

Operational Concept Report

April 2018

Document Description

Client	WSDOT Eastern Region
Contract Number	
Project / Proposal Name	I-90: Four Lakes to Idaho Stateline Operations Study
Related Task	
Prepared By	DKS Associates and System Metrics Group, Inc.
Document Name	Operational Concept
Date Document Approved	

Version Control

Version Number	Date	Description of Change	Author
1	10/5/2017	Draft Outline	SMG/DKS
2	11/21/2017	Draft Report	SMG/DKS
3	2/6/2018	Final Report	SMG/DKS
4	3/28/2018	Final Report V2	SMG/DKS
5	4/4/2018	Updates to figures 6 and 7	SMG/DKS

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INTRODUCTION AND PROJECT PURPOSE

Interstate 90 (I-90) through the Spokane region was completed in 1974, and since that time the region has relied upon the interstate as an essential transportation corridor for the regional and interstate movement of people and goods. As the region's population grew, traffic volumes increased on I-90. Higher traffic volumes, combined with crashes, construction work zones and other incidents have increased the operational strain on I-90.

The I-90 Four Lakes to Idaho Stateline Operations Study details current issues and needs and develops an operations strategy for improving safety and managing traffic flow within the I-90 corridor over the next ten years. As part of the study the project team reviewed and evaluated 31 concepts. After careful screening and thorough vetting process with the Washington State Department of Transportation (WSDOT) and its stakeholders, three systems were selected for phase one implementation with current funding levels: ramp metering system, wrong way notification system, and queue/merge warning system. These three systems will serve as a platform for future projects, and can be expanded upon as funding becomes available. As other advanced traffic management systems (ATMS) are added to these three systems, the operational concept will be revised to incorporate additional capabilities and concepts.

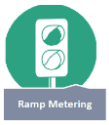
Overview of Strategies Selected for Operational Concept Advancement

The Operational Concept Report is a component of an on-going study and implementation stemming from the I-90: Four Lakes to Idaho Stateline Operations Study. As part of the larger study, the project team evaluated various strategies and techniques to address the issues associated with congestion and areas with higher incident rates. Following a thorough evaluation[1] of potential strategies to improve safety and operations along I-90, three systems were selected for phase one implementation with current funding levels: ramp metering system, wrong way driver notification system, and queue/merge warning system. To guide the implementation, this report will explore and provide recommendations and guidance for WSDOT on each of the systems proposed as the project moves from project development into operations and will include discussion for agency coordination and support requirements.

The three concepts detailed in this report are new to the Spokane area, but they are time tested tools deployed in other areas of the state and country.

Installation of all three systems should be consistent with the current Spokane Region ITS Plan[2].

Ramp Metering System – Install ramp meters at five eastbound on-ramps and one westbound on-ramp to manage the flow of entering vehicles. Ramp metering can help reduce crashes at merge areas and reduce congestion on the mainline by breaking up vehicle platoons and regulating the flow of vehicles entering the mainline without having to reduce the hourly flow rate. Ramp signals alternate between red and green lights to control the flow of vehicles entering the mainline. Metering rates can be adjusted based on the current mainline and on-ramp traffic volumes. The proposed ramp metering system to be implemented as part of Phase 1 includes the following locations shown in Table 1.



[1] Draft Implementation Plan Memorandum: I-90 Four Lakes to Stateline Operations Study
[2] Spokane Regional ITS Plan. Prepared for WSDOT by DKS Associates and IBI Group. April 2013.

Table 1: Proposed Phase 1 Ramp Metering System Locations

EASTBOUND	WESTBOUND
EB US 195 on-ramp	WB Division/Browne on-ramp
EB Walnut on-ramp	
EB Monroe on-ramp	
EB Browne/Division on-ramp	
EB Hamilton on-ramp	

Wrong Way Driver Notification System – Install sensors on seven eastbound off-ramps and nine westbound off-ramps that can detect wrong-way drivers, alert the travelers using electronic message signs, and notify law enforcement and operators of the wrong way driver detection. The proposed wrong way driver notification system to be implemented as part of Phase 1 includes locations shown in Table 2.

In addition to the technology enhancements, the wrong way driver notification system should also address low-cost static signing and pavement marking improvements. WSDOT recently installed larger wrong way signs on the off-ramps. Additional improvements could include mounting the wrong way signs at a lower height, improving channelization near access locations, providing pavement markings to indicate the correct travel direction, and curbing or other hard channelization.

Table 2: Proposed Phase 1 Wrong Way Driver Notification System Locations

EASTBOUND	WESTBOUND
EB Walnut off-ramp	WB Freya off-ramp
EB Division off-ramp	WB Altamont off-ramp
EB Hamilton off-ramp	WB 2nd Avenue off-ramp
EB Altamont off-ramp	WB Hamilton off-ramp
EB Freya off-ramp	WB Division off-ramp
EB Sprague off-ramp	WB Lincoln off-ramp
EB Broadway off-ramps	WB Maple/Walnut off-ramp
	WB Broadway off-ramp
	WB Sprague off-ramp

Queue/ Merge Warning System – install electronic message signs at two eastbound locations and one westbound location that can alert the travelers of the upcoming queues and merging hazards, reducing crashes. Existing electronic message signs could also be used to display queue warnings where applicable.

In the eastbound direction, upstream of the US-195 merge, the key purpose is to warn drivers about the upcoming merge and encourage drivers to use the left most lanes, leaving the right lane open for merging traffic. The queue/merge warning system would replace the existing static sign with flashing beacon approaching the US-195 merge that is posted off to the shoulder. The existing sign is not as visible as it is off the roadway and less effective. Commuters have a tendency to ignore static signs over time. The new system is intended to increase visibility and solicit greater response.

In the westbound direction, upstream of the Division Street exit, the key purpose of the system is to provide a queue warning to approaching drivers. This location is an area that typically experiences congestion and queueing.

The proposed queue warning system to be implemented as part of Phase 1 includes the following locations shown in Table 3.

Table 3: Proposed Phase 1 Queue Warning System Locations

EASTBOUND – Merge Warning	WESTBOUND – Queue Warning
EB advance of US 195 Merge, Mile Post 278.8	WB advance of Division Off-ramp - Arthur Street Overpass
EB advance of US 195 Merge, Mile Post 279.0	

Report Organization

The report is organized into three sections: **ramp metering system, wrong way driver notification system, and queue or merge warning system**. Each section includes a general description of the system followed by:

- Intended purpose of the system – describes what the system is intended to achieve and where it will be applied.
- Functions and system design – highlights a variety of capabilities to consider for functional implementation, as well as providing an overview of design considerations for each site.
- System operations – outlines how the system can operate, such as operational scenarios or coordination with other systems.
- Support environment and costs – summarizes roles and responsibilities, and resource needs including estimated costs for the system.
- Operational policies and constraints – documents potential policies, constraints, and challenges to be aware of prior to implementing the system.

RAMP METERING SYSTEM

Ramp metering can reduce crashes on the mainline by as much as 36%[3], and ramp metering projects typically yield high benefit to cost (B/C) ratios that range from 2 to 10. In fact, for the 13 locations along the I-90 corridor (from US 195 to Freya) analyzed, the estimated B/C ratio ranged from 6.4 to 9.6. Ramp meters perform best when installed in groups along the corridor instead of isolated installations. WSDOT provides a typical ramp metering design layout in the ITS Design Requirements document.[4] Figure 1 illustrates the typical ramp meter design layout for WSDOT, which can be modified for single or multi lane on-ramps. In addition to the equipment shown in WSDOT's typical layout, a CCTV camera may be considered, so operators can observe the location including merging vehicles and queue storage to be able to remotely adjust the ramp meter rate.

The ramp meter control cabinet is typically positioned so that maintenance personnel can observe the signal indication and see the controller face, allowing a single person to observe the complete installation when in operation.

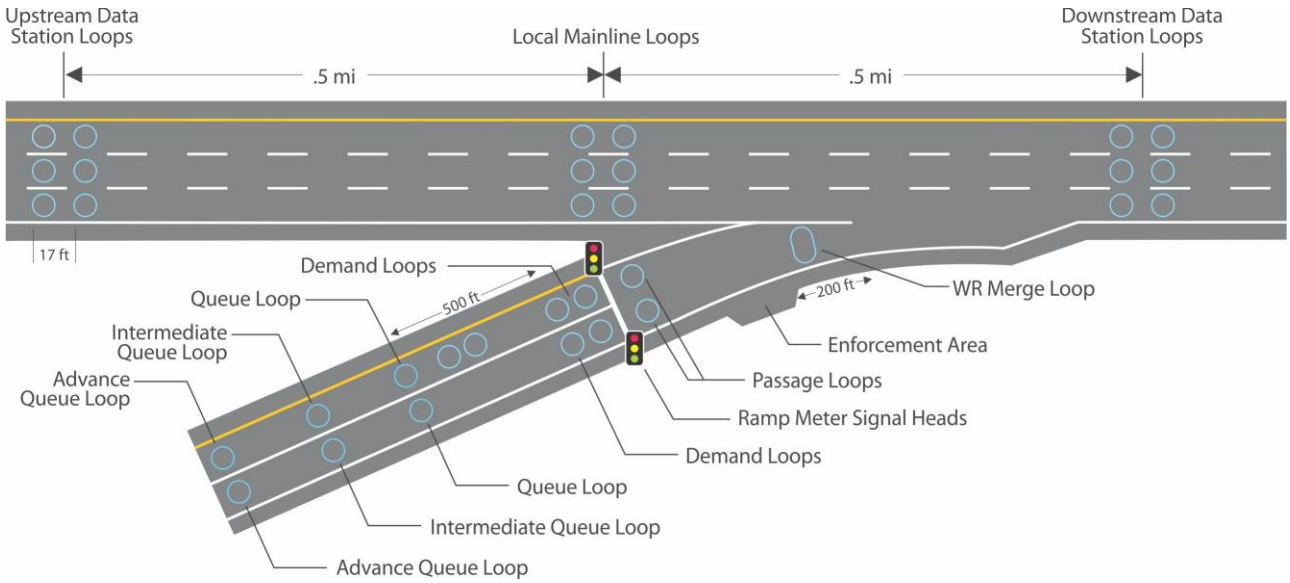


Figure 1: Typical Ramp Meter Layout (Dual Lane On-Ramp)

Intended Purpose of the Ramp Metering System

For the I-90 corridor, 13 locations were initially considered from US 195 to Freya. For the Phase 1 deployment, five eastbound locations (from US 195 to Hamilton) and one westbound location (at Division/Browne) are proposed as shown in Table 4.

[3] CMF ID = 5436 (three star). Liu, C. and Wang, Z. "Ramp Metering Influence on Freeway Operational Safety near On-Ramp Exits". June 2013.
[4] WSDOT, ITS Design Requirements. 2016 August Revision.

Table 4: Proposed Phase 1 Ramp Metering System Locations

EASTBOUND	WESTBOUND
EB US 195 on-ramp	WB Division/Browne on-ramp
EB Walnut on-ramp	
EB Monroe on-ramp	
EB Browne/Division on-ramp	
EB Hamilton on-ramp	

Ramp metering is a commonly used effective freeway management and operations strategy to reduce congestion and collisions. Regional benefits of ramp metering typically include mainline traffic speed increase, travel time reduction, crash reduction, improve travel time reliability, and emissions reduction. Without ramp metering, multiple vehicles merge in tightly packed platoons, causing drivers on the mainline to slow down or even stop to allow vehicles to enter and avoid crashes. The cascading slower speeds lead to congestion and increased rear-end crashes. Ramp meters can break up the platoons by controlling the rate at which vehicles enter the freeway from the on-ramp, allowing vehicles to merge smoothly and reducing the need for mainline vehicles to reduce speed. Unless demands are extremely high (near or exceeding ramp capacities), the ramp hourly flow rate need not change with ramp metering. The intent is not to reduce the volume of traffic entering the freeway but to manage the flow of vehicles entering.

Functions and System Design

To meet the objectives, there are different design layouts to consider for each location depending on the existing ramp geometry (since the system will be retrofitted into an existing facility) and operational parameters to consider that can affect the design. Ramp metering can be implemented with many different options. When and how the system begins operation on a daily basis (Operational Mode) and how the metering algorithm determines the timing parameters (Timing Algorithms) represent two of the most significant choices for ramp meter operation.

Modes of Operation

The operational mode determines when and how the ramp metering system is going to control the traffic. There are four potential options to consider for the operational mode:

- Local time of day (pre-timed) ramp meter control
- Locally traffic responsive ramp meter control
- System-wide ramp meter control
- Adaptive ramp meter control

The **local time of day** ramp meter control becomes active based solely on the time of day and day of the week. Generally, all ramps along a freeway segment in one direction are set to become active at the same time of day, typically during the peak hours when merging can cause congestion. Options can be preprogrammed for implementation on holidays, for seasonal variations and other known special events. This type of a system requires the operators to actively update the localized information as conditions change. While this does require some effort to maintain, it is the simplest and most common mode to implement. It requires periodic manual updates to the control parameters. This type of implementation is generally more difficult to activate and

therefore not as responsive for any given incident along the freeway segment, and the ramp metering may not be active when needed under all conditions. Therefore, it is not effective for non-recurring conditions.

Locally responsive ramp meter control is where the local controller is given the ability to activate at a time when the "local" (near the ramp) conditions warrant (typically based on data from mainline detection sensors just upstream of the ramp meter location). The ability to become activated is typically controlled by a pre-determined table of metering criterion based on mainline and ramp volumes (and/or mainline density). This can be implemented via a central system (e.g., traffic control system or ATMS) or completely under localized control at the controller. Under this control system, ramps upstream and downstream may not become activated at the same time. This allows for ramps to remain inactive that are not sensing volumes that exceed the freeways capacity. This control is also able to automatically respond to incidents that results in congestion. The system can become activated at any time the mainline threshold values become triggered.

The third type of ramp meter control is **system-wide**. With system-wide, the ramp meters along the corridor are coordinated or integrated. It requires that all meters along the corridor are interconnected. The system can be pre-timed but that is not common. More commonly, a system-wide traffic responsive system is used for corridor application. Different operational or timing algorithms are used by different agencies for this system. It can be a simple lookup table of threshold criteria to determine operational parameters for the system-wide application. This system can yield better operational performance outcome and benefits.

The most advanced and complex system is the dynamic or **adaptive ramp metering**. Under this operation, the system typically uses a central computer algorithm to dynamically set the metering controls to maximize the corridor traffic operational performance. It requires the corridor to be fully instrumented with vehicle detection sensors. This is the most complex system to implement initially, but once established can often function with little intervention. The adaptive ramp metering system takes both upstream and downstream conditions and ramp flows into consideration when determining the dynamic ramp metering control assignments. Communications to the localized controllers must be maintained and the controllers must be capable of receiving timing parameters remotely from the central system. This ramp metering control provides the best in system responsiveness and performance outcomes. Seattle currently uses this system.

Timing Algorithms

In addition to the operational mode of the ramp meter system, there are two types of ramp metering "timing algorithms": isolated or coordinated. In the case of the isolated algorithm the controller only acts on local information. Local time of day and locally responsive systems typically work in this manner. While this is easier to setup and requires generally less maintenance of timing parameters it does not generally return the same benefits of a coordinated system.

Two types of coordinated systems have been used by WSDOT in the past. A competitive system was used as part of the bottleneck metering methodology where metering rates were calculated based on local conditions and then a second set of timing parameters are calculated based on the systems analysis. Implementation of the more restrictive timing parameters was then implemented.

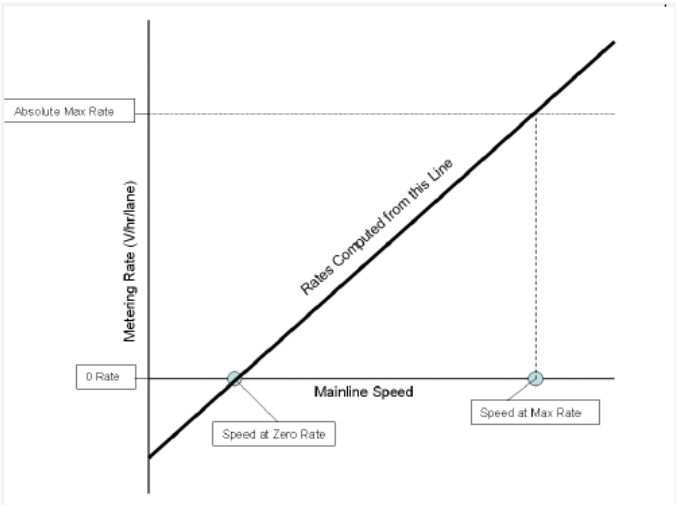
The second type of coordinated metering used by WSDOT is "fuzzy logic". The fuzzy logic methodology calculates timing parameters based on both the local and system-wide traffic demands while developing the timing parameters. The fuzzy logic algorithm was developed by WSDOT under a research project with the University of Washington. It addresses multiple objectives and weighs rules that implement those objectives. It has a user-friendly tuning process that uses linguistic variables, not numerical variables. The rule groups used by

the WSDOT algorithm include: local mainline speed and occupancy, and downstream speed and occupancy. After the fuzzy states are determined, weighted rules determine the metering rate. The numerical metering rate is based on the rule weight and the degree of activation of each rule outcome. The final meter rate determination combines the contributions from all the weighted rules.

Key features of the fuzzy logic algorithm include:

- The overall framework allows rules to be changed or added. Weights can be modified to tune to local conditions.
- The parameters are robust and do not need extensive or frequent tuning.
- The fuzzy logic algorithm can be used to turn metering on and off.
- Ramp queues are integral to the algorithm, not an adjustment to the outcome.

The Spokane area is also considering the use of the Corridor Adaptive Ramp Metering Algorithm (CARMA). With CARMA metering rates are determined based on the smoothed mainline speeds and prevailing local controller's conditions. These are then optimized over each freeway segment. It tempers rates based on downstream conditions. The concept is based on the assumption that a ramp can allow the maximum number of vehicles to enter the freeway when freeway travel speeds are high. A nice feature is that CARMA allows time of day metering (AM and PM Peak) to be included. This algorithm considers queue length for a dump function, but not as part of the timing algorithm directly.



Vehicle Queueing

When ramp metering is initiated in a region, concerns for queueing impacts on the arterial roadways feeding the freeway are generally expressed. These concerns can be mitigated using a queue override feature. Under queue override, detectors located near the entrance to the ramp detect the presentence of vehicles and activate the queue override function, releasing more vehicles. The queue override can either speed up the release rate of the ramp meter or turn the ramp meter into a solid (flush) green indication, allowing all vehicles to enter the freeway. This dumping of the ramp traffic typically impacts the freeway flow and may not completely remove the queue of vehicles from the ramp if the freeway is very congested, as could be the case if ramp metering was activated for a freeway incident. The formation of a secondary queue at the merge zone is also likely to occur once a queue dump is initiated and may prevent the complete removal of the ramp queue. The use of a fuzzy logic algorithm can almost completely mitigate the need for a queue override feature, as the presence of queue formation is used as part of the fuzzy logic calculation. Rather than waiting for a queue to build to the point where a queue dump would be required, a continuous adjustment is made within the timing algorithm to prevent the formation of an excessively large queue.

Detector placement plays a critical role in the detection of queuing. Studies completed by WSDOT indicate that the placement of the advance detection loops should be in a position where queueing is found to be at an

acceptable distance. This requires the placement of an intermediate loop at a location that allows for the storage of a platoon of vehicles entering the ramp from a signal actuation (left turn phase) without extending into the intersection. The typical placement of an advance detector at the ramp terminus only allows the ramp metering software to respond when the system has exceeded the storage capacity rather than making metering rate adjustments to maintain an acceptable queue length.

Capacity

The number of lanes available and the number of vehicles allowed to pass through each metering cycle effects the throughput or capacity of the ramp. If merging and weave areas are not considered congested the throughput capacity of an un-metered ramp is 1800 to 2200 vehicles per hour (VPH). The same ramp will have lower capacity when metered. The maximum theoretical metering capacity depends on the type of timing and number of vehicles allowed to pass in each cycle. There are four ramp-metering methods and lane configurations that may be implemented in the Spokane area. Each method provides a different maximum hourly vehicle throughput capacity, ranging from 900 vehicle per hour to 1700 vehicles per hour. An explanation of each method is provided in the following paragraphs and a summary of capacity expectations are shown in Table 5.

Table 5: Ramp Metering Methods and Capacities

Ramp Metering Release Method	Maximum Hourly Capacity (Vehicles)
Single Lane – One Vehicle per Green	900
Single Lane – Two Vehicles per Green	1200
Two Lanes – Alternating Greens	1400
Two Lanes – Tandem (simultaneous) Greens	1700

<u>Single-Lane One Car per Green</u>

This methodology allows one car to enter the freeway during each signal cycle. Each signal cycle typically rotates between green and red signal indications. Including yellow in the rotation can be considered as well, and may be based on agency preference. The length of red interval should be sufficient to ensure that the following vehicle completely stops before proceeding. From a practical point of view, the smallest possible cycle is 4 seconds. This produces a meter capacity of 900 VPH. However, field observations have shown that a 4-second cycle may be too short to achieve the requirement that each vehicle must stop before proceeding. Also, any hesitation on the part of a passenger-car driver may cause the consumption of two cycles per vehicle. A more reasonable cycle is around 4.5 seconds, obtained by increasing the red time to 2.5 seconds. This increase in red would result in a lower meter capacity of 800 VPH.

<u>Single-Lane Multiple Cars per Green</u>

Platoon metering, also known as bulk metering, would allow for two or more vehicles to enter the freeway during each green indication. The most common form of this strategy is to allow two cars per green. Contrary to what one might think, bulk metering does not produce a drastic increase in capacity over a single-lane one car per green operation. This is because this strategy requires longer green times as ramp speed increases, resulting

in a longer cycle length. Consequently, there are fewer cycles in one hour. For instance, two cars per green strategy requires cycle lengths between 6 and 6.5 seconds and results in metering capacity of 1100 to 1200 VPH. This analysis illustrates that bulk metering does not double capacity and this finding should be noted.

Dual-Lane Metering – Alternating Greens

Dual-lane metering requires two lanes be provided on the ramp at the stop bar for the ramp meter. Downstream of the ramp meter the two lanes commonly merge to a single lane before merging with the freeway, such as the eastbound on-ramp at Walnut. For this methodology, the controller displays the green-red cycle for each lane, synchronizing the cycles such that the green indications never occur simultaneously in both lanes. Furthermore, the green indications should be timed to allow a constant headway between vehicles from both lanes. Dual-lane metering with alternating release can provide metering capacity of up to 1400 vehicles per hour.

Dual-Lane Metering – Simultaneous Greens

This system also provides two lanes from the stop bar through the upstream ramp storage area, similar to the previous method. The difference is that the ramp meter releases both lanes simultaneously. The vehicles then merge into a single lane before merging with freeway traffic. Dual-lane metering with tandem release can provide metering capacity of up to 1700 vehicles per hour.

ATMS Integration

The ramp metering system (RMS) can be independently operated or coordinated out in the field, or centrally integrated and operated. With central operations, all of the ramp meters must be interconnected via communications to a central control location at the Spokane Regional Traffic Management Center (SRTMC). Central operations have significant advantages. It allows adjustments to the ramp metering control without having to go out to the field and the changes are implemented immediately. Performance data analysis can also be conducted and evaluated. The ramp metering system can also be integrated with other systems, namely the wrong way driver notification system, such that should a vehicle enter the wrong way through the off-ramp, the immediate upstream on-ramp meter can go all red.

SRTMC currently operates the iNET advanced traffic management software (ATMS). With the current software SRTMC could operate time of day ramp metering functions. To operate adaptive ramp metering, there are a couple module options that can be added to the system. Adding the iNET Adaptive Ramp Metering algorithm with CARMA would cost around $150,000 (see the description of the CARMA algorithm in the previous *Timing Algorithms* section of this report).

To install a module with the newer System-Wide Adaptive Ramp Metering (SWARM) algorithm with added capabilities, the cost increases to approximately $350,000. The SWARM algorithm calculates rates based on the current density, required density, and the number of vehicles that should be removed or added to the freeway between each ramp. The SWARM algorithm can activate upstream ramps as necessary and distribute wait times equally among ramps.[5]

[5] Ramp Metering: A Proven, Cost-Effective Operational Strategy – A Primer. FHWA. February 2017

One additional option is to install the Fuzzy Logic algorithm that WSDOT developed and operates in the Seattle region on the iNET ATMS. Details of the Fuzzy Logic algorithm were discussed previously in the *Timing Algorithms* section. Adapting the iNET ATMS to operate Fuzzy Logic would cost approximately $325,000 to $350,000.

All things considered, it may be best to start with a lower-cost option of implementing local time of day and/or locally responsive control system with Phase 1. As more ramp metering locations are implemented in the future for a longer corridor operation, an upgrade to a more advanced application such as corridor-wide or adaptive system could be considered at that time. Advanced control system are more cost-effective with a longer corridor-wide operations.

Design Layout

WSDOT developed a set of standards for the installation of ramp meters. The most recent version is dated August of 2016 as part of the Intelligent Transportation Systems Design Requirements – Chapter 4, Ramp Metering[6]. It provides information on ramp meter stop-line location, signal and cabinet placement, vehicle storage minimum requirements, loop detectors, signal poles, advance warning signs/beacon and emergency vehicle pre-emption. The layout for a dual lane on-ramp with ramp metering is illustrated in Figure 2.

Based on WSDOT standards[7], an acceleration length of 720 feet is needed to accelerate from zero to 50 miles per hour. Although the freeway speed limit is 60 miles per hour, the freeway is typically congested when the ramp meter operates, lowering the free flow speed by about 10 miles per hour. The final determination of stop bar placement and acceleration length should be determined during preliminary design.

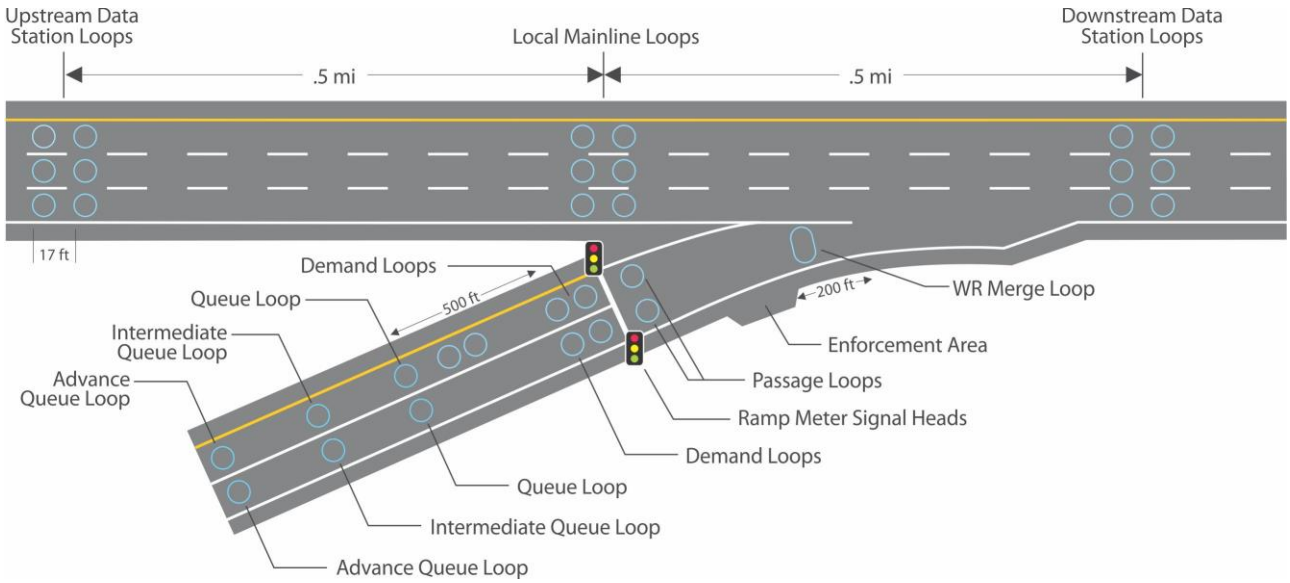


Figure 2: WSDOT ITS Design Requirements – Ramp Meter Layout Guidelines (Dual Lanes)

A field review of each proposed ramp meter location was conducted by WSDOT, DKS, and DEA staff in August 2017. Based on the field review and a vehicle queuing sensitivity analysis at each location, the project team

[6] Accessed at: http://www.wsdot.wa.gov/NR/rdonlyres/1C4C6252-17AD-429B-98BA-265E06926B3B/0/Designrequirements.pdf)
[7] WSDOT Design Manual M 22-01.14. Exhibit 1360-6. July 2017.

determined which type of ramp metering operations best addresses the needs and challenges at on-ramp. The identification of potential required exceptions to the standard guidelines is presented. The most re-occurring challenge is with ramp storage length. Figure 3 shows the WSDOT requirements for minimum storage lengths based on peak hour on-ramp volume. Widening of the ramps for additional lanes or storage capacity is not being considered for this implementation phase.

Current peak hour volume	Metered Lanes		
	1	2	3
1-300	450 ft	-	-
301-400	525 ft	-	-
401-500	600 ft	-	-
501-600	700 ft	-	-
601-900	-	900 ft	-
901-1000	-	1050 ft	-
1001-1100	-	1200 ft	-
1101-1200	-	1400 ft	-
1201-1600	-	-	1350 ft
1601-1700	-	-	1575 ft
1701-1800	-	-	1800 ft
1801-1900	-	-	2050 ft
1901-2000	-	-	2300 ft

Figure 3: WSDOT ITS Design Requirements – Ramp Metering Minimum Storage Length Guidelines

Shoulder widths were also found to be narrow at all locations. Emergency vehicle pre-emption to flush the queued traffic and allow the passage of emergency or tow vehicles to access the freeway would be preferred in this case. With many constrained single lane ramps, a disabled vehicle could effectively block a ramp. Coordination protocols with law enforcement and emergency responders (including WSDOT incident response team) should be prepared by SRTMC. Right of way and space for enforcement pullout area are also generally not available. Enforcement activities will need to occur from the mainline lanes.

A typical single lane ramp meter is shown in Figure 4. To increase the storage for single lane ramps, some locations may allow for two lanes during ramp metering operations by using the shoulder as a second storage lane, as shown in Figure 5. The project team is conducting further analysis for the ramp meter locations to determine if any of the on-ramps will need dual metering lanes.

Alternatively, a transit bypass lane could be considered for the first lane for dual-lane metering locations. A transit bypass lane would allow for travel time savings for transit vehicles, without having to wait in queue or at the meter. It should be considered only for those locations where transit vehicles use (or will use in the future) the particular on-ramp. In many of the dual-lane locations, however, it may be too geometrically constrained to make this a feasible option.

An additional consideration is whether to provide an indicator light on the backside of the ramp meter signals, allowing downstream law enforcement or traffic operators to know whether the ramp meter is on. The indicator light could be programed to turn on anytime the ramp meter signal displays the red phase. For most of the ramp meter installations described in this document, there is limited space downstream for an enforcement or monitoring pad.

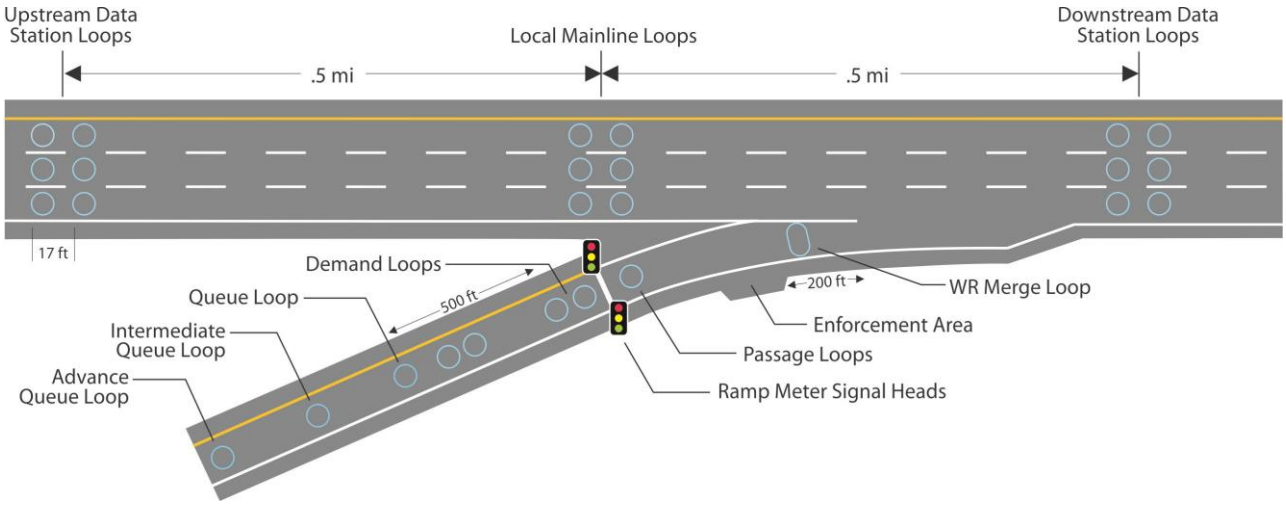


Figure 4: Ramp Meter Layout - Single Lane

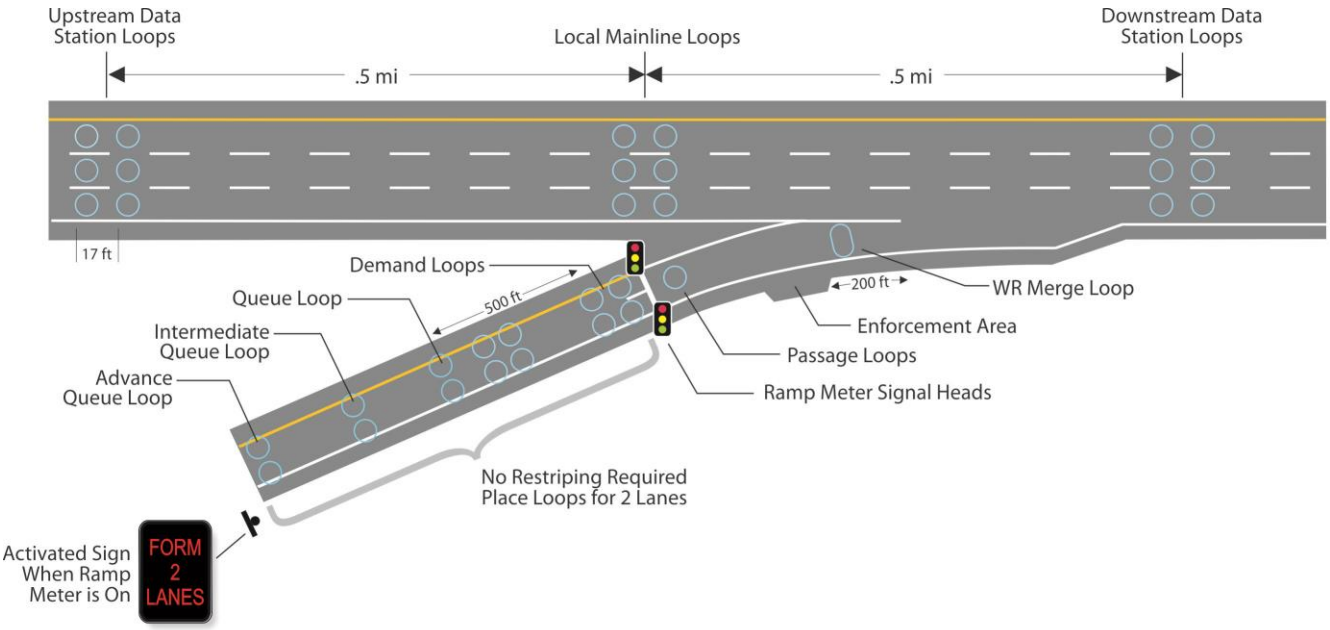


Figure 5: Ramp Meter Layout – Retrofit Single Lane to Dual Lanes While Ramp Meter is Activated

EB US 195 On-Ramp

The merge from US-195 to I-90 is short and the possibility for expansion is limited. The ramp metering stop line will need to be positioned such that acceleration can take place, but in a position to limit the potential of the formation of a secondary queue at the merge point. Downstream loop detection should be provided to allow the software to adjust metering rates if a queue is detected. This same location has advance warning signage for a "Congested Area" and is under consideration for additional advance signage as part of this project. Integration with this signage will be necessary when ramp metering is active, to decrease the likelihood of rear-end crashes with vehicles waiting for release. Cabinet placement within visual range of the ramp signal and development of enforcement areas appear to be feasible.

The existing ramp AM peak hour volume is about 1,000 vehicles per hour (VPH), the PM peak is lower. As according to the WSDOT design guidelines, a minimum of two metered lanes with at least 1,000 to 1,200 feet of storage is preferred. Final stop bar location will be determined during preliminary design. Placement should balance the need for storage and acceleration distance. The existing width of this ramp allows for two-lane operations during ramp metering, using an activated "Form 2 Lanes" signs. Figure 6 shows the notes from the field review summary.

Recommended Operations: Retrofit single lane ramp to a two-lane on-ramp during ramp metering and use alternating green release (maximum throughput = 1400 vehicles per hour). Consider a downstream enforcement or monitoring pad.

Figure 6: Ramp Meter - EB US 195 On-Ramp

EB Walnut Street On-Ramp

The eastbound on-ramp at Walnut Street is a two-lane ramp with limited storage given the necessary location of the stop line. The existing AM peak hour volume is 1,300 VPH. The design guidelines suggest three lanes with a combined storage capacity of 1,350 feet. Adding a storage lane to the Walnut eastbound on-ramp is not anticipated at this time.

Cabinet placement allowing for signal observation should be feasible. Development of an enforcement pad will not be feasible at this location. Shoulders are also limited at this location. Figure 7 shows the notes from the field review summary. Placement should balance the need for storage and acceleration distance and will be determined during preliminary design.

Recommended Operations: Two-Lane ramp meter with tandem release (maximum throughput = 1700 vehicles per hour).

Figure 7: Ramp Meter - EB Walnut Street On-Ramp

EB Monroe On-Ramp

The eastbound on-ramp at Monroe Street is a single lane ramp with approximately 700 feet of available storage capacity. The existing AM/PM peak hour volumes are 390/700 VPH. As according to the design guidelines, two lanes with a minimum of 700 feet of storage is suggested. Adding a storage lane to the Monroe eastbound on-ramp is not anticipated at this time.

The on-ramp becomes an auxiliary lane, which provides well over the minimum acceleration distance of 720 feet based on the stop bar location shown in Figure 8. While there is an uphill grade at this on-ramp, the grade decreases significantly where the proposed stop bar is shown.

Shoulder widths are limited at this location and Cabinet placement will not allow for the observation of the signal indications. An enforcement pad will also not be feasible at this location. Figure 8 shows the notes from the field review summary.

Recommended Operations: Single lane ramp meter with one vehicle per green (maximum throughput = 900 vehicles per hour).

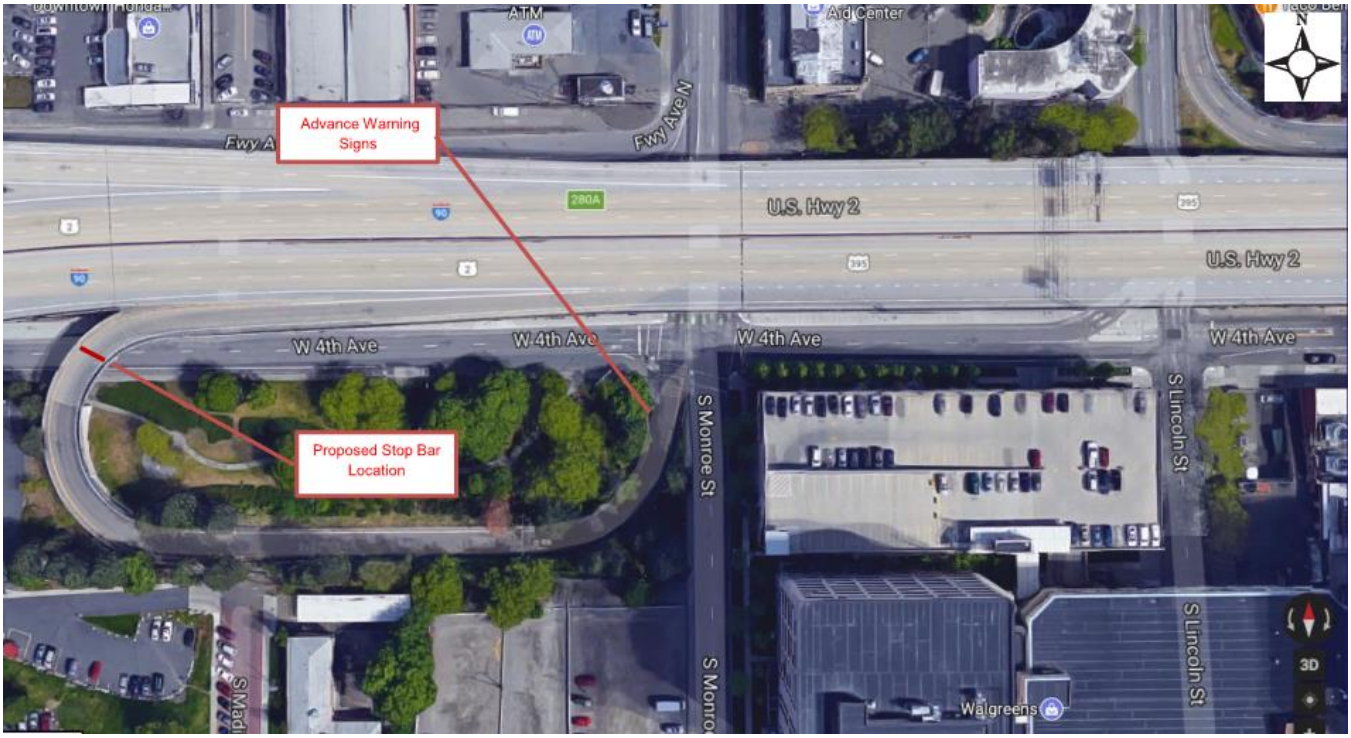


Figure 8: Ramp Meter - EB Monroe Street On-Ramp

EB Browne (Division Street) On-Ramp

The existing AM/PM peak hour volumes for Browne Street (Division Street) on ramp are 930/1,600. The design guidelines based on the PM peak hour volume suggest that three lanes with a minimum of 1,575 feet be provided where feasible. The existing facility is a two-lane ramp that can provide approximately 1,750 feet of storage. Widening this ramp (to three lanes) is not part of the initial implementation.

Shoulder widths are limited at this location. Placement of the controller cabinet will be outside the visual range of the signal indications. Enforcement area will not be feasible at this location. Figure 9 shows the notes from the field review summary.

Placing the stop bar as shown in Figure 9 provides over 825 feet of acceleration, meeting the minimum requirement for a freeway speed of 60 mph, a ramp speed of 40 mph, and a grade of 3% to 5%.

Recommended Operations: Two-Lane ramp meter with tandem release (maximum throughput = 1700 vehicles per hour).

Figure 9: Ramp Meter - EB Browne Street On-Ramp

EB Hamilton On-Ramp

The existing peak hour ramp volumes for Hamilton Road are 580/1040. Based on the design guidelines for the higher PM peak hour volume, two lanes with a minimum of 1200 feet are suggested. This facility is one lane, but wide enough to accommodate a two lane retrofit during ramp meter operations and can provide sufficient storage capacity.

Advance warning for queued vehicles during periods of metering would need to be a priority considering the higher approach speeds (posted at 40 MPH) combined with the depressed curve, affecting sight distance and stopping sight distance. These conditions and other applicable design standards would need to be evaluated and addressed during the detail design. Placement of the cabinet within visual range of the signal indications should not present a problem. An area for the placement and construction of an enforcement pad could be provided within the right of way. There are shoulders available on this ramp, consistent with ramp standards. Figure 10 shows the notes from the field review summary.

Recommended Operations: Retrofit single lane ramp to a two-lane on-ramp during ramp metering using alternating greens (maximum throughput = 1400 vehicles per hour).

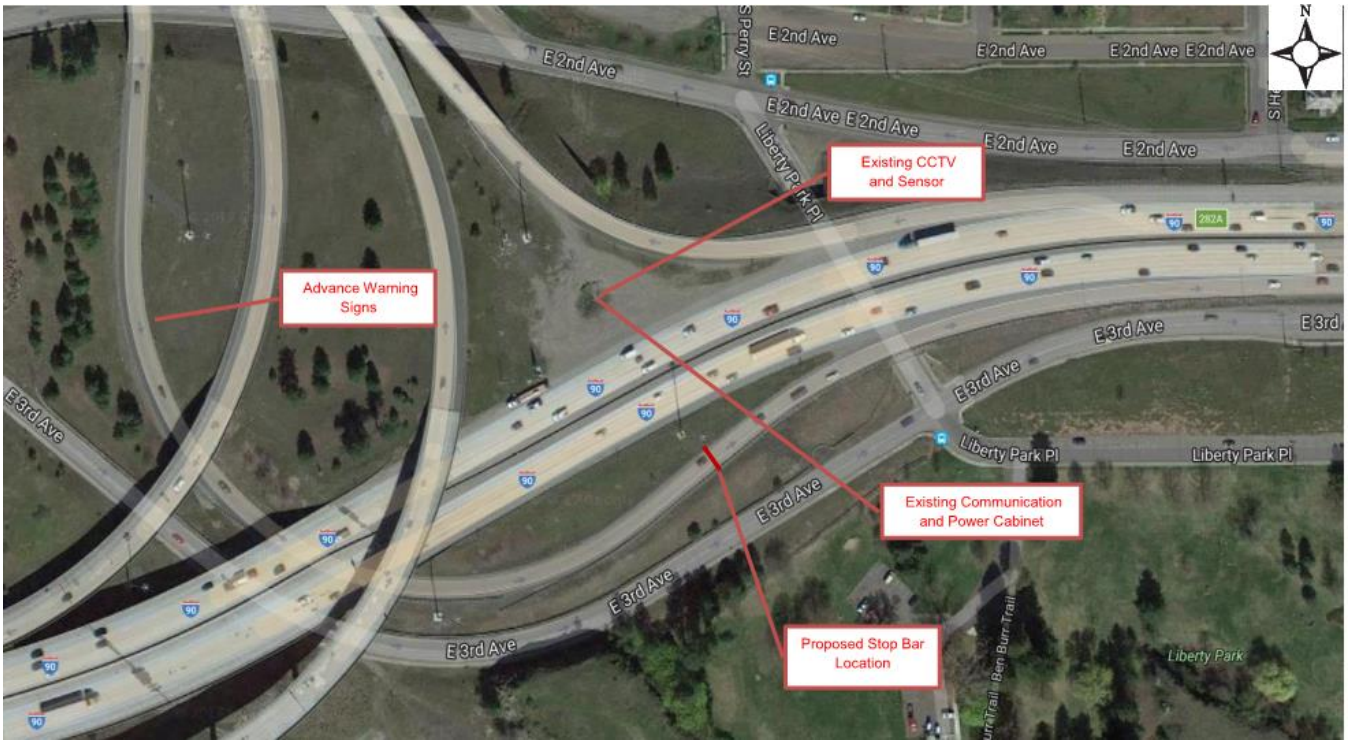


Figure 10: Ramp Meter - EB Hamilton Street On-Ramp

WB Browne (Division Street) On-Ramp

The westbound on-ramp at Browne Street is a single lane ramp that is accessed from a one-way street. The ramp rises up to meet I-90 which is elevated through this segment. With existing AM/PM peak hour volumes of 500/960, the design guidelines suggest two lanes with a minimum of 1050 feet of storage be provided for the PM peak hour. The existing one-lane facility provides about 500 feet of storage. Higher metering rate would need to be set to limit the queuing on the ramp during the PM peak hour.

Cabinet and advance warning beacons will be difficult to place at this location due to the proximity of a building, narrow sidewalk and a utility pole at the ramp entrance. Shoulder width is limited and an enforcement pad is infeasible. Figure 11 shows the notes from the field review summary. Placement should balance the need for storage and acceleration distance and will be determined during preliminary design.

Recommended Operations: Single lane ramp meter with two vehicles released per green (maximum throughput = 1200 vehicles per hour).

Figure 11: Ramp Meter - WB Division Street On-Ramp

System Operations

Operating and turning off ramp meter timing parameters requires a special skill set. Typically, this is accomplished with an engineer who is trained on the use of the specific ramp metering software. With six initial installations, the software vendor is likely to be able to provide the initial setup, training and fine tuning. An alternative would be for WSDOT experienced ramp metering personnel from another region to provide support for the initial setup, training and fine tuning. This would become more considerable if the Spokane area were to utilize the same software as that in Seattle (adaptive fuzzy logic). To maintain ramp meter timings after installation and initial fine tuning, dedicated ramp metering personnel or traffic signal personnel could assume the duties necessary for ramp meter adjustments.

The SRTMC operator roles depend on the system ultimately selected for implementation. Adaptive systems such as the WSDOT fuzzy logic system or CARMA, once fully setup, require little intervention, even in the event of a major incident. If a less advanced system of ramp metering were to be implemented, protocols should be established as to how often operators will monitor, review, and adjust the metering rates.

Ramp metering system operations depend largely on how aggressive WSDOT desires to manage the system. Common activities associated with ramp metering system operations are shown in Table 6. More detail, including specific resource needs for each activity, is provided later in Table 7.

Table 6: Ramp Metering Activities and Frequency

Activity	Frequency
Initial system installation, setup, and training	Once
System monitoring and fine-tuning adjustments	During weekday AM and PM peak hours
Periodic tuning and adjustments	Monthly, quarterly, or bi-annually
Maintenance repair or re-setup	As needed
Stakeholder coordination and public education efforts	Weekly (or more or less frequently as needed)
Annual review and analysis for potential upgrades	Once annually
Future upgrades implementation efforts	As needed (includes system upgrades as well as infrastructure improvements)

Ramp metering operations could vary depending on the different operational scenarios.

Operational Scenarios

This section describes different potential operational scenarios for ramp metering including peak commute hours, special events, incidents, and wrong way drivers.

<u>Weekday AM/PM Peak Commute Hours</u>

During the morning and evening commute hours, heavy traffic in both directions along I-90 in the Spokane area begins to cause slowing due to merging and weaving at the ramps. In response, the ramp metering system senses this occurrence and activates the affected (or all) ramp metering. Ramp metering rates are set depending on the system software (by time of day table or adaptive algorithm). The system also takes queuing into account and makes adjustments to the metering rates accordingly to limit excessive queuing.

Special Events

Nearby special events, such as after a major afternoon concert event at the Spokane Arena or an event ending at the Convention Center, affect the flow of traffic onto the freeway from Monroe Street and Browne Street and begin to significantly slow traffic on mainline during the commute hours or during off-peak hours. In response, the ramp metering system senses the slowing and higher densities and activates the (affected or all) ramp metering. Ramp metering rates are set depending on the system software (by time of day table or adaptive algorithm). The system also takes queuing into account and makes adjustments to the rates accordingly to limit excessive queuing.

Incidents and Crashes

Either during the peak commute hours or during the off-peak, a stalled vehicle or collision occurs that causes congestion and slowing vehicles. The ramp metering system detects the slow down and activates the (affected or all) ramp metering, and queues begin to form on the ramps. An emergency responder vehicle needs to access the incident's adjacent on-ramp but it is blocked with the ramp metering queued vehicles. The preemption is triggered (depending on the software either automatically, or manually by the TMC operator), turning the meter to all green to flush the traffic. Once the incident is cleared metering continues until the queue on the Interstate is dissipated. Once dissipated, the ramp metering system returns to standby status.

Wrong Way Driver Notification System

The Wrong Way Driver Notification System detects a wrong-way vehicle in the eastbound direction of I-90, all ramp meters in the eastbound direction upstream of the detection, automatically activate to red light as part of an effort to hold traffic from entering the freeway and avoid the potential of a head on collision. After the WWD incident is cleared, the system may return to normal operations either by a manual reset or automated means.

System Coordination with Other Systems

Local Agencies that operate the arterial signals should be kept informed during design. Until the system can be tuned to work with demand, keeping the local agencies informed on what is being done to limit queueing will be important in maintaining support for ramp metering at the local political level. During the initial deployment and operations, close communications with local traffic engineers are needed. Adjustments to the local intersection signal operations may also help control the demand to the ramps and limit the queuing. Once the ramp metering operations are established and stable, continued coordination with the local stakeholders on a weekly or periodic basis will help to keep the operations efficient and smooth running.

Support Environment and Costs

This section describes the stakeholders, their roles and responsibilities, resource needs, and high-level cost estimate for the ramp metering system.

Ongoing system maintenance and support will be needed. Planning and budgeting support will be essential.

Stakeholders

The primary stakeholders of the ramp metering include the following:

- WSDOT operations and Signals and Electronics personnel
- State patrol, local law enforcement, and other emergency responders
- Local agency operations personnel
- traveling public
- SRTMC

Roles and Responsibilities

The stakeholders responsible for the operation of the ramp meter system will be WSDOT Eastern Region Traffic and SRTMC personnel. Their primary responsibility will be to monitor traffic performance and operating conditions and maintain the timing parameters associated with ramp metering software. The operators should also work with local agencies on traffic operations around interchanges and management of queue lengths. Depending on how the system is implemented a contracting vendor may provide for the initial setup of timing parameters; however, the responsibility for the quality execution of that effort will be with WSDOT personnel. The personnel should also be prepared and work with local stakeholders continuing outreach about the need, use and benefits of ramp metering.

WSDOT Signals or Electronics crews will need to maintain the ramp metering system. Response to ramp meter signal damage or malfunction should be treated as if they were a signalized intersection and given a high priority of response.

Operations staff should also work with the State Patrol to work on ensuring compliance and enforcement of the ramp metering. Initially this could be handled as a “warning” activity to help with education. Most areas with ramp meters have found that special enforcement periods may be needed to ensure compliance.

Operations staff should also coordinate with the appropriate local agencies operating the arterial network to communicate with the public to set expectations for ramp metering and to assist with educational outreach. Open lines of communication will need to be maintained if queuing is found to be problematic at any location.

Resource Needs

Resources needed for ramp metering operations depend largely on how aggressively WSDOT desires to manage the system. In general, ramp metering could be regarded in a similar manner as traffic signal management, in terms of resource effort. There is a need for initial tuning for optimization for effectiveness. Once established, the system can operate without need for much interaction. Routine monitoring and periodic adjustments are then made as needed.

At least one assigned ramp metering system operator, one or more assigned ramp metering system maintenance technicians, and dedicated enforcement by State Patrol should be considered for future operations and maintenance. Table 7 outlines the potential ramp metering resource needs to consider for each activity.

Table 7: Ramp Metering Resource Needs

Activity	Description	Frequency
System installation, setup, and training	**Operator:** In this activity, one or more (potential) operators would be assigned to ramp metering system operations and maintenance support. Estimating four weeks of installation, setup, testing, and refinement at 6 hours per day would total about 120 hours for consideration. Two days of training would add about 16 hours. This estimate would apply for the assigned operator(s) and additionally for the field maintenance support. **IT Support:** For system installation and setup, IT support will be needed to ensure all software integration and initiation is done and working properly with cybersecurity protection. An estimate of about 24 hours may be needed. **Enforcement:** Initial law enforcement would be more frequent than for on-going need, handing out warnings as part of educating the public instead of citations. Estimating four weeks of initial operating period, initial enforcement could be provided for about 40 hours (about 2 hours per day during the peak operating hours for 20 weekdays).	one-time resource need
System monitoring and adjustments	**Operator:** On-going monitoring is assumed for the AM and PM peak hours for an annual total of about 480 hours (2 hours per day during the peak operating hours for 240 weekdays) for consideration. **Field Maintenance:** For maintenance support, it is assumed half hour of monitoring each day for an annual total of about 120 hours. **Enforcement:** For on-going law enforcement, it is assumed citations would be issued after the initial period, for an annual total of about 150 hours (periodic enforcement during the peak hours at various times at estimated 3 hours per week for 50 weeks).	on-going resource need
Periodic tuning and adjustments	**Operator & Field Maintenance:** Periodic tuning and adjustments to the ramp metering rates, program parameters, and settings would be needed. For the operator and for field maintenance support, each group is estimated at 4 days of 6 hours per day, 2 times each year, for an annual total of 48 hours. **IT Support:** Periodic tuning and adjustments may include adjustments to the system connections, firewalls, and software upgrades. To provide this support, about 8 hours is estimated for each year. **Enforcement:** With changes to operating days or times and/or metering rates, increased violations could result. Increased enforcement should be assigned during the brief period following the changes. The resource need should be taken or shifted from the on-going system monitoring so no additional resources would be needed.	on-going resource need

Activity	Description	Frequency
Maintenance repair or re-setup	The system will need periodic maintenance and repair including the system software, hardware, or detection. Once repaired, the system will need to be re-set and operations observed for any adjustments or tuning. **Operator:** An estimate of at least 4 days at 6 hours per day, 2 times each year, for an annual total of 48 hours. **IT Support:** An estimate of about 8 hours may be needed each year to provide IT support to re-install or upgrade software, trouble-shoot errors or software glitches, and/or implement system solutions. **Field Maintenance:** For the maintenance support, it could take considerably more resources to conduct the repairs for an estimate of 2 people, 10 days of 8 hours per occurrence (2 times each year), for an annual total of 320 hours. **Enforcement:** No additional resource need is estimated for law enforcement.	on-going resource need
Stakeholder coordination and public	For successful and effective ramp metering operations in the long term, close coordination and collaboration with local agencies, emergency responders, and stakeholders would be needed. In addition, efforts to educate the public motorist, as well as local agency and elected officials, would also help. **Operator:** For the operator, an estimated 2 hours of coordination and education effort per week, 50 weeks per year, would total 100 hours annually for consideration. Education effort could include providing information to the local agencies and stakeholders, posting information messages on the WSDOT VMS, participating in meetings, and presenting at various forums and events. **IT Support and Field Maintenance:** No additional resource need is estimated for IT or maintenance support. **Enforcement:** Law enforcement personnel interact directly with the public motorists. Educating motorists on traffic safety is part of their routine. Additional resource need for this activity could include participating in meetings and presenting at various forums and events. Estimate of 4 hours per month for 12 months, for an annual total of 48 could be considered.	on-going resource need
Annual review and analysis for upgrade	**Operator:** The operator should conduct a review, research, and analysis for possible upgrades as needed, occasionally participating in meetings and events that pertain to ramp metering. Assuming that this occurs once a year for about 3 days, at 8 hours per day, an estimate of 24 hours could be considered.	on-going resource need

Activity	Description	Frequency
	IT Support, Field Maintenance, and Enforcement: No additional resource need is estimated for IT support, maintenance support, or law enforcement. However, they can be consulted for any significant potential changes to the existing ramp metering system. The resource needs can be shifted from on-going monitoring.	
Future upgrades implementation	It is anticipated that eventually the system will need to undergo a significant modification for upgrade, either system software, hardware, detection, or even system configuration and redesign. Operator, IT support staff, field maintenance support staff, and even law enforcement personnel would need to get involved in the upgrade. Field maintenance support staff would need to review and coordinate the support needs of any significant changes. Law enforcement personnel should review and coordinate impact to enforcement needs with the changes. Estimate of the hours needed would depend on the occurrence and level of upgrade.	one-time resource need

Planning-Level Cost Estimate

Ramp metering costs for installation can increase greatly if roadwork is required to accommodate storage. All estimates provided do not include any roadwork and have assumed that design exceptions can be obtained for the shorter than needed storage lengths available in the Spokane area. Other factors that have significant influence on installation costs are availability of communications not only for the ramp meter, but the necessary up and down stream detection stations as well. The re-use of existing detection on the mainline can decrease the costs of installation so long as the detection is reliable and operational in all lanes.

The planning level cost estimate includes assumptions that may change when the project moves to detailed design. For that reason, some contingency is added to the cost estimate. As detailed design plans are developed, the costs will be refined. The cost estimate assumptions and unit costs are shown in Table 8.

Total installation of the six ramp meters described in this operational concept is expected to be approximately $2 million.

Table 8: Ramp Meter High Level Cost Estimates – Six On-Ramps

Item	Quantity	Cost	Total
Ramp Meter w/ Detection (includes signal, foundation, detection, advance signs, and controller)	6	$95,000	$570,000
Additional Communication and Power connections	6	25,000	150,000
Software Package (Adaptive Ramp Metering)	1	$350,000	$350,000
Software activation and tuning	6	$20,000	$120,000
Design, Construction Engineering, and Contingency	1	850,000	850,000
Total Initial Cost			$2,040,000
Maintenance (Annual)			$50,000

The annual maintenance includes the necessary services to keep the ramp meters running as well as additional staff time for "tuning-up" the ramp meter timing. Ramp meters running the adaptive algorithms will require periodic data collection and analysis. Timing adjustments must be made to keep the ramp meters running in balance between arrivals, releases, queueing and freeway capacity. While the program is "self-adjusting" timing parameters should be reviewed twice a year to avoid queueing problems due to traffic shifts. The first year of ramp metering will require additional funding to maintain a smooth operation and to respond to queueing issues.

Operational Policies and Constraints

The WSDOT design standards and specific policies regarding ITS and ramp metering should govern ramp metering development, deployment, and operations. Local design and operational practices could also provide policies and/or constraints. Coordinating with local agency staff could help avert any potential conflicts with design and future operations. WSDOT should anticipate a request to put limitations on queueing from the ramp meters onto the surface streets. If ramp meters malfunction maintenance response should be a priority similar to that of a malfunctioning signal system at a major intersection with a State route. Impacts due to malfunctions can cause major delays and quickly erode the public's respect for the ramp metering system.

WRONG WAY DRIVER NOTIFICATION SYSTEM

While wrong way driving incidents are infrequent, when wrong way crashes do occur the results are typically severe. Studies indicate that wrong way crashes are up to 27 times more likely to result in a fatality than other crash types.[8]. Along this corridor, there were nine wrong way crashes over the five years of crash data analyzed (2011-2015) and three of those resulted in fatalities, accounting for 38 percent of all fatalities along the corridor. A wrong way driver notification system is an investment that could reduce the number of wrong way crashes. Wrong way notifications systems can reduce wrong way crashes by over 40 percent. In San Antonio the number of wrong way driver reports fell from 269 to 162 in the five years since the WWD notification system was installed; and in Rhode Island and Florida's turnpike system 99 percent of detected wrong way drivers self-corrected after the WWD notification system was installed. [9]

In addition to added technology, a wrong way driver notification system should also address low cost countermeasures such as signing, pavement marking, and other physical improvements. WSDOT recently increased the size of all the off-ramp WRONG WAY signs, which is one such countermeasure. Other effective low-cost countermeasures to consider include:

- Install wrong way arrows on exit ramps
- Lower the mounting height of WRONG WAY and DO NOT ENTER signs
- Add red retroreflective sheeting on sign supports
- Install pavement markings to improve channelization
- Consider improved signing and channelization at access points where drivers can more easily access the freeway the wrong way.

The technology based side of the wrong way driver notification system would actively alert drivers entering the freeway ramp in the wrong direction. These alerts could include flashing lights around WRONG WAY signs, and even in-pavement activated lights (as illustrated in Figure 13, Option C). Under optimal conditions this would allow the driver of the wrong way vehicle time and space to turn around before entering the freeway in the wrong direction. These solutions are typically effective for elderly and slightly impaired drivers.

However, when these solutions are not effective, additional measures to notify right way drivers, TMC operators, and law enforcement can help minimize crashes. Radar (or other detection such as thermal cameras) can detect a wrong way vehicle entering the freeway. When a vehicle is detected entering the freeway in the wrong direction, travel alerts could automatically be sent out from the controller. The alert could also be sent to law enforcement dispatch services, operators at the TMC, and possibly integrated into other operational systems, such as the ramp meter systems for holding of traffic and/or confirmation of the wrong way vehicle's location.

In the future, further integration with in-vehicle devices may be possible either directly or through "pushed traveler information messages". Pushed traveler information messages are messages that can be sent to cellular phones within a specific geographic location sending a personalized warning message to all potentially affected

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[8] Highway Special Investigation Report: Wrong-Way Driving. National Transportation Safety Board. NTSB/SIR-12/01. PB2012-917003. Adopted Dec 11, 2012.
[9] Article: http://www.pewtrusts.org/en/research-and-analysis/blogs/stateline/2017/12/19/technology-is-turning-wrong-way-drivers-around, Dec 19, 2017. Accessed Jan 2018.

drivers. Data collected by the system as part of the maintenance monitoring activity, will provide volume data from the off ramp for planners and system operators. Data from the sensors can also be used to identify the ramps with the highest number of wrong way drivers allowing engineers to target improvements at the ramps with the most wrong way drivers.

Existing geometry and its potential to allow wrong way vehicles at each off-ramp determines the design layout for a wrong way driver notification system. Figure 12 and Figure 13 illustrate some typical components and layout of a wrong way notification system. Several states are working on different types of WWD notification systems including Arizona and Texas. Figure 13 is a prototype from Arizona DOT, and shows how the system will connect to VMS, ramp meters, law enforcement and TMC operators.

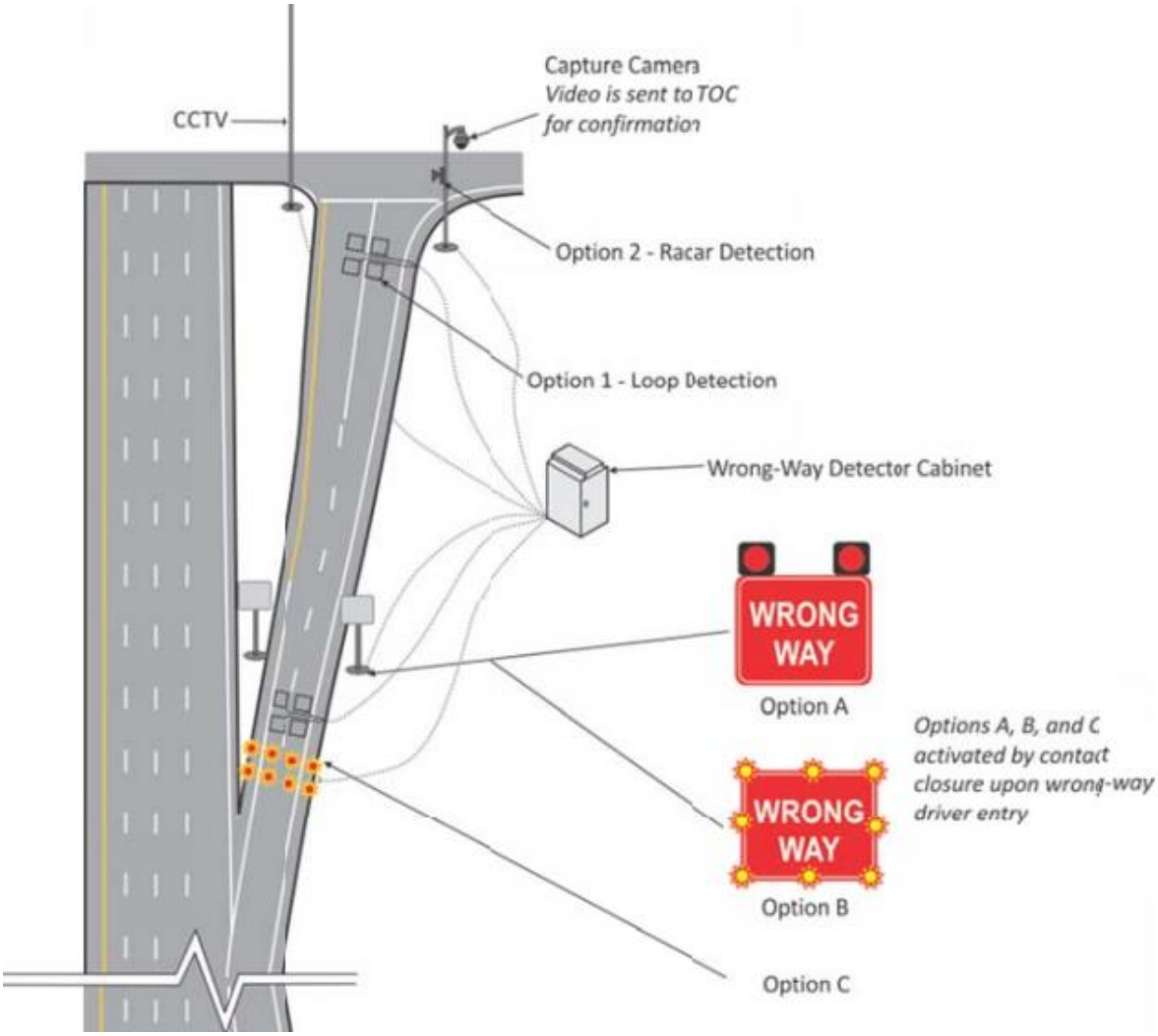


Figure 12: Example Components and Layout of a Wrong Way Driver Notification System

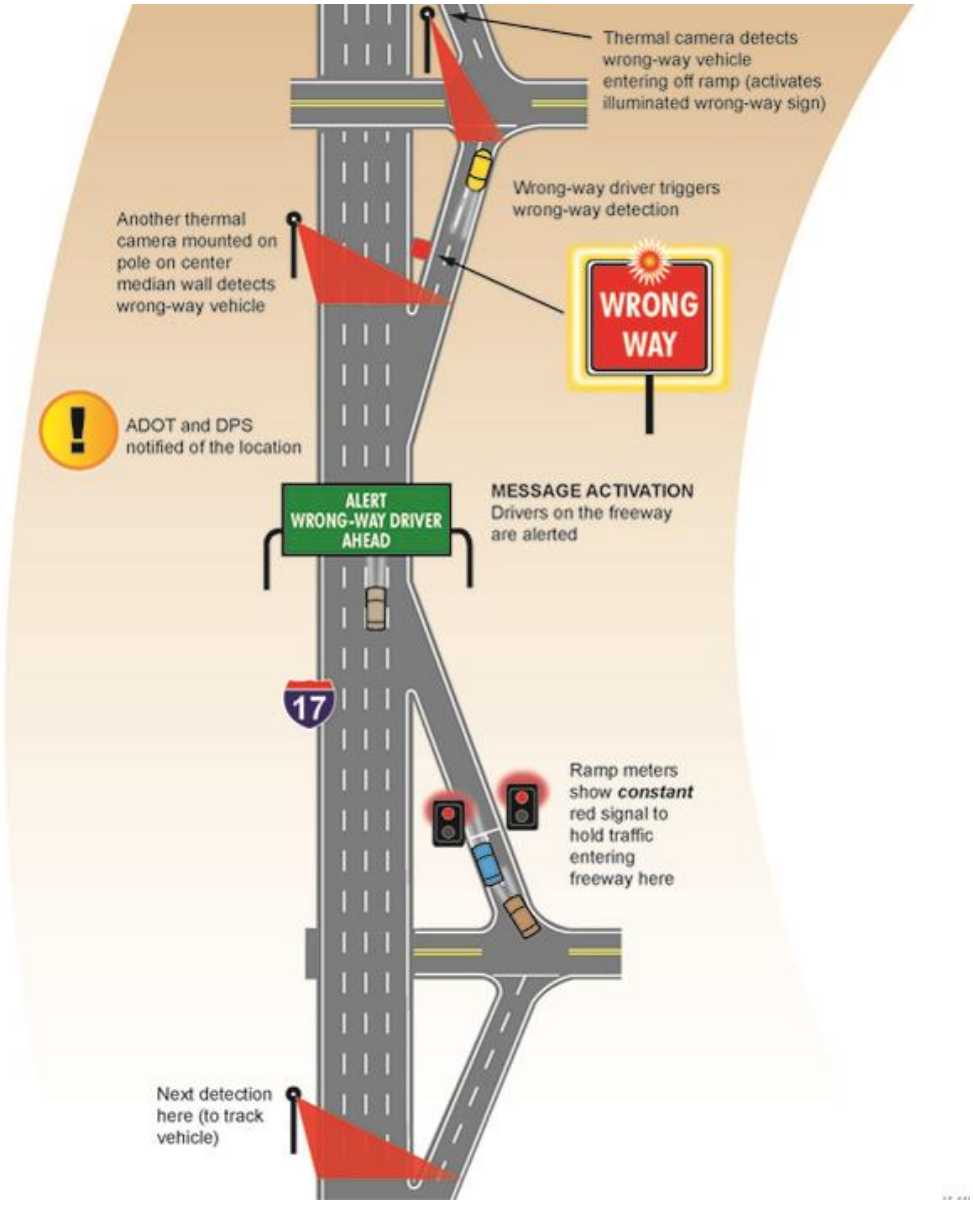


Figure 13: Example Wrong Way Notification System Configuration – Arizona DOT

Intended Purpose of the System

The purpose of the wrong way driver notification system is to alert drivers that they are entering the freeway in the wrong direction to allow for self-correction prior to entering the freeway ahead. If the driver does not self-correct, then messages can be displayed to inform right way drivers and allow them to make decisions to minimize their risk, while also informing TMC operators and law enforcement. The wrong way driver notification system consists of detection (e.g., loops, radar, or video), video capture, warning signs (many different designs most utilizing red LED indications) and freeway entry detection, as well as improvements to signing and pavement markings. Alert systems to the public traveling along the same route in the proper direction include the use of VMS messaging. All systems automatically alert the State Patrol or law enforcement

agency responsible for the highway. Further consideration for development in Spokane may include integration with the ramp metering system.

For the first phase of implementation, 16 off-ramps were selected:

EASTBOUND	WESTBOUND
EB Walnut off-ramp	WB Freya off-ramp
EB Division off-ramp	WB Altamont off-ramp
EB Hamilton off-ramp	WB 2nd Avenue off-ramp
EB Altamont off-ramp	WB Hamilton off-ramp
EB Freya off-ramp	WB Division off-ramp
EB Sprague off-ramp	WB Lincoln off-ramp
EB Broadway off-ramps	WB Maple/Walnut off-ramp
	WB Broadway off-ramp
	WB Sprague off-ramp

Functions and System Design

The wrong way driver notification system typically operates in an automatic mode, requiring no initial action by personnel. The greater the automation will translate into a rapid response being provided to the public. Wrong way driver notification systems have two basic modes. The first allows for "driver self-correction" before they pass the warning sign and enter the freeway in the wrong direction. The second mode is the full response mode. This mode is automatically activated once a vehicle is detected as entering the freeway in the wrong direction.

Driver Self-Correction Mode

At this level of activation, the wrong way driver has entered the freeway off-ramp as if it were an on-ramp, but has not reached the freeway lanes. At the point of off-ramp entry, the system detects the vehicle and activates the warning system. The warning system consists of an active warning message typically in the form of a wrong way sign with red LED flashing indications around the border. Other systems to consider for deployment include the use of red flashing beacons above or below the sign, and illuminating pavement markers (similar to cross walk marking devices, only with red indications). This self-correction mode allows the driver to respond to the indications by turning around or seeking shelter on the ramp shoulder before entering the freeway. The driver will present a hazard while turning around or possibly can exit the ramp in reverse on a shoulder if available for use and stay out of the travel lanes.

Full Response Mode

The full response mode is activated once the vehicle moves past the warning sign and passes over the gore point detection system, entering the freeway in the wrong direction. It is the passing over the gore point detector that generates the activation of the fully automated response. Law enforcement and the TMC operators are both sent notices of the activation allowing for immediate dispatch of law enforcement and response personnel. Simultaneously the ATMS can activate pre-approved messages for display on all affected VMS along the freeway for motorists traveling in the correct direction.

ATMS Integration

ATMS integration can be accomplished via multiple methodologies depending on the objectives and user requirements. The wrong way driver notification system will at a minimum require integration for activation of the VMS messaging. Beyond the basic integration for VMS messaging will be dependent on the other systems existing integration and the capabilities of the existing ATMS software. This system software module may be available as a stand-alone module and use of a tested module may be a better solution if it exists from the potential vendors.

Integration with law enforcement agencies may also help to minimize the exposure time to the potential wrong way vehicles. This can be accomplished through integration with the ATMS system or potentially a more fault tolerant methodology would be directly from the controller cabinet via a contact closure upon activation of the full response mode.

Design Layout

Central to the wrong way driver detection is the inclusion of two zones of detection. Both zones must maintain a high level of reliability for the system to function effectively. Any detection technology can be deployed in these zones, but careful consideration should be given to the weather conditions typical for the area and the condition of the pavement. Assuring the continuous operability of the detection systems will need to be accomplished by the software package developed to analyze the wrong way system. If a fault is discovered through an extended period of non-reporting of detections then a maintenance alert should be generated. WSDOT personnel should be consulted before selecting the technology for these zones of detection for the best solutions given all constraints including the number of lanes. The software selected and the reliability of that software to accurately identify wrong way drivers is equally critical. Warning sign technologies are considered independent of the software and detections systems. Most warning systems will be controlled via a contact closure so any appropriate technology will work. Reliability and serviceability should also be carefully considered as these systems once deployed must remain fully operational. Consideration should be given for redundancy within the system if WSDOT determines these systems to be critical safety systems or as having liability consequences if they fail to detect a wrong way driver.

The system components are positioned with a detection zone near the exit of the off ramp (providing initial detection of the wrong way vehicle), a warning sign positioned on the ramp such that the driver can see and understand the message before they would pass it, and a detection zone at the beginning of the ramp near the gore point for detecting entrance onto the freeway.

Each of the wrong way driver notification system ramp locations were field reviewed in August 2017 for consideration of installation. Ramps typically present similar design challenges including: the need to mount equipment on a structure due to the limited shoulder widths and the constraints imposed by the raised freeway segment, the need to expand communications and power to access the project site, and short ramps or multi-lane ramps. The matrix in Figure 14 shows design considerations for each location.

	Off – Ramp Location	Short Ramp (Slip), need for detection internal to sign	Radio Communications required	Need to mount equipment on structure	Multi-lane ramp, use of video or radar detection	New service drop/point required
EB Walnut St.			X	X		
EB Division St.			X			
EB Hamilton St.						
EB Altamont	X	X - to S Thor St				X
EB Freya	X	X - to S Thor St				X
EB Sprague				X		X
EB Broadway				X		
WB Broadway				X		
WB Sprague				X		
WB Freya	X	X - to S Thor St				X
WB Altamont	X	X - to S Thor St				X
WB 2nd Avenue	X	X - to Hamilton IC				X
WB Hamilton		X - to Hamilton IC				X
WB Division St						
WB Lincoln						X
WB Maple/Walnut						X

Figure 14: Wrong Way Driver Notification System Design Considerations

A short slip ramp could present design challenges for the implementation of wrong way driver notification system. With short slip ramps the period of time between detection and entry onto the freeway is very short. It would be helpful for these locations to have a warning sign with integrated detection be used for the initial "driver self-correction mode" detection. Another design consideration is the detection of vehicles traveling along the parallel frontage road as entering the freeway off ramp. Careful screening of the detection technology will be required to ensure false positive detections are avoided or minimized.

As with all design features related to the wrong way driver notification system, maintenance and reliability of communications from the field elements will be critical to assuring system operators that the system will function properly in the event detection takes place. The use of radio communication, as required for many of the installations, will need to be monitored by the system to assure that the link remains open at all times. The use of direct fiber or leased service connections is preferred over radio communication where available.

The development and deployment of wrong way driver notification systems are increasing across the U.S. as such the technologies and alternatives to address special design concerns are growing as well. The development of warning signs with internal detection capabilities is also being proposed for deployment. Presently the deployment of this type of integrated technology is limited.

System Operations

This section describes how the wrong way driver notification system can coordinate with other systems, as well as different operational scenarios.

System Coordination with Other Systems

The wrong way driver notification system will need to interface with systems internal and external to the WSDOT system. The wrong way driver notification system may be integrated into the existing ATMS software through the development of a new module or operated as a standalone software package. If an interface is desired with the ramp meter system and/or the VMS control module that is contained in the ATMS system additional interface development will need to be required.

In addition to the WSDOT ATMS integration, an interface will be required for the State Patrol dispatch system or at a minimum the development of a standalone notification system through which the Dispatchers can be automatically notified of an activation of the full response system. The interface for a self-correcting event could be automated or possibly handled via a standard operating procedure designed to direct TMC operators to provide the proper information to the dispatchers as desired by the State Patrol.

Operational Scenarios

The following paragraphs describe the difference between driver self-correction and full response operational scenarios.

<u>Driver Self-Correction Scenario</u>

A vehicle would inadvertently enter a freeway off-ramp. As the vehicle enters the ramp, it would be detected by the system which immediately activates the alert messaging signs. The flashing red LED's and wrong way sign catch the driver's attention, and the driver pulls over to the shoulder and quickly and safely executes a "U-turn". Potential crash would be averted because of the driver notification system. Notification of the initial self-correcting scenario is sent to the TMC where operators review the CCTV images. The TMC operator notifies the State Patrol of the averted incident and passes on the pertinent information as required.

<u>Full Response Scenario</u>

A vehicle would inadvertently enter a freeway off-ramp. As the vehicle enters the ramp, it would be detected by the system which immediately activates the alert messaging signs. The flashing red LED's and wrong way sign would catch the driver's attention; however, rather than noticing and reacting to the flashing red LED lights on the wrong way signage, the driver would continue up the off-ramp to the freeway. Immediately the system automatically would notify the State Patrol and SRTMC that a wrong way vehicle just entered the freeway at the specific ramp location. The upstream on-ramp signals would automatically be activated and display continuous red indications, holding traffic from entering the freeway as the wrong way driver approaches. VMS signs would also be activated for the traffic that opposes the wrong way driver and many begin to pull onto the shoulders seeking to avoid a head on crash and clearing the freeway of vehicles. The State Patrol would send all available units to the freeway as part of an effort to stop the wrong way driver. The State Patrol requests any additional information about the description of the vehicle from the TMC operators who begin to review the CCTV images captured beginning moments before the vehicle entered the off-ramp.

The State Patrol would then notify their dispatch that the vehicle has been stopped and that the ramp meter lights can be released and the VMS's deactivated. As the situation is de-escalating the TMC operators manually de-activate the forced ramp meter all red system and de-activate the VMS messages.

Support Environment and Costs

This section describes the stakeholders, their roles and responsibilities, resource needs, and high-level cost estimates for the wrong way driver notification system.

Stakeholders

The primary stakeholders of the ramp metering include the following:

- WSDOT ER Traffic and Maintenance personnel
- State Patrol, local law enforcement, and other emergency responders
- Local Agency Operations personnel
- Traveling public
- SRTMC

The interaction is mostly between the SRTMC operators and the traveling public. State Patrol as well as local agencies can be involved when they become aware of the system not working properly and notifying WSDOT personnel.

Roles and Responsibilities

WSDOT will develop, install, operate, and maintain the wrong way notification system. Maintenance will be dependent on the degree of criticality assigned to these systems. Coordination meetings with State Patrol and local agencies should be conducted to inform them of the system installation and who to notify if they come to know that the system is not functioning properly.

Resource Needs

Resources needed for the wrong way driver notification system depend largely on the level of system automation. If the system requires the messaging to be made manually, it will require dedicated resources ready to respond during peak times. If the system is semi-automatic to automatic, resource needs would be higher at the initial operating period and would lessen as the system matures. Once established, the system can operate on their own without need for much interaction. Routine monitoring and periodic adjustments are then made as needed.

At least one assigned system operator and one or more assigned system maintenance personnel should be considered for future operations and maintenance. Table 9 outlines the potential wrong way driver notification system resource needs to consider for each activity.

Table 9: Wrong Way Driver Notification System Resource Needs

Activity	Description	Frequency
System installation, setup, and training	**Operator:** In this activity, one or more (potential) operators would be assigned to system operations and maintenance support. Estimating four weeks of installation, setup, testing, and refinement at 6 hours per day would total about 120 hours for consideration. Two days of training	one-time resource need

Activity	Description	Frequency
	would add about 16 hours. This estimate would apply for the assigned operator(s) and additionally for the maintenance support. **IT Support:** For system installation and setup, IT support will be needed to ensure all software integration and initiation is done and working properly with cybersecurity protection. An estimate of about 24 hours may be needed.	
System monitoring, testing and adjustments	**Operator:** In this activity, routine on-going monitoring and system adjustment is assumed for an annual total of about 240 hours (1 hour per day for 240 weekdays) for consideration. This can be tapered down as the system matures and is proven reliable. **Field Maintenance:** For maintenance support, it is assumed half hour of monitoring each day for an annual total of about 120 hours.	on-going resource need
Periodic tuning and adjustments	**Operator:** In this activity, periodic testing, tuning, and adjustments would be needed. For the operator and for system maintenance support, each group is estimated at 2 days of 6 hours per day, 2 times each year, for an annual total of 24 hours. **IT Support:** Periodic tuning and adjustments may include adjustments to the system connections, firewalls, and software upgrades. To provide this support, about 8 hours is estimated for each year.	on-going resource need
Maintenance repair or re-setup	The system will need periodic maintenance and repair including the system software, hardware, or detection. Once repaired, the system will need to be re-set and operations observed for any adjustments or tuning. Once repaired, the system will need to be re-set and operations observed for any adjustments or tuning. **Operator:** For the operator, an estimate of 4 days at 6 hours per day, 2 times each year, for an annual total of 48 hours. **IT Support:** An estimate of about 8 hours may be needed each year to provide IT support to re-install or upgrade software, trouble-shoot errors or software glitches, and/or implement system solutions. **Field Maintenance:** For the maintenance support, it could take considerable more resources to conduct the repairs for an estimate of 2 people, 5 days of 8 hours per occurrence (2 times each year), for an annual total of 160 hours to be conservative.	on-going resource need
Stakeholder coordination and public	Coordination and collaboration with local agencies, emergency responders, and stakeholders is recommended. In addition, efforts to educate the public motorist, as well as local agency and elected officials, may also be needed, if requested by a stakeholder.	on-going resource need

Activity	Description	Frequency
	Operator: For the operator, a nominal 40 hours annual total is estimated for consideration. Education effort could include providing information to the local agencies and stakeholders, participating in meetings, and presenting at various forums and events. No additional resource need is estimated for IT or field maintenance support.	
Annual review and analysis for upgrade	**Operator:** It is anticipated that the operator will conduct a review, research, and analysis for possible upgrade as needed, occasionally participating in meetings and events that pertain to wrong way notification system. Assuming that this occurs once a year for about 3 days, at 8 hours per day, an estimate of 24 hours could be considered.	on-going resource need
Future upgrades implementation	It is anticipated that eventually the system will need to undergo a significant modification for upgrade, either system software, hardware, detection, or even system configuration and redesign. Operator, IT support staff, field maintenance support staff, and possibly law enforcement personnel would need to get involved in the upgrade. Field maintenance support staff would need to review and coordinate the support needs of any significant changes. Law enforcement personnel would need to review and coordinate impacts to response need with the changes. Estimate of the hours needed would depend on the occurrence and level of upgrade.	one-time resource need

Planning-Level Cost Estimate

The planning level cost estimate includes assumptions that may change when the project moves to detailed design. For that reason, some contingency is added to the cost estimate. As detailed design plans are developed, the costs will be refined. The cost estimate assumptions and unit costs are shown in Table 10.

For the purposes of this project, two types of wrong way driver notification systems are assumed: an internal detection system for the off-ramps that are short, and a more advanced version including separate detection and activated signs for the longer ramps. The reuse of existing CCTV's cameras will help contain the overall cost of the system. The cost for software required to analyze the wrong way detection and push the necessary activation notices is largely unknown as very few systems have been deployed. A conservative place holder of $200,000 is included for this software development work.

Table 10: Wrong Way Driver Notification System High Level Cost Estimates – 16 Off-Ramps

Item	Quantity	Cost	Total
Install system with alert signs	11	$50,000	$550,000
WWD system with internal detection (short ramps)	5	$6,000	$30,000
Additional power and communication connections	16	$20,000	$320,000
Additional mainline detection	10	$10,000	$100,000
System software upgrade and setup	1	$200,000	$200,000
Additional VMS	1	$400,000	$400,000
Signing and pavement marking improvements (at off-ramps)	16	$10,000	$160,000
Design, Construction Engineering, and Contingency	1	$1,200,000	$1,200,000
Total Initial Cost			$2,960,000
Maintenance (Annual)			$25,000

Operational Policies and Constraints

As these are new systems to be deployed for the first time by WSDOT, operational policies or design constraints are likely to be limited. The policy area that needs to be defined is with the system up time reliability or the wrong way drive alert system. Depending on final decisions being made the need for immediate response to failure detections or other system errors the cost to operate these systems could vary widely.

Because of the interconnection to the State Patrol dispatch, some additional constraints or requirements may be placed on the systems design. Law enforcement agencies are typically bound by the State Department of Justice or even Federal requirements for control of personnel information, allowing the interconnection to the dispatch system the first time in a State can present challenges.

QUEUE AND MERGE WARNING SYSTEM

Queue or merge warning system is part of the active traffic management (ATM) strategy to reduce rear-end collisions and reduce congestion. A queue warning system is typically deployed to alert motorists to queuing conditions ahead. With advance warning, drivers can slow down and possibly avoid crashes. This system will use the existing electronic message signs on the corridor and three new electronic signs at specific locations to target areas where vehicle queues and merging issues are most frequent along the I-90 corridor. The installations typically incorporate an electronic message board (referred to as a variable message sign, or VMS), and a detection system with software to determine the existence of a vehicle queue. A message that is pre-approved for the condition will automatically activate and de-activate as queues form and dissipate. Figure 15 illustrates an example of a queue warning system design layout.

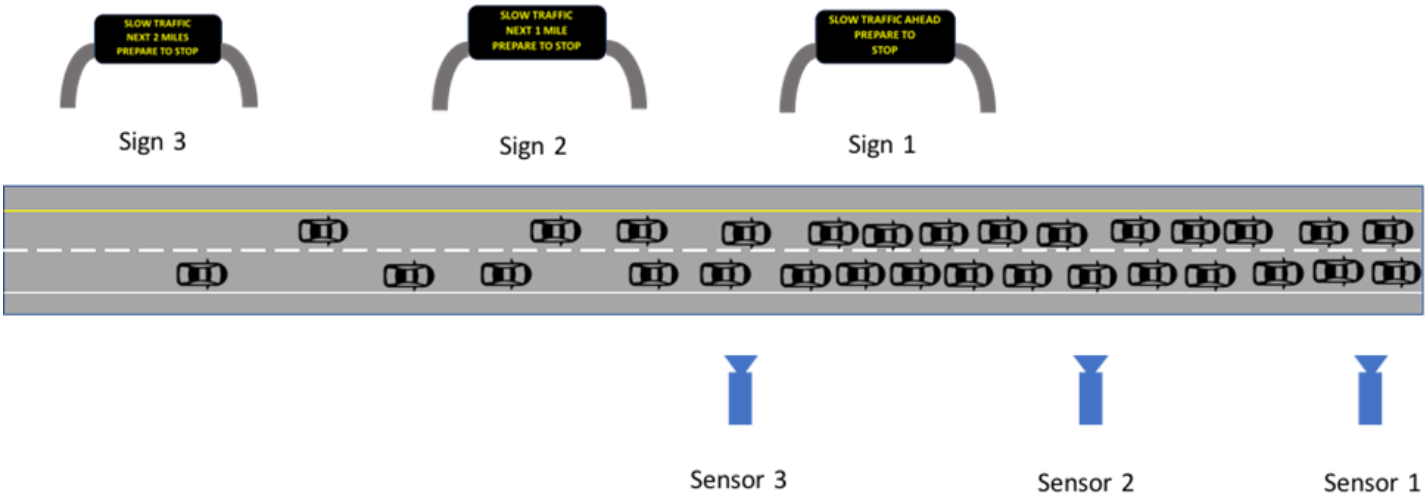


Figure 15: Example Queue Warning System Layout

Intended Purpose of the System

Queue warning systems are installed to warn motorists about conditions that may not be typical or readily apparent to the operators of the vehicles. Typical conditions might include queued traffic due to re-occurring congestion, incidents or special events, rapidly changing roadway conditions related to weather, construction/roadwork or other specialty messaging (e.g., Wrong Way Driver Notification System). Determining when to begin messaging the public can be accomplished through speed and weather sensors in combination with analysis software or manual input. In all cases keeping the information accurate is critical to maintaining credibility with motorists. Benefits often include reductions in incident rates, crashes, congestion, and improvements in travel time and reliability.

Queue and merge warning systems are proposed at three locations along the I-90 corridor in the Spokane area:

EASTBOUND - Merge Warning	WESTBOUND - Queue Warning
EB advance of US 195 Merge, Mile Post 278.8	WB advance of Division Off-ramp - Arthur Street Overpass
EB advance of US 195 Merge, Mile Post 279.0	

In the eastbound direction, upstream of the US-195 merge, the key purpose is to warn drivers about the upcoming merge and encourage drivers to use the left most lanes, leaving the right lane open for merging traffic. The merge for the high traffic volume US-195 to I-90 eastbound is relatively short, traffic condition conducive to vehicle platooning and creating congestion. By warning upstream motorist of the merging traffic and encouraging use of the left most lanes for through traffic, entering vehicles from US-195 will have more gaps and room to merge, improving mobility and safety. Queue warning could also apply here when congestion increase and the friction from the merge creates a queue back-up.

In the westbound direction, upstream of the Division Street exit, the key purpose of the system is to provide a queue warning to approaching drivers. This location is an area that typically experiences congestion and queueing.

The queue warning system can expand to existing electronic message signs, additional detection may be necessary for more extensive capabilities.

Functions and System Design

The queue warning system can operate in three different modes: always active, a manual mode, or a semi-automatic/automated mode. The perceived credibility of the warning system is key to getting drivers to initiate actions based on the information being presented. The warning system messages may be presented as a static message on a sign panel or as proposed on an electronic Variable Message Sign (VMS).

The always active mode is similar to the existing signs located along I-90 at the present time. These signs present “congested area” static messaging and may have flashing beacons on them. The flashing beacons may be remotely operated or run continuously. These are the most basic of queue warning signs and over time tend to become less effective as regular commuters becomes complacent with the same sign after a few viewings. Creditability may also become an issue with static signs as motorists will pass these signs at times when no congestion is present.

With a VMS, messages can be displayed only when conditions warrant. The messaging can be displayed via multiple modes. The simplest is the manual mode where an operator in the TMC can remotely enter the message into the VMS system for display. This mode requires staff resources and tedious repetition. This mode can also have credibility issues if the message is displayed when conditions do not warrant or if there are no messages and the conditions warrant. Also with manual messaging, as the “condition” being messaged dissipates, timely removal of the messaging is critical to maintain credibility. Timely and accurate removal of messaging is typically the greatest challenge to the manual method of display.

Another mode, deployment of a semi-automatic or automatic detection system for congestion can be implemented to display the message. The difference between the semi and automatic systems is the requirement of the TMC operator approval prior to the activation (or removal) of the messaging for the field

display. With this mode, the initial operations can be semi-automatic and then transition to automatic as confidence level is increased. Advanced applications can provide alerts, and information on the type of congestion (recurring or non-recurrent).

ATMS Integration

ATMS integration can be accomplished via multiple ways with differing objectives. Integration with the ATMS for general VMS usage is the most basic function and depending on the sign interface specifics may already be integrated with the existing ATMS software. This is the function that allows the queue warning VMS to be utilized for multiple purposes. By integrating the VMS controls into the ATMS product the sign can be used for incidents (crashes), construction, weather conditions, wrong way driver notification, or other special messaging. These functions bring a greater flexibility to the sign and will provide much greater benefits to the traveling public. These are all functions that could be developed and integrated into the ATMS software or the tasks completed as a standalone module. WSDOT will need to work with its ATMS vendor to determine the most cost-effective method to integrate the various system functions and capabilities.

The integration with detector based technologies can automate queue detection activation. This integration could utilize existing detectors or those that are required to be installed as part of the ramp metering system or wrong way notification system projects. Additionally, software could be developed that utilizes speed data from outside sources such as WAZE, HERE or INRIX as part or all of the source detection data. Automatic detection of traffic queueing and generation of VMS sign commands can be completed from the ATMS software. These functions may be able to be provided by implementing a Queue Detection/VMS interface module if it is offered by the vendor.

Design Layout

Central to the queue warning system is the installation of VMS and speed detection stations allowing for the determination that a queue is forming. These ITS elements should be designed and implemented using the WSDOT Intelligent Transportation Systems (ITS) Design Requirements, August 2016. Basic requirements for design include the centering of the VMS over all lanes for freeways with 3 or more lanes. The 334 cabinet must be ground mounted adjacent to the structure or within 150 feet upstream of the VMS structure. A maintenance vehicle pull out-pad should be provided. Each of the proposed locations was field reviewed in August of 2017 and the field notes are shown on the following pages.

VMS EB I-90 at M.P. 278.8

I-90 is a three-lane freeway at this location. The VMS could be placed on a full sign bridge to center the VMS over the travel lanes, which will require slight widening of the center median for the central support column installation. Alternatively, a cantilever support could be used, placing the sign slightly closer to the right shoulder. Rock is known to exist in the area with subsurface material likely affect the ultimate cost for this installation. Concerns were raised during the field review for difficulty in trenching for conduits, but runs should be short, as communications and power exist on this site. Right of way for a maintenance pad is available and a pad should be constructed at this location.

Figure 16 shows the area near MP 278.8 and some notes about the potential VMS installation.

Figure 16: VMS - EB I-90 in Advance of US-195 (MP 278.8)

VMS EB I-90 at M.P. 279

I-90 is a three-lane freeway at this location. Two bridge structures exist for possible mounting of the VMS unit. WSDOT will need to determine if the existing structures can support a VMS and the installation of conduit on the structure. The two bridges under consideration are Rosamond Avenue (Br. No.90/535, at P.M. 279.13) or Lindeke Street (Br. No. 90/537, at P.M. 279.27). The Rosamond bridge structure would provide the greater sight distance and allow for better comprehension by the motoring public. Power and communications are available to the sign. By installing the new dynamic system, the existing static flashing signs can be removed.

Figure 17 shows the area near MP 279 and some notes about the potential VMS installation.

Aerial View of I-90: Rosamond Avenue and Lindeke Street crossing vicinity

I-90 EB at Rosamond Avenue Overpass

I-90 EB at Lindeke Street Overpass

Figure 17: VMS - EB I-90 in Advance of US-195 (MP 279)

VMS WB I-90 at Arthur Street Overhead

I-90 is a three-lane freeway at this location with a two-lane merge on the right from Hamilton Street. The overhead structure for Arthur Street will need to be examined by WSDOT to determine if the existing structure can support a VMS and the installation of conduit on the structure. A VMS mounting structure may be required by WSDOT for the VMS. Alternatively, a cantilever sign installed on the shoulder could be considered. Power and communications are available to the sign.

Figure 18 shows the area near the potential westbound VMS installation.

Figure 18: VMS - WB I-90 Arthur Street Overpass

System Operations

In the eastbound direction, upstream of the US-195 merge, the primary purpose of the system would be to encourage traffic to use the left most lanes, keeping the right lane open for traffic merging onto I-90 from US-195. The detection system could monitor traffic on the US-195 on-ramp, and at predetermined thresholds, activate VMS to display a message encouraging drivers to move left. Additionally, the VMS at this location could include mainline detection to warn upstream drivers of queues or slow traffic through the merge area.

In the westbound direction upstream of the Division off-ramp, the primary purpose of the system would be for queue warning. The queue detection system on the mainline would sense the slowing and queue building across two consecutive detector stations indicating the formation of a queue. The system would alert the TMC Operators via an audible "ping" and flashing alert message requesting the activation of a message to be displayed on the sign similar to "CAUTION/CONGESTED AREA/1 MILE AHEAD". The TMC operator would then verify the presence of a queue using CCTV cameras and approve the display of the message. Message would get displayed and motorists react accordingly. If the system is automated, it would bypass the operator approval process and upload the message once queue is detected.

Support Environment and Costs

This section describes the stakeholders, their roles and responsibilities, resource needs, and high-level cost estimates for the queue and merge warning system.

Stakeholders

The primary stakeholders of the ramp metering include the following:

- WSDOT ER Traffic and Maintenance personnel
- State Patrol, local law enforcement, and other emergency responders
- Local Agency Operations personnel
- traveling public
- SRTMC

The interaction is mostly between the SRTMC operators and the traveling public. State Patrol as well as local agencies can be involved when they become aware of the system not working properly and notifying WSDOT personnel.

Roles and Responsibilities

WSDOT will develop, install, operate, and maintaining the queue warning system. Maintenance will be similar to other electronic signs and vehicle detection stations installed in the Spokane area. A coordination meeting with State Patrol and local agencies should be conducted to inform them of the system installation and who to notify if they come to know that the system is not functioning properly.

Resource Needs

Resources needed for queue warning system depend largely on the level of system automation. If the system requires the messaging to be made manually, it will require dedicated resources ready to respond during all hours of the day. If the system is semi-automatic to automatic, resources needs would be higher at the initial operating period and would lessen as the system matures. Once established, the system can operate on their own without need for much interaction. Routine monitoring and periodic adjustments are then made as needed.

At least one assigned system operator and one or more assigned system maintenance personnel should be considered for future operations and maintenance. Table 11 outlines the potential queue warning system resource needs to consider for each activity.

Table 11: Queue Warning Resource Needs

Activity	Description	Frequency
System installation, setup, and training	**Operator & Field Maintenance:** In this activity, one or more (potential) operators would be assigned to system operations and maintenance support. Estimating four weeks of installation, setup, testing, and refinement at 6 hours per day would total about 120 hours for consideration. Two days of training would add about 16 hours. This estimate would apply for the assigned operator(s) and additionally for the field maintenance support.	one-time resource need

Activity	Description	Frequency
	IT Support: For system installation and setup, IT support will be needed to ensure all software integration and initiation is done and working properly with cybersecurity protection. An estimate of about 24 hours may be needed.	
System monitoring and adjustments	**Operator:** In this activity, routine on-going monitoring and system adjustment is assumed for an annual total of about 240 hours (1 hour per day for 240 weekdays) for consideration. This can be tapered down as the system matures and is proven reliable. **Field Maintenance:** For maintenance support, it is assumed half hour of monitoring each day for an annual total of about 120 hours.	on-going resource need
Periodic tuning and adjustments	**Operator & Field Maintenance:** In this activity, periodic testing, tuning, and adjustments would be needed. For the operator and for system maintenance support, each group is estimated at 2 days of 6 hours per day, 2 times each year, for an annual total of 24 hours. **IT Support:** Periodic tuning and adjustments may include adjustments to the system connections, firewalls, and software upgrades. To provide this support, about 8 hours is estimated for each year.	on-going resource need
Maintenance repair or re-setup	The system will need periodic maintenance and repair including the system software, hardware, or detection. Once repaired, the system will need to be re-set and operations observed for any adjustments or tuning. Once repaired, the system will need to be re-set and operations observed for any adjustments or tuning. **Operator:** For the operator, an estimate of at 4 days of 6 hours per day, 2 times each year, for an annual total of 48 hours. **IT Support:** An estimate of about 8 hours may be needed each year to provide IT support to re-install or upgrade software, trouble-shoot errors or software glitches, and/or implement system solutions. **Field Maintenance:** For the maintenance support, it could take considerable more resources to conduct the repairs for an estimate of 2 people, 5 days of 8 hours per occurrence (2 times each year), for an annual total of 160 hours to be conservative.	on-going resource need
Stakeholder coordination and public	Coordination and collaboration with local agencies, emergency responders, and stakeholders would be needed. In addition, efforts to educate the public motorist, as well as local agency and elected officials, may also be needed, if requested by a stakeholder. **Operator:** For the operator, a nominal 40 hours annual total is estimated for consideration. Education effort could include providing	on-going resource need

Activity	Description	Frequency
	information to the local agencies and stakeholders, participating in meetings, and presenting at various forums and events. No additional resource need is estimated for IT or field maintenance support.	
Annual review and analysis for upgrade	**Operator:** It is anticipated that the operator will conduct a review, research, and analysis for possible upgrade as needed, occasionally participating in meetings and events that pertain to queue warning system. Assuming that this occurs once a year for about 3 days, at 8 hours per day, an estimate of 24 hours could be considered.	on-going resource need
Future upgrades implementation	It is anticipated that eventually the system will need to undergo a significant modification for upgrade, either system software, hardware, detection, or even system configuration and redesign. **Operator, IT Support, and Field Maintenance:** Operator, IT support staff, and maintenance support staff would need to get involved in the upgrade. Maintenance support staff would need to review and coordinate the support needs of any significant changes. Estimate of the hours needed would depend on the occurrence and level of upgrade.	one-time resource need

Planning-Level Cost Estimate

Queue warning system costs for installation are driven largely by right of way and sign installation (structural and geotechnical). The locations given for placement should be considered flexible and if longitudinal adjustment can lower cost those adjustments should be considered. Other factors that have significant influence on installation costs are availability of communications not only for the sign controller. The re-use of existing detection on the mainline, depending on the locations, can decrease the costs of installation so long as the detection is reliable and operational in all lanes.

The planning level cost estimate includes assumptions that may change when the project moves to detailed design. For that reason, some contingency is added to the cost estimate. As detailed design plans are developed, the costs will be refined. The cost estimate assumptions and unit costs are shown in Table 12.

Table 12: Queue and Merge Warning System High Level Cost Estimates – Two Locations

Item	Quantity	Cost	Total
VMS and structure*	3	$600,000	$1,800,000
New detection systems w/communications	6	$20,000	$120,000
Communication and Power	3	30,000	$90,000
System software upgrade and installation	1	$150,000	$150,000
Design, Construction Engineering, and Contingency	1	$1,000,000	$1,000,000
Total Initial Cost			$3,160,00
Maintenance (Annual)			$60,000

*Note that the structure costs could vary significantly if existing structures can be used for mounting the VMS.

Operational Policies and Constraints

Messaging to be displayed on the VMS must conform to the standards and/or practices associated with messaging by WSDOT. Messages developed for display by WSDOT personnel should be in compliance with the ITS and VMS operations policies of WSDOT. The design requirements for placement, mounting, sizing and functions associated with the Variable Message Sign are contained in Section 5 of the WSDOT, ITS Design Requirements, August 2016 Revision.

FINAL REPORT

I-90 Operations Study

May 2018

Appendix F

WSP Wrong Way Driver Incidents (2017)

DKS

RESEARCH, ANALYSIS, & MAPPING (RAM)

Date prepared: January 8, 2018

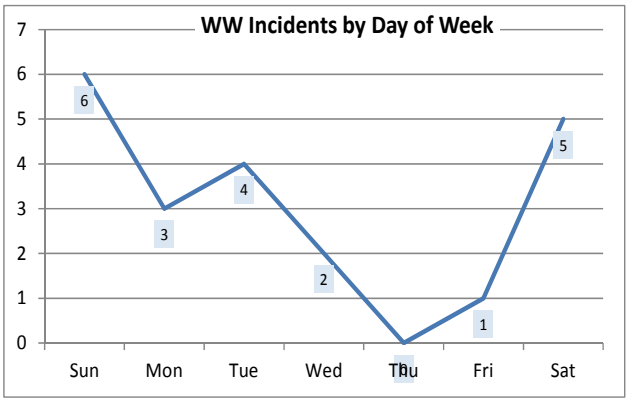
APA 19: 2017 Wrong Way Incidents on I-90 (MP 279-299)

In 2017 there were 21 wrong way incidents that occurred on I-90 between milepost 279 and 299. Out of those incidents, one was fatal collision where commercial vehicle was involved. This fatal collision occurred on West I-90 MP 280 on December 23rd, 2017, at midnight. Out of the other 20 incidents, three vehicles were contacted and the other 17 were reported as unable to locate or notified.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	**Total**
WW Incidents	2	1	1	1	0	4	1	0	3	2	3	3	**21**

Hr/Day	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Total
1	1						2	3
2	2						1	3
3			1	1				2
4								0
5								0
6								0
7								0
8								0
9	1							1
10								0
11								0
12		1						1
13								0
14								0
15	1							1
16								0
17				1				1
18								0
19		2	1			1		4
20								0
21								0
22			1					1
23	1		1				2	4
Total	**6**	**3**	**4**	**2**	**0**	**1**	**5**	**21**

Above Avg



Months with the highest WW incidents:

- June
- Sept/Nov/Dec

Days with the highest WW incidents:

- Sunday
- Saturday
- Tuesday

Time of Day with the highest WW incidents:

- 23:00
- 1:00/2:00
- 3:00

Data Source: WSP CAD

APA 19: 2017 Wrong Way Incidents on I-90 (MP 279-299)

In 2017 there were 21 wrong way incidents reported to CAD on I-90 between milepost 279 and 299. Out of those incidents, one was fatal collision where commercial vehicle was involved. This fatal collision occurred on West I-90 MP 280 on December 23rd, 2017 at midnight. Out of the other 20 incidents, three vehicles were contacted and the other 17 were reported as unable to locate or notified.

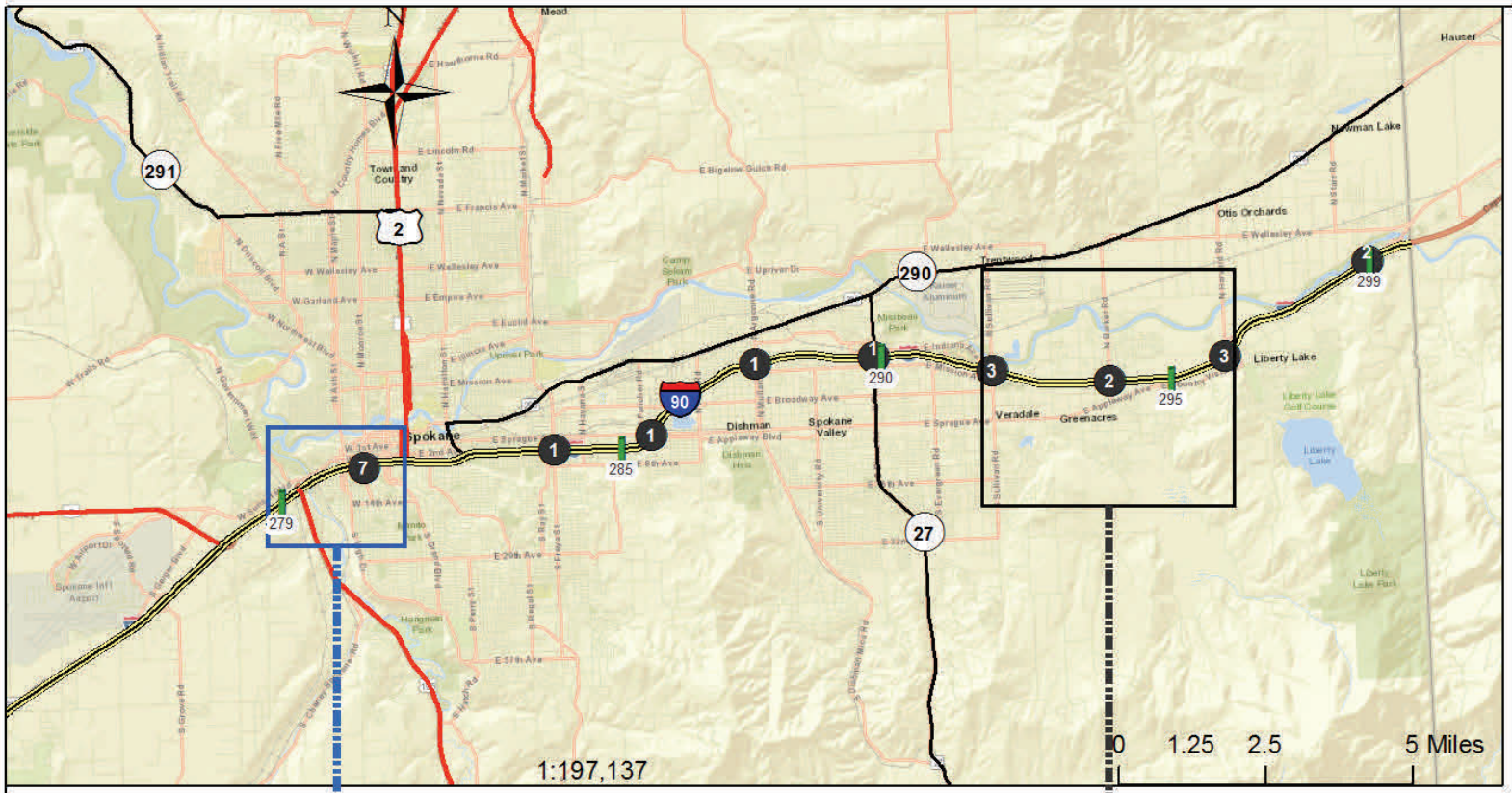
2017 Wrong Way Incidents

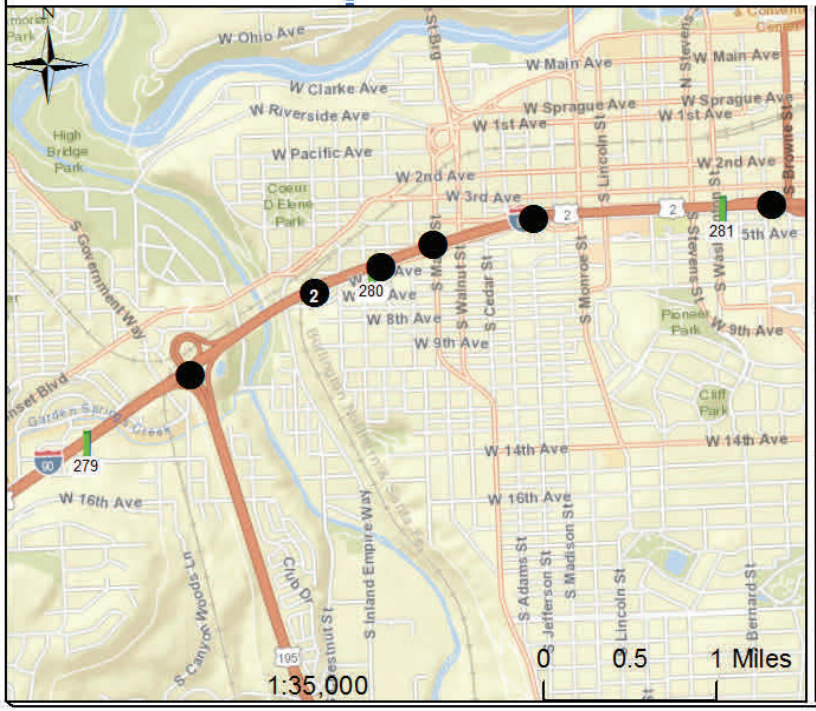
reported in WSP CAD

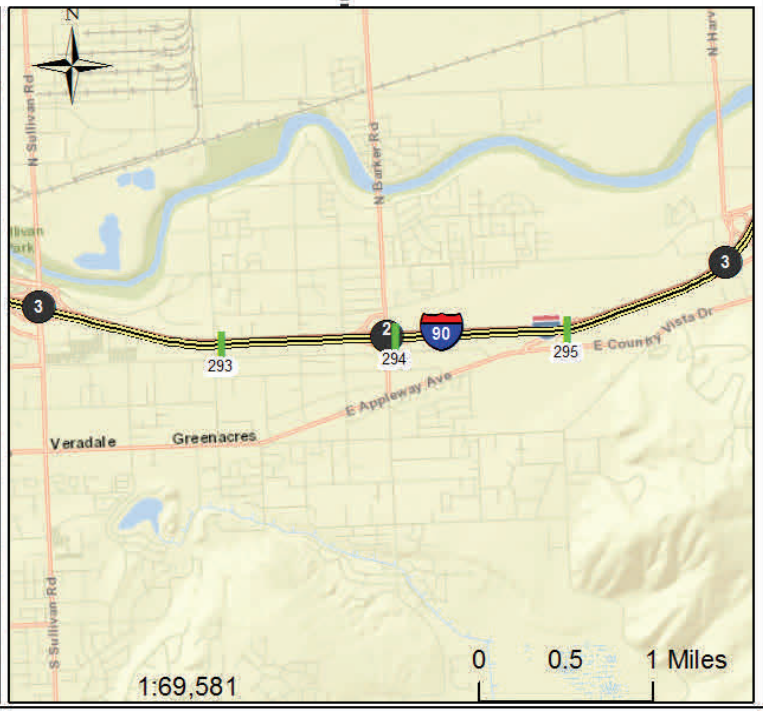
WW Incidents	Milepost	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Total
N195 I90 MP95-9	MP095						1		1
E90 MAPLE MP279-8	MP279	1		1					2
E90 MP280	MP280		1						1
W90 MAPLE MP280-2	**MP280**							**1**	1
W90 MONROE MP280-5	MP280				1				1
E90 DIVISION MP281-2	MP281							1	1
W90 FREYA MP283-9	MP283			1					1
E90 SPRAGUE AVE MP285-6	MP285	1							1
E90 ARGONNE MP287-8	MP287							1	1
E90 PINES MP289-9(OFF)	MP289			1					1
E90 SULLIVAN MP291-9	MP291							1	1
W90 SULLIVAN MP291-9	MP291	2							2
E90 BARKER MP294-0	MP294		1						1
W90 (JE)BARKER MP294-0	MP294	1							1
E90 LIBERTY LAKE MP296-0	MP296				1				1
W90 LIBERTY LAKE MP296-0	MP296		1					1	2
W90 STATE LINE MP298-8	MP298			1					1
E90 STATE LINE MP299-2	MP299	1							1
	Totals	**6**	**3**	**4**	**2**	**0**	**1**	**5**	**21**

COLF

Data Source: WSP CAD





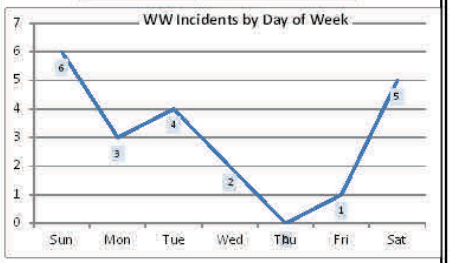


WASHINGTON STATE PATROL

Wrong Way Incidents I-90 MP 279 to 299 Spokane Area

In 2017, there were 21 wrong way incidents on I-90 between MP 279 and 299. One of these incidents was a fatal collision that occurred at I-90 MP 280 on December 23, 2017, at 1:00 a.m. and involved commercial vehicle.

Month	WW Incidents
Jan	2
Feb	1
Mar	1
Apr	1
May	0
Jun	4
Jul	1
Aug	0
Sept	3
Oct	2
Nov	3
Dec	3
Total	21



Milepost

Prepared by: FOBHQ Analyst on 01/08/2018
Data Source: WSP CAD