Feasibility Assessment

I-90 Variable Speed Limit Feasibility Study

Lookout Pass, MT

Draft

June 3, 2016

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Project No. 18459

June 2016

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INTRODUCTION

PROJECT PURPOSE AND OVERVIEW

This report summarizes an effort initiated by the Montana Department of Transportation (MDT) to assess the feasibility of implementing variable speed limits (VSL) along the Lookout Pass section of I-90 (Reference Post (RP) 0.0 to 33.4). This feasibility assessment was conducted to determine:

1. Does VSL have the potential to reduce the number and severity of crashes along this segment of I-90?
2. If so, what gaps in current infrastructure and processes would need to be filled to implement VSL and what are the associated costs?

To conduct this assessment, the following framework was used. This assessment framework also forms the presentation of material in this report.

- Assess existing conditions and conduct stakeholder outreach
- Research VSL systems implemented by other states
- Develop and assess initial concepts and cost estimates
- Refine the initial concepts into a final concept(s) based on stakeholder feedback
- Make recommendations for next steps

VARIABLE SPEED LIMIT DESCRIPTION

Speed zones are established either statutorily for a particular class of roadways or based on an engineering study that evaluates the distribution of speeds for free-flowing vehicles. Speed limit signs are posted to inform drivers of the established speed limit, which reflects the maximum allowable speed under normal weather and roadway conditions. However, it is the responsibility of the driver to "operate a vehicle in a careful and prudent manner and at a reduced rate of speed no greater than is reasonable and prudent under the conditions existing at the point of operation, taking into account the amount and character of traffic, visibility, weather, and roadway conditions.[1]"

While it is incumbent upon the driver to operate their vehicle at a reasonable and prudent speed based on conditions, some agencies have begun to replace static speed limit signs with dynamic signs capable of displaying a variable speed limit. VSL systems allow agencies to adjust the posted speed in response to changing traffic, roadway,

> VSL systems are typically installed to:
>
> - Improve safety by responding to changing road and weather conditions
> - Manage congestion by reducing the variability in driver speeds

[1] Montana Code Annotated 61-8-303(3). 2015.

or weather conditions. Due to installation and maintenance costs, VSL systems are typically deployed in targeted areas to respond to specific congestion or safety issues.

A number of devices and processes are required for a VSL system to function. These devices and processes can be broadly categorized into three subsystems:

- The *Data Source Subsystem* collects information about the current conditions in the corridor from field personnel and/or various sensors.
- The *Decision and Management Subsystem* determines how the VSL activation, monitoring, and deactivation process will be accomplished.
- The *Field Infrastructure System* includes the VSL signage and other information communicated to the driver, as well as the power and communications systems needed to operate them.

This assessment considers alternative concepts for each of these subsystems.

EXISTING CONDITIONS AND STAKEHOLDER OUTREACH

The first phase of this assessment included an examination of the existing conditions to establish a baseline understanding of the issues to be addressed with a potential VSL application. The existing conditions assessment included a review of available data, an information gathering meeting with key stakeholders, and a field review of the corridor. This section summarizes the primary findings of the existing conditions assessment and input from stakeholders.

CRASH HISTORY

Historical crash data supplied by MDT indicate a total of 557 crashes were reported over a five-year period, January 2010 through December 2014. The data associated with these crashes was analyzed in detail, and a summary of the trends and findings is summarized in this section. MDT staff also provided a comprehensive analysis of the crash data and found the study corridor is currently performing at a Level of Service of Safety III, which indicates a moderate to high potential for crash reduction. The MDT analysis and summary is included as Appendix A.

Of the 557 total crashes, 13 crashes occurred at non-mainline locations, such as interchange ramps. They were filtered out of the analysis data set. Although there is potential for secondary benefits to crash reduction on the interchange ramps, mainline crashes are the primary crash type targeted with VSL. Also filtered out of the data set were crashes that occurred when the weather and road conditions were classified as clear and dry as VSL would be used only during inclement weather and road conditions. The resulting data set consisted of 377 crashes during the five year analysis period[2].

Approximately 88% of crashes in the resulting data set (377) were single vehicle crashes (330), as shown in Exhibit 1, with the majority of those (284) occurring when vehicles hit a fixed object at the side of the road or the vehicle rolled. Of the single-vehicle crashes, 282 were non-injury crashes resulting in property damage only. The analysis also found that, as shown in Exhibit 2, the majority of inclement condition crashes occurred during the winter months (November through March). Analysis of the data shows that there is no significant difference in crashes in the eastbound or westbound directions.

[2] MDT maintenance staff indicated their observation is that not all crashes are reported, particularly single-vehicle crashes in which the vehicle is not disabled and no serious injuries occur. Therefore, it is likely that a higher number of crashes actually occur in the corridor.

Exhibit 1: Number of Vehicles Involved in Crashes (Inclement Road/Weather Conditions)

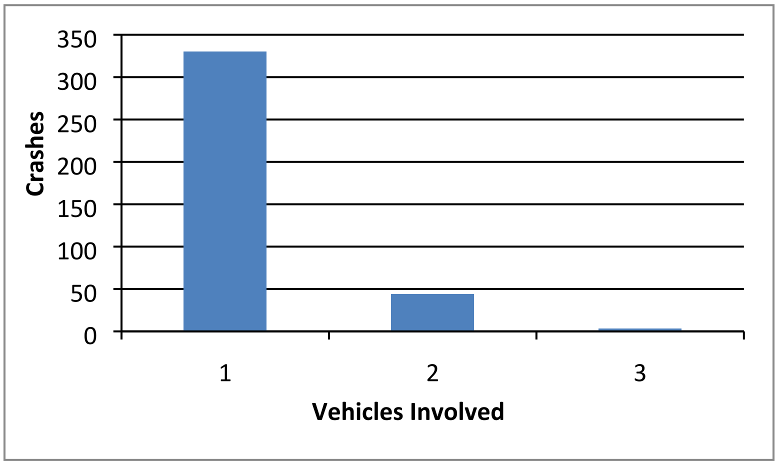
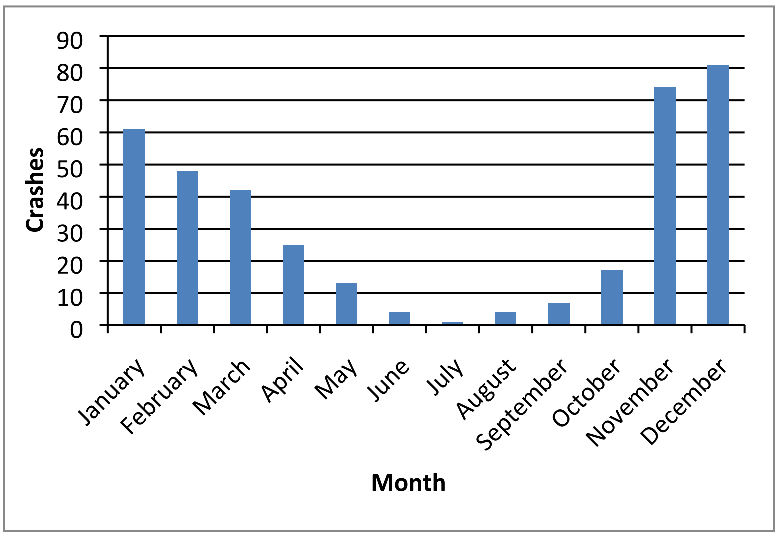


Exhibit 2: Crashes by Month (Inclement Road/Weather Conditions)



The crashes in the filtered data set were mapped and a density analysis was performed, which is shown in Exhibit 3. Darker contours shown in Exhibit 3 indicate a greater density of crashes, identifying a number of locations where crashes repeatedly occur. The identification of inclement-condition crashes and their locations was useful to 1) confirm there is an opportunity to use VSL to target the types of crashes other states have been able to mitigate with VSL and 2) identify opportunities to split the corridor into zones that can address crashes over specific segments.

Exhibit 3: Existing Conditions Summary

EXISTING CORRIDOR INFRASTRUCTURE

There is currently a limited amount of infrastructure (e.g., sensing equipment, dynamic signage, power, communications) along this section of I-90 to support the implementation of VSL. The current infrastructure is summarized in Exhibit 3 and described below.

- Reference Post 0
  - Eastbound variable message sign (VMS)
  - Road Weather Information System (RWIS) with camera, the only RWIS along the corridor
  - Both these devices are A/C powered and have a dedicated phone line for communication
- Reference Post 5
  - Rest Area – A/C powered and communication through a phone line
- Reference Post 6.5
  - Westbound VMS – A/C powered and communication through a dedicated phone line
- Reference Post 10.5
  - Eastbound weigh-in-motion (WIM) and automatic traffic recorder (ATR) site
  - Both these devices are A/C powered and have a cellular connection for communication
- Reference Post 15
  - Weigh Station – A/C powered and communication
- Reference Post 16.5
  - Westbound VMS – A/C powered and communication through a dedicated phone line
- Reference Post 23 and 27
  - Cantilever flashing beacons (eastbound and westbound respectively) with curve warning signs.
  - These beacons are solar powered and do not have communication. Discussion with MDT maintenance staff indicated the terrain and weather do not provide optimal conditions for continuous solar powered operation of devices with a power draw exceeding that of a single flashing beacon.
- Reference Post 32
  - Westbound WIM and ATR site
  - Both these devices are A/C powered and have a cellular connection for communication

Exhibit 3 also summarizes a concept-level understanding of the availability of power and communication along the corridor. If MDT advances the VSL concept, a more detailed assessment of power and communication availability will need to be conducted.

OTHER INFRASTRUCTURE AND RESOURCES

Additional infrastructure and resources associated with the corridor are described below.

- Mobile Weather Monitors
  - MDT maintenance staff indicated some of the maintenance vehicles and snow plows in the Missoula District have on-board weather sensing systems in place that can report road and ambient temperatures, but that communication issues have limited use of these systems. One tow plow is equipped with a camera and is communicating on a regular basis via a cellular connection.
- Existing Speed Signs
  - Exhibit 3 shows the existing static regulatory and advisory speed signs currently on the corridor. As shown, the average spacing of the regulatory speed signs is approximately 6.5 miles. The advisory speed signs are focused around horizontal curves along the corridor.
- Road/Weather Condition Reporting
  - The District staffs the road reporter position 24 hours, seven days a week (24/7) during the winter season (November through March/April).
  - The role of the road reporter is to gather information from field personnel regarding road and weather conditions and input that information to the MDT 511 system, which provides traveler information to the public. The road reporters do not dispatch maintenance personnel.
- District Maintenance and Operations Staff
  - During the winter season, the District maintains coverage of the corridor six days a week. Personnel are called in on Sundays on an as-needed basis. The number of maintenance operators on duty by time of day on Monday through Saturday is as follows:
    - 4:00 a.m. – 7:00 a.m. – 2 maintenance operators
    - 7:00 a.m. – 2:00 p.m. – 4 maintenance operators
    - 2:00 p.m. – 3:00 p.m. – 6 maintenance operators
    - 3:00 p.m. – 8:00 p.m. – 4 maintenance operators
    - 8:00 p.m. – 10:00 p.m. – 2 maintenance operators
    - 10:00 p.m. – 4:00 a.m. – Staffed on an as-needed basis based on weather
  - Staff in addition to the regular staffing levels shown above are activated on an as-needed basis during weather events or other incidents.

STAKEHOLDER OUTREACH

The project team met with agency stakeholders during meetings in Missoula and Helena in February 2016. During these meetings, feedback was gathered regarding a potential VSL system. The following is a summary of input received regarding motivations for considering VSL, potential challenges to implementation, and potential opportunities that could support a VSL system. A list of stakeholder attendees, meeting minutes, and the meeting presentation are included as Appendix B.

Motivations for Considering VSL

- Improve safety through reduced number and severity of crashes
- Reduce the number of incidents and weather-related closures, resulting in improved goods movement
- Enhance the safety of field personnel while maintaining the roadway and responding to incidents
- Improve efficiency of resources by responding to fewer crashes
- Preserve infrastructure and reduce the need to repair or replace guard rail, barriers, etc.

Potential Challenges

- Lack of available corridor infrastructure (i.e. sensing, power, communication) to support a VSL system
- Extreme nature of the study area
- No centralized management center to collect data, make decisions, and ensure a consistent application of VSL
- Limited resources to maintain a VSL system and the need to provide the personnel necessary to effectively run VSL

Potential Opportunities

- Potential to utilize the existing Montana Highway Patrol (MHP) Communications Center at Fort Harrison as a potential traffic management center (TMC)
- VSL has the support of MDT staff and management subject to funding and resources

COORDINATION WITH IDAHO TRANSPORTATION DEPARTMENT

Given that Lookout Pass shares a border with Idaho, the project team contacted representatives of the Idaho Transportation Department (ITD) to understand the potential for interstate interaction. Generally, ITD's experience with I-90 on the Idaho side of Lookout Pass is similar to Montana's experience. The following is a summary of the conversation with ITD staff:

- ITD experiences a lot of issues with crashes and keeping I-90 open during inclement conditions.
- ITD noted the limited availability of communication along I-90 near Lookout Pass. They have interest in adding cellular connectivity to I-90.
- ITD has been using satellite communication in some remote areas (e.g., Lolo Pass on Idaho Highway 12).
- The posted speed changes in Idaho from 55 mph (at the top of the pass) to 65 mph (middle section) and then to 75 mph (at the lower section) in less than 40 miles.
- The staff interviewed were not aware of much communication that occurs between ITD and MDT with regard to operations of I-90. However, there was interest in increasing the level of coordination.
- AT&T operates fiber along I-90 up to Lookout Pass from the Idaho side of the border.
- ITD has a VMS in the eastbound direction approximately nine miles from the border.
- ITD has an RWIS near the border.

RESEARCH OF OTHER STATE EXPERIENCE WITH VSL

VSL systems operational in other states were researched with the intent of informing the MDT VSL feasibility assessment and concept development. The states contacted included:

- Wyoming Department of Transportation (WYDOT)
- Utah Department of Transportation (UDOT)
- Oregon Department of Transportation (ODOT)
- Washington State Department of Transportation (WSDOT)

Each state was contacted by phone (with the exception of Wyoming where an on-site visit was conducted in December 2015) and an interview form helped guide the discussion. The questions focused on understanding the other state's VSL system, the data sources that were used to trigger and activate the systems, how activation decisions and system management was accomplished, what level of TMC involvement was used, and what advice they would offer MDT to assist with system planning and implementation. These topics are each discussed below.

VSL CHARACTERISTICS

Each state VSL system is based on their specific needs, existing infrastructure, and organizational structure. This resulted in learning about very different systems, each with strong support for their approach. The following summarizes the general characteristics of each VSL system.

Wyoming (I-80)

WYDOT has deployed several regulatory VSL systems, mostly on rural stretches of the I-80 corridor in especially problematic areas. The systems are primarily focused on improving safety during severe weather events (snow, wind, blowing snow, etc.). The VSL corridors are heavily instrumented sections of I-80 with RWIS, speed sensors, and VMS. Additionally, maintenance crews report road weather conditions by designated road segments. The resulting data are transmitted to a TMC where traffic management decisions are implemented. Wyoming also has a sophisticated traveler information system providing information to travelers and commercial vehicle operators.

Utah (I-80)

Utah's VSL system is also on I-80, but operated in a heavily traveled commuter route in Parley's Canyon approximately 15 miles in length traveling east from the Salt Lake City center. The system is regulatory in nature and focuses mainly on reducing congestion in this corridor. Although there are RWIS sensors in the corridor, speed sensing is the most important data used in the corridor for VSL activation. UDOT traffic engineers use the speed data to determine the 85th-percentile speed and set the VSL speed to that speed. UDOT also has a sophisticated statewide traveler information system operated from their TMC.

Oregon (OR217)

Oregon has an operational VSL system on OR217, located in a heavily urbanized area in the Portland, OR metropolitan region. This fully automated system uses both speed and road weather sensing to operate the system. The system is advisory only and focuses mostly on reducing congestion and improving vehicle throughput in this 7.5 mile corridor. The automation is achieved through numerous weather and speed sensor inputs located throughout the corridor and sophisticated software developed to activate and manage the system. VSL speeds change as often as needed to address the current conditions.

ODOT is planning several other VSL corridors throughout the state. One of the first implementations is on a rural stretch of I-84 near Baker City. This location will be triggered primarily with weather information and will be regulatory in nature. The same automation software will be used.

Washington (I-90)

Washington's VSL system is on I-90 through Snoqualmie Pass. This is a 24-mile rural section of interstate that experiences severe winter weather. The primary focus of this regulatory speed system is safety improvement. Although there are sensors in the area, the VSL system trigger is solely based on field input from their maintenance crews that provide road condition information to a regional TMC. During the winter months, Snoqualmie Pass has a 24/7 presence with between four and twelve maintenance operators depending on conditions.

A summary of these states VSL system characteristics and VSL sign spacing is shown in Table 1. The sign spacing ranged from ½ mile to 6 miles and is strongly correlated to the terrain and primary purpose of the VSL system. Closer spacing is required for urban congestion-based systems. The system that is most similar to the conditions in Montana on I-90 in the study area is the Washington system, which has set a sign spacing at approximately three miles. A common response from all the states was that VSL sign spacing should be approximately half of what would be normal spacing for static speed signs.

Table 1: State VSL Characteristics and Sign Spacing

State	Location, Character	Year of Implementation	Focus	Type	VSL Sign Spacing
Wyoming	I-80, rural, open	2009/2010	Safety	Regulatory	~6 miles
Utah	I-80, rural/urban, mountain pass	2014	Congestion	Regulatory	~1 mile
Oregon	OR217, urban, open	Mid-1990s	Congestion	Advisory	~1/2 mile
Washington	I-90, rural, mountain pass	2014	Safety	Regulatory	~3 miles

DATA SOURCE/SENSOR DEPENDENCE

Good road and weather condition information is needed to support VSL activation and speed determination decisions. A clear data source, or sources, and an approach to obtain and provide that data is needed. Among the four states researched, data sources ranged from field personnel, to roadside sensors, to a combination of both. Table 2 shows the primary data input, sensor dependency, and sensor spacing for each of the state VSL systems.

Table 2: State Data Input and Sensor Spacing

State	Primary Data Input	Sensor Dependency	Sensor Spacing
Wyoming	Combination of speed, weather, pavement condition, cameras	High. Also uses input from field personnel.	RWIS ~3 miles Speed ~2 miles
Utah	Speed	High. No field input.	RWIS ~4 miles Speed ~1 mile
Oregon	Combination of speed, weather, pavement condition, cameras	High – to support fully automated system. No field input.	RWIS ~2 miles Speed ~1/2 mile
Washington	Field personnel	None	RWIS ~3 miles Speed ~1 ½ miles

It is important to note the different approaches in each system. WYDOT is highly dependent on a combination of sensors to provide the needed data, but also uses input from the field to support their VSL decisions. UDOT has RWIS in the corridor, but almost exclusively uses the speed detectors to set the VSL speed based on the measured speed already occurring. ODOT is similar to WYDOT in its use of sensor data with one major exception – Oregon's system is fully automated and input from field personnel is not used. WSDOT began using sensor data when they first implemented a VSL system but lack of reliable sensor data caused them to change their approach and they now use only input from field personnel. This approach requires a heavy staffing requirement to ensure the input is available where and when needed to activate and manage the VSL system. As noted above, in this 24-mile section of I-90, WSDOT has a complement of between four and twelve maintenance personnel on the road 24/7 during winter weather events.

DECISION/MANAGEMENT

Once data input procedures are established, a well-documented decision and management approach to activate, monitor, and deactivate the system is needed. Again, these processes are different in each state. A summary of how this is accomplished in each state is provided below.

Wyoming

The Wyoming statewide TMC operators obtain field input from the Wyoming Highway Patrol (via radio) and maintenance crews (via radio or on-board tablets) and review the sensor data to determine if the conditions warrant a speed change. If a change is warranted, they use an established tabular guide to determine the appropriate speed for the conditions and activate the VSL signs. Each corridor has established speed zones and the system software changes the appropriate VSL signs for the selected zones. The WYDOT TMC is operational 24/7 during the winter months. The TMC operators monitor the conditions by continuing to review sensor data and receive field input. If changes are warranted (i.e. conditions either worsen or improve), operators make the appropriate changes to the VSL speeds. When the conditions return to normal, the VSL signs are set to the standard speeds.

Utah

UDOT depends on travelers to tell them, indirectly, that conditions are such that lower speeds are warranted. Speed sensors trigger an alert that speeds have reduced. An on-call traffic engineer evaluates the information (collected and made available through their statewide TMC) and makes the decision to utilize the VSL system. The traffic engineer's evaluation consists of a "mini speed study", combined with assessment of road conditions to determine if a speed change is warranted and what that speed should be set to. They strive to set the speed at the current 85^{th}-percentile speed. The traffic engineer monitors the situation until the conditions return to normal, making appropriate VSL speed changes as warranted by the changing conditions.

Oregon

Oregon's VSL system is fully automated and based on sensor input. The system is triggered by both weather and speed conditions. Sophisticated software determines if a speed change is needed in different corridor zones based on conditions to reduce crashes and maximize vehicle throughput. ODOT believes that this approach results in the quickest response and is the most reliable and consistent. Speed changes can occur frequently based on rapidly changing conditions. A manual override is built into the system that could be activated at the regional TMC. However, the manual override has not been implemented in the first year and half of operation.

Washington

The I-90 Snoqualmie Pass VSL system is managed by regional TMC operators. The operators receive input from field maintenance personnel and determine the appropriate VSL speed based on traction requirements, pavement condition, weather conditions, and other conditions (incidents or other roadway activities). A reference table guides the TMC operators' decisions to activate and deactivate the VSL system. The data inputs are all provided by maintenance personnel; not by sensors. WSDOT has determined that sensors have not been reliable enough to make speed decisions.

TMC INVOLVEMENT

All the states researched have a TMC to support VSL operation. However, the level of TMC involvement in that process varies widely. Table 3 summarizes the level of TMC support and type of TMC involvement in VSL operation for each state. Wyoming's statewide and Washington's regional TMC have the highest level of involvement where operators are actively involved in data collection, decision making, and monitoring to support an effective VSL system. Utah's statewide TMC acts as the speed sensing data management function and alerts the traffic engineer when conditions dictate a speed analysis. Additionally, they house the RWIS and camera information as a source of data for the traffic engineer to use in their assessment. Oregon's TMC has a low level of involvement. The TMC manages the data and supports the software that operates the automated system. Also, if a manual override is required, that decision would come from the TMC.

Table 3: TMC Involvement by State

State	TMC Level	TMC Involvement
Wyoming	High	Collects data, makes VSL decisions, monitors
Utah	Medium	Data management, speed alert
Oregon	Low	Data management, manual override
Washington	High	Collects data, makes VSL decisions, monitors

ADVICE TO MDT

Each of the states was asked what advice they would offer to MDT to assist in their efforts to potentially implement a VSL system. Their responses are provided below.

Wyoming:

- A TMC with a "human in the loop" is very important to the success of a VSL system.
- The decision to raise the speed limit is as important as lowering it to maintain driver respect.
- Sensors and a documented process is critical to the success of the system.

Utah:

- VSL is a corridor wide application – don't try and solve spot issues with a VSL system.
- Don't underestimate staffing needs – don't build a VSL system unless you have the resources committed to support it.
- UDOT was surprised by how many times the VSL system is used in summer months.

Oregon:

- Learn from other state implementations and apply the best practices that work for your conditions.

Washington:

- Power and communications can be significant obstacles.
- Establish clear speed limit policy early in the VSL system development process.

CONCLUSIONS FROM OTHER STATE VSL SYSTEMS

Although the end goal of these VSL systems was essentially the same, to reduce speed during certain inclement conditions, the implementation approach was quite different in each case. The primary factors that drove the differences were the specific needs of the corridor, existing infrastructure, and organizational structure of the organization. The differences were highlighted in the data used to activate and deactivate the system, level of dependency on sensors, decision process to operate the system, and level of TMC involvement.

One item that was generally consistent was VSL sign spacing guidelines. Most states suggested deploying two VSL signs for every static sign currently posted. The actual VSL sign spacing was dependent on conditions: closer for urban applications and farther apart for rural conditions.

The following conclusions are meant to inform the development of MDT VSL concepts:

- Each state depends on field and sensor input regarding road and weather conditions in various ways to support VSL decision making. Some used sensors only, one didn't use sensors at all, and other's used a combination. Consider concepts that employ each of these options to determine which would best fit MDT's needs and organizational structure.
- All states had an existing TMC. However, not all states used TMC staff to make VSL decisions. MDT does not currently have a TMC. Consider concepts that both do and don't rely on a TMC to operate the VSL system.
- All the states had a defined process to determine if VSL should be activated and, if so, what speed should be set depending on the conditions. MDT will need to determine a VSL operational approach. Concepts should include various options including "human in the loop" and fully automated approaches.
- The Montana I-90 Lookout Pass corridor has several accident hot spots. Don't use VSL system to specifically address these spot issues. Rather, consider VSL a corridor-wide tool to manage speed and identify speed "zones" to address the different needs in the corridor.
- Currently, the corridor lacks significant power and communication infrastructure and has very limited deployment of sensors and active signage. When considering various VSL concepts, balance the need for new equipment with the cost of deploying supportive infrastructure.
- Each state used varying degrees of staffing (field maintenance, law enforcement, and TMC operators) to operate their systems. MDT has limited staff resources addressing the current needs of the I-90 Lookout Pass corridor. VSL concepts should consider this fact and, if additional staff is deemed important to the success of the system, appropriate costs and management commitment should be included.

INITIAL CONCEPTS AND ASSESSMENT

Understanding the I-90 existing conditions and operations, and identifying lessons learned from other states that have implemented VSL, laid the foundation for the development of a set of initial VSL concepts for the I-90 Lookout Pass corridor. This chapter defines and assesses the initial concepts and discusses the process to make refinements on a final concept.

CONCEPT DEVELOPMENT

As presented in the Introduction, the following three fundamental elements are required to implement a VSL system:

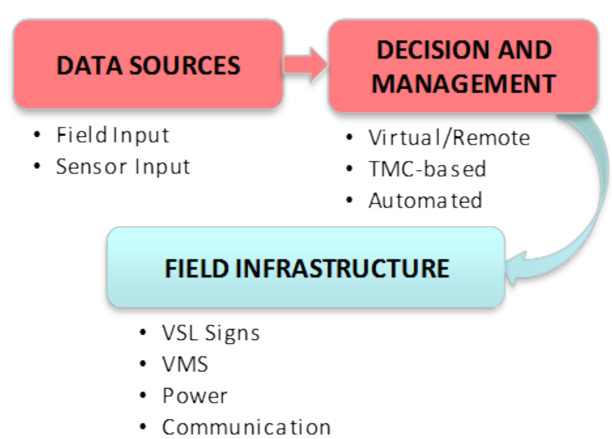
- Data Source – information about the current conditions in the corridor obtained from field personnel and various sensors
- Decision and Management – how the VSL activation, monitoring, and deactivation will be accomplished
- Field Infrastructure – the VSL and VMS signage, as well as the power and communications system needed to operate them

Within each system element, there are possible options for how the elements will accomplish their objectives. Allowing every system element to have multiple options would have generated too many concepts to understand and analyze. Instead the consultant team decided to define the field infrastructure needed to implement a VSL system in the project corridor and allow that defined infrastructure to be constant among all the concepts. The field infrastructure defined for MDT's VSL application was primarily based on the outcomes of the other states research and review of the existing conditions infrastructure. The resulting infrastructure assumptions are described later in this chapter.

Concept Framework

The three fundamental concept elements defined above establish the framework applied to this evaluation. The framework includes options for data sources, decision and management processes, and field infrastructure components. Exhibit 4 shows the framework and information flows between the elements. Each of these elements is described in more detail below.

Exhibit 4: VSL Element Framework



Data Sources

The VSL concept framework begins with understanding what road and weather condition data is available to support VSL decisions. Two primary data sources were considered:

- *Field input* – Field input would come primarily from maintenance or highway patrol forces. Other input could also be considered, for example a motorist 911 call. Input could include weather conditions, road/pavement conditions, incidents, or recommended speed limits. This input could be facilitated through existing radio communications or future automated technology options.
- *Sensor input* - Sensor input using sensors deployed in the field or mobile sensors mounted on vehicles could include vehicle speeds, weather conditions, and road/pavement conditions.

The concepts described below also considered a combination of both these data sources to maximize the content and extent of data available for decision making.

Decision and Management

The Decision and Management element of the concept framework determines how MDT would make VSL decisions and manage the supporting systems. Three primary decision and management options were considered:

- *Virtual/remote control* – This concept would require a dedicated staff person(s) to make the decisions and manage the system. It would be web-based allowing for the persons assigned the task of VSL control to be located anywhere. That person would have access to the system and field input remotely and could virtually adjust the speed displayed on the VSL signs.
- *TMC-based control* – This concept would require a TMC be established to control the VSL system and perform other related functions such as road reporting, maintenance dispatching, etc. This concept would require dedicated staffing and be located in either the Missoula District offices or in Helena.
- *Fully automated control* – A fully automated system would collect all the necessary information and incorporate sophisticated software to make the decision regarding whether or not to activate the VSL, what speed would be established for each sign (could vary during event as conditions change), and when to deactivate the system. This concept would require a high level of sensor input and would not rely much on field input. It would require lower staffing levels to operate and would react quickly to conditions.

The Virtual/Remote and TMC-based control concepts would require 24/7 staffing, either on-duty or on-call, to ensure the VSL system was operational at any time that conditions warranted. Either of these concepts could also operate with field input, sensor input, or both.

Field Infrastructure

The third concept framework element is the VSL-specific and supportive field infrastructure. This infrastructure includes VSL signs, VMS, sign bridges, and power and communications to support operations. Assumptions regarding types, quantities, and support approaches were made to support the efficient development and analysis of VSL concepts. A detailed description of the infrastructure assumptions is provided below.

Corridor Infrastructure Assumptions

To deploy an effective VSL system, assumptions were made regarding the signage, power, and communications needed. These assumptions were based on what was learned from other state VSL system deployments. The following paragraphs describe the infrastructure assumptions used to define and estimate costs for a VSL system within the project corridor. Exhibit 5 graphically summarizes these assumptions.

I-90 Corridor Zones

The project corridor is currently divided into three maintenance segments: a top zone (0-5 miles) that represents the most challenging driving portion during inclement weather, a middle zone (5-10.5 miles) with both straight sections and sharp curves, and a bottom zone (10.5-33 miles) that also has sharp curves and can be challenging. Driving conditions are different depending what direction a driver is traveling. An effective VSL system needs to have the ability to display different speeds, reflecting road conditions, in each of these segments. Therefore, the six VSL zones shown in Table 4 were established for the initial concept assessment. These zones were developed based on the location of existing infrastructure, roadway geometrics, and the historical crash experience. While it is not critical for the function of VSL for these zones to match the maintenance segments, to simplify reporting MDT should consider adjusting the maintenance segments to match the VSL zones if VSL is implemented.

Table 4: I-90 Corridor VSL Zones

Roadway Segments	Eastbound	Westbound
Top (RP 0-7)	Zone 1	Zone 6
Middle (RP 7-17)	Zone 2	Zone 5
Bottom (RP 17-33)	Zone 3	Zone 4

Each zone will have multiple VSL signs. The VSL Management System will be designed to separately activate the VSL signs by zone in a coordinated manner.

VSL Signs, Bridges, Cabinets

The VSL system will include electronic signs with variable speed display options looking similar to a static regulatory speed limit sign. The following assumptions were made regarding the signs, bridges, and cabinets:

- VSL speed limits would be regulatory.
- VSL signs will be spaced roughly every three miles; this is consistent with other similar state VSL deployments in rural, mountainous terrain.
- Two VSL signs per direction will be installed to ensure the sign can be seen from each lane of travel and not blocked by large trucks.

- Due to buildup of roadside snow banks, VSL signs will be mounted on sign bridges directly over the travel lanes. In sections with a split alignment, two sign bridges, one for each direction, will be needed. Clearance to the sign bridges for over-dimensional freight movements should be considered in a future design phase.
- One control cabinet would be required per VSL location.
- Quantities
  - 44 VSL signs
  - 12 sign bridge locations, with a total of 15 sign bridges
  - 12 control cabinets
- Power and communications will be provided to each site (see below for details).

VMS Signs

Variable message signs will be used to alert motorists of hazardous driving conditions, VSL system activation, and incidents ahead. This assessment assumes one VMS will be installed at the beginning of each VSL zone, resulting in a total of six VMS. There are three existing VMS in the project area, and to the degree possible, these VMS would be retained in their existing locations. However, the cost estimate does include contingency costs in case these VMS need to be moved to a new location. Power and communications will be made available at each VMS location (see below for details).

Power Availability

Dependable electrical power is a critical part of the required infrastructure to operate the field equipment. Documentation of existing infrastructure revealed there was more power available than originally assumed through the kickoff meeting discussions. The following assumptions were made regarding power availability:

- There is not enough sun exposure and storage capacity for solar power to be viable.
- Electrical power does not always exist where VSL system equipment is planned.
- Power will be brought to the field equipment sites from existing locations. Preliminary estimates are that approximately 10 miles of power extension will be necessary to power all required field infrastructure.

Communication Availability

Communication with the field equipment is another critical infrastructure element to ensure a successful VSL system. Possible communication approaches include fiber, telephony, radio, cell modem, and satellite. Some form of reliable communication will be available at each VSL system field equipment site in the project area. The precise communication approach for each location would be determined in a more detailed concept phase. Planning-level cost estimates have been included for communication infrastructure.

Exhibit 5: Assumed VSL Infrastructure

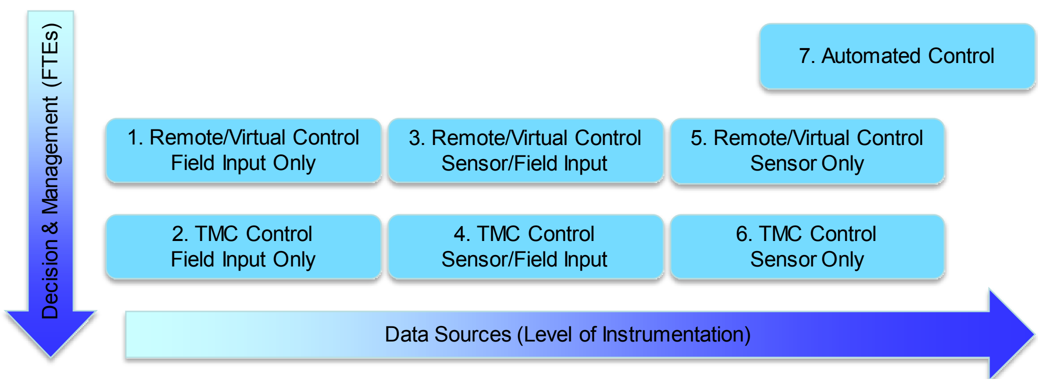
INITIAL CONCEPTS DEVELOPED

The following seven initial concepts were developed for analysis by combining the options contained within the framework (data sources and decision/management):

- Remote/Virtual Control – Field Input Only
- TMC Control – Field Input Only
- Remote/Virtual Control – Sensor/Field Input
- TMC Control – Sensor/Field Input
- Remote/Virtual Control – Sensor Only
- TMC Control – Sensor Only
- Automated Control

Each initial concept included the field infrastructure described above. Exhibit 6 identifies the seven initial concepts and illustrates their relationship to the concept framework. Data sources increase in level of instrumentation required from field input, to levels of sensor inputs, to fully automated. Decision and management increases the level of full time equivalent (FTE) staff from automation, to virtual control, to TMC control.

Exhibit 6: Initial VSL Concepts



The following section describes each of the seven initial concepts. An assessment of each of these seven initial concepts follows the descriptions with advantages and disadvantages discussed.

Remote/Virtual Control – Field Input Only (Initial Concept #1)

The data source for Concept #1 is field input only. The costs include a minimal amount of additional sensors to support field operations. Field input comes from maintenance crews and Highway Patrol officers via radio communications and includes weather conditions, road conditions, incident reports, and potentially speed limit recommendations. VSL system decisions will be made by dedicated personnel (split duties with other assignments) utilizing a web-based, virtual control computer system. The VSL system management will be available 24/7 and occurs remotely from any location. The decision maker will need access to the field input via radio communications. Staffing requirements include four operators (to cover all shifts), and one dedicated system operations and maintenance staff. Additional maintenance field operators would be needed to provide enough information and corridor coverage for confident VSL decisions. Based on input from WSDOT, which relies solely on field input to make VSL decisions, a total of eight maintenance operators per shift were assumed.

TMC Control – Field Input Only (Initial Concept #2)

Concept #2 is similar to Concept #1; however, the decision and management of the VSL system will be located in a fixed facility, a TMC. The center could be located in the Missoula District offices or in Helena. The staffing requirements would be generally the same as Concept #1, but include one additional TMC operator to act as a supervisor/trainer.

Remote/Virtual Control – Sensor/Field Input (Initial Concept #3)

Concept #3 expands the data sources to add sensors to the field input described in Concept #1. This data source combination has the primary advantage of additional corridor condition information to enhance coverage when field staff is not present on the corridor or staffing levels do not result in complete coverage of the corridor. Sensor data would include speed (by lane, including classification), RWIS stations, CCTV cameras, and mobile weather. RWIS stations include atmospheric weather conditions, visibility, and pavement conditions. Mobile weather sensors mount to a maintenance vehicle or Highway Patrol car and provide additional atmospheric and pavement conditions as the vehicle travels along the corridor. Included are 24 total speed sensors, an additional 5 RWIS (one existing at the summit) with cameras, and 10 mobile weather sensor suites. The required power and communication infrastructure to support this data collection is included in the costs. The staffing requirement is similar to Concept #2, but an additional dedicated equipment maintenance staff person is assumed to ensure consistent and effective sensor operation.

TMC Control – Sensor/Field Input (Initial Concept #4)

Concept #4 is a combination of Concept #2 (TMC Control) and Concept #3 (Sensor/Field Input). The level of sensor deployment is the same as Concept #3. The staffing requirements include five TMC operators, one dedicated equipment maintenance staff, and one dedicated information technology (IT) system staff.

Remote/Virtual Control – Sensor Only (Initial Concept #5)

Concept #5 removes the field input from Concept #3 and replaces it with a higher level of sensor coverage. Concepts #5 and #6 were conceived to relieve field staff of the responsibility to provide additional road and weather condition reports. Especially during extreme weather conditions when VSL would be needed most, the maintenance personnel are very busy with their primary function of maintaining a safe and passable roadway. There was a concern among the stakeholders that additional duties may negatively impact their ability to perform this primary function. Quantities of sensors were increased in this concept to include a total of 32 speed sensors, 6 RWIS with cameras, 12 dedicated pavement condition sensors (separate from full RWIS stations in other locations), and the same 10 mobile weather sensor suites. The sensor outputs will be provided to the remote decision maker electronically for VSL operation. Staffing requirements would include four VSL management staff, one dedicated equipment maintenance staff, and one dedicated IT system staff.

TMC Control – Sensor Only (Initial Concept #6)

Concept #6 is similar to Concept #5 and includes the same high level of sensor quantities; however, control is changed from virtual/remote back to the TMC concept described in Concept #2. Staffing requirements for the decision and management element would be the same as Concept #4.

Automated Control (Initial Concept #7)

Concept #7 automates the VSL management process with more sophisticated software to collect and analyze data; determine a course of action; and implement that action to activate, monitor, and deactivate the VSL system. The high-level sensor suite described in Concept #5 is included in this concept. Staff requirements are reduced for this concept to one dedicated equipment maintenance staff and one dedicated IT system staff. Missoula District management staff would be assigned to monitor the system on a rolling on-call basis.

PLANNING-LEVEL COSTS FOR INITIAL CONCEPTS

Table 5 summarizes the planning-level cost estimates developed for each of the initial concepts. The cost estimates included both one-time capital costs and annual operating and maintenance (O&M) costs. The estimates were developed using unit costs obtained from MDT input, other states, national cost databases, and the team's experience with similar projects. Appendix C includes the cost estimate worksheet used to develop these estimates.

Table 5: Planning-Level Cost Estimate for Initial Concepts (Millions of Dollars)

Initial Concept	Capital Costs				Annual O&M Costs			
	Field Infra-structure	Data Source	Decision/ Manage-ment	Total Capital Costs	Field Infra-structure	Data Source	Decision/ Manage-ment	Total O&M Costs
1: Virtual/Field	$6.2	$2.0	$1.0	**$9.2**	$1.1	$1.1	$0.5	**$2.7**
2: TMC/Field*	$6.2	$2.0	$1.7	**$9.9**	$1.1	$1.1	$0.7	**$2.9**
3: Virtual/Field+Sensor	$6.2	$3.2	$1.0	**$10.4**	$1.2	$0.6	$0.5	**$2.3**
4: TMC/Field+Sensor*	$6.2	$3.2	$1.7	**$11.1**	$1.2	$0.6	$0.7	**$2.5**
5: Virtual/Sensor	$6.2	$4.1	$1.0	**$11.3**	$1.2	$0.8	$0.5	**$2.5**
6: TMC/Sensor*	$6.2	$4.1	$1.7	**$12.0**	$1.2	$0.8	$0.7	**$2.7**
7: Automated	$6.2	$4.1	$2.2	**$12.5**	$1.2	$0.8	$0.4	**$2.4**

* TMC costs only reflect integration of VSL functions for Lookout Pass into the existing MHP Communications Center. A full MDT-operated TMC is not reflected in these costs.

INITIAL CONCEPT ASSESSMENT

Each of the initial concepts was assessed to determine level of feasibility with the goal of identifying one or two concepts for further analysis. Advantages and disadvantages were identified for data sources and decision/management options. A mid-project review was conducted with the MDT project team to discuss the assessments and obtain guidance on which concept(s) could be implementable within the department's structure, culture, and operational constraints. This section documents the initial concept assessments.

Data Sources

The data source options included field input only, sensor input only, and a combination of field and sensor input. Table 6 identifies the advantages and disadvantages of each.

Table 6: Advantages and Disadvantages of Data Source Options

Advantages	Disadvantages
Field Input Only	
Minimal sensor costs	Potential limited corridor coverage
Capture incidents and other activities	Requires higher level of training/procedures
	Possible latency of communication
Sensor Input Only	
Data consistency	High cost of sensors to obtain needed coverage
Eliminates reliance on field staff	Sensors don't detect issues/incidents other areas
Timely transmission of data	
Combined Field and Sensor Input	
Ability to balance data input and validate	Need for a process to resolve conflicting data
Redundancy	

Discussion around the field input only option quickly determined that this was not viable. The primary concern was being able to ensure high-level coverage of the entire corridor with limited staffing resources. Washington State (I-90 Snoqualmie Pass VSL) relies solely on their field maintenance staff. In the winter months they have between four (light conditions) and twelve (severe conditions) maintenance staff in the 24-mile VSL corridor 24-hours a day. This is a level of staffing density (one staff per 2-6 miles) that MDT did not feel was achievable in the I-90 Lookout Pass corridor under current budget realities. However, having some field input was desirable.

The sensor only option was also deemed not viable. The number and specific location of sensors required to obtain full corridor coverage was determined to be not feasible.

Therefore, the preferred option was the combined field and sensor input. This would allow consistent, timely data collection in the most problematic areas through the comprehensive sensor suite and the ability to collect information regarding issues and incidents in other parts of the corridor with existing maintenance staff levels.

Decision and Management

Decision and management options included virtual/remote control, TMC control, or fully automated. Table 7 identifies the advantages and disadvantages of each.

Table 7: Advantages and Disadvantages of Decision/Management Options

Advantages	Disadvantages
Virtual/Remote Control	
Flexible, adaptable to staffing and location	Potential for inconsistency
Facilitates split duty and on-call arrangement	Primary focus is I-90 VSL system; doesn't address other needs (road report, etc.)
TMC Control	
More responsive, proactive monitoring	Capital and operations costs
Opportunities for 511 road reporting, point of contact, maintenance dispatching duties	Maintaining staff training/proficiency
Future growth opportunities	
Partnership opportunity with Highway Patrol	
Fully Automated	
Responsiveness	Cost of high level of sensors
Consistency	Does not detect other issues, incidents
Limited resources needed, once built/operational	Need experienced IT staff to maintain system

It was determined that MDT did not support a fully automated system – at least not as a starting point. A human in the loop to make the VSL operation decisions is an important element of a VSL system. The virtual/remote concept includes potentially challenging staffing issues. The on-call approach was tried at MDT on similar technology/data projects and determined to be not-workable with the department structure. Furthermore, the delay associated with response times of on-call staff could result in differing road and weather conditions from when an event first begins. The discussion concluded that the VSL decision and management role should be staffed 24/7 during the winter season. These staff could have other duties when VSL was not in effect but would be fully dedicated to VSL when necessary. Given the staffing required to cover 24/7 shifts, the stakeholder group felt it would make the most sense to house the personnel in a TMC and take advantage of their abilities to perform other related functions. Additionally, staffing levels should be maintained all year as other states noted the extensive use of VSL systems in the summer months to respond to related weather events (e.g., heavy rain).

The TMC control concept evolved somewhat during the assessment activities to be more of an Operations Desk located in either the Missoula District offices or at MDT Headquarters in Helena. The idea that a TMC could be collocated with Montana Highway Patrol at Fort Harrison was determined to not be the best option primarily due to lack of expansion space at that facility.

Although the automated system was rejected, many of that concept's attributes could be included in the selected Operations Desk concept. Namely, a VSL Management System could be developed to automatically collect all the sensor and field data (from the 511 road report database), alert the operators of conditions that may warrant VSL activation, recommend specific VSL actions, and (following the operator's decision) implement VSL control through direct connection with the signs. These system features were included in the final concept definition.

PREFERRED CONCEPT SUMMARY

One I-90 VSL system concept emerged following the completion of the initial assessments: Concept #4 TMC Control – Combined Field and Sensor Input. This concept was chosen for further refinement for the following reasons:

- Demonstrates the most balanced approach to data collection and system management that is supported by MDT.
- Combines input from strategically located sensors with input from field personnel to ensure the VSL decision maker/manager would have the right level and quantity of information to make an informed decision regarding use of the VSL system.
- Defines a "smart" VSL Management System that provides decision makers with the data, options, and recommendations needed for efficient and effective VSL actions.
- The Operations Desk approach will utilize the required staffing in the most efficient way possible to manage the VSL system as well as perform other important and related functions.
- The Operations Desk approach will also provide MDT with flexible options for future expansion into a full statewide Transportation Management Center (TMC).

CONCEPT REFINEMENTS

The development and assessment of the seven initial concepts resulted in the selection of a data source and decision and management approach. The attributes of the preferred VSL concept include:

- Data sources that combine sensor data and field input to provide a comprehensive picture of the corridor conditions. These data will be used by the decision maker to determine if and how the VSL system should be implemented.
- An Operations Desk that operates 24/7 to control the VSL system and conduct several other duties – restructuring how technology systems are managed in the Missoula District.
- A VSL Management System that will collect, process, and operate the VSL system with a human in the loop to monitor the conditions and make final decisions regarding the use of VSL technologies.

This section refines the preferred concept and provides some additional details that can be used as a starting point for future activities to develop a concept of operations and define system requirements.

OPERATIONS CENTER FUNCTIONS AND LOCATION

As mentioned previously, during the assessment process the TMC concept evolved to an Operations Desk. The Operations Desk could be located in either the Missoula District offices or at MDT Headquarters in Helena. Each location option has distinct advantages.

The primary advantage of locating the Operations Desk in Missoula District offices is the proximity to the I-90 VSL corridor, resulting in no additional communication costs and a focus on the District's operations. In addition to the VSL management activities, the current duties of the 511 road reporting staff could be consolidated into the new Operations Desk.

The advantage of locating the Operations Desk at MDT Headquarters was the opportunity and potential cost savings related to expanding VSL to other Districts.

The final decision regarding location of the Operations Desk will be made by MDT at a later time. The costs of the two location options are the same, with one exception. Communication with the field personnel will be essential to the success of the VSL system. That communication is currently available in the Missoula District offices. However, communication to field staff from Helena is not currently available and would have to be established. The cost to establish that communication connection is estimated to be $225,000.

Regardless of which location is selected, it is important to understand that the Operations Desk will be operational 24/7 and perform more than just VSL management duties. Potential other duties of the Operations staff may include:

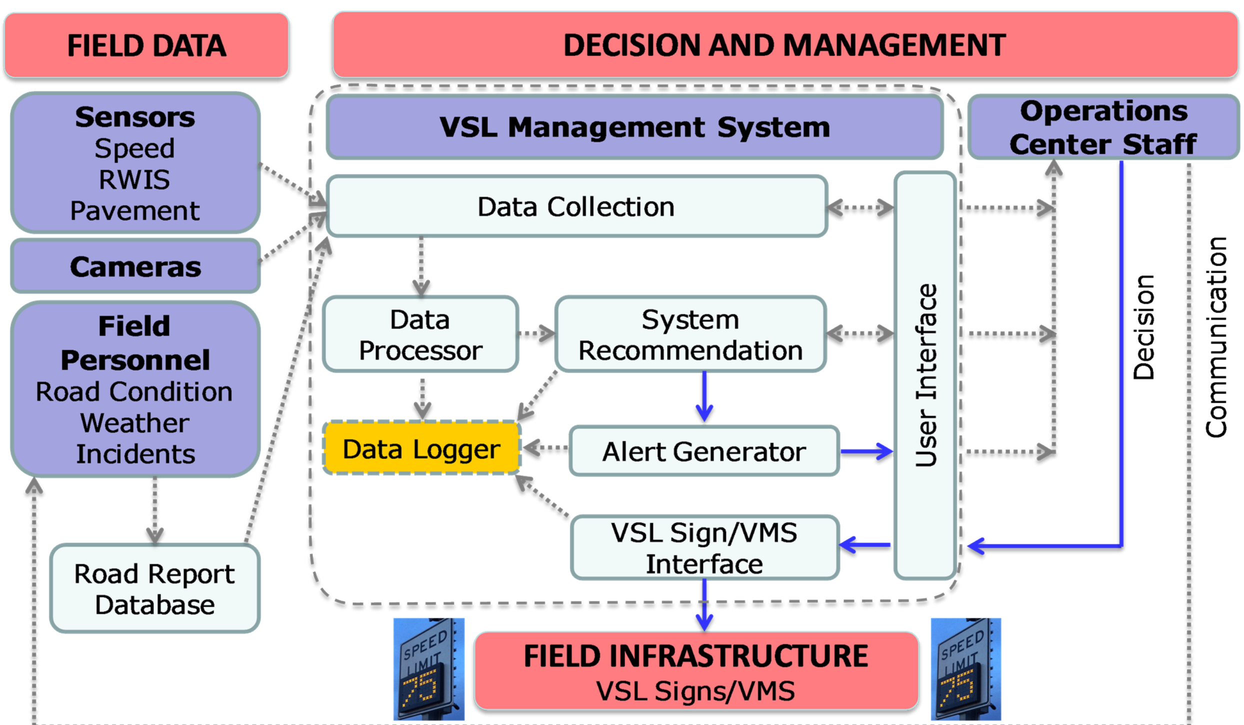
- 511 winter road reporting
- VMS sign control
- Maintenance dispatching

- Incident detection/coordination with emergency response
- Act as the point of contact for the District for all transportation issues and coordinate with other MDT Districts or Headquarters

VSL MANAGEMENT SYSTEM

Based on stakeholder feedback, the concept of a VSL Management System, as previously described, was developed during concept refinement. The VSL Management System will act as a decision support application to assist the Operations Desk staff to be as efficient as possible and to ensure responsive VSL operation. The management system will be housed in the Missoula District Offices and have several integrated components acting together to collect field data, process the data and make VSL recommendations, alert users based on defined criteria, interact with the operations staff users, and implement the VSL signs. Exhibit 7 illustrates the high-level architecture of the VSL Management System. The following paragraphs provide an overview of each major component.

Exhibit 7: VSL Management System High-Level Architecture



Field Data Collection

Field data includes sensors (speed, RWIS, and pavement), CCTV cameras, and input from field personnel (road conditions, weather, and incidents). Input from the field personnel will be obtained through a connection to the 511 road reporting database.

Data Processing and VSL Recommendations

The primary function of the data processor will be to answer the following three questions:

- Do the corridor conditions warrant the use of a different speed limit?
- What VSL zones are affected?
- If a new speed limit is warranted, what should the new speed limits be set to, by zone?

The answers to these questions will be achieved through a sophisticated set of algorithms that will assess corridor conditions (from the field data inputs) against pre-defined criteria and determine if action is warranted and what that action should be. When certain conditions are met, VSL recommendations will be made that define VSL changes. The corridor conditions will be constantly monitored, data collected and processed, and revised recommendations generated, as warranted by conditions.

User Alerts

An alert generator will provide the recommendations to the system users. The alerts can be made via email or text and will be based on a defined set of alert criteria. For instance, alerts might be generated because a specific road, weather, or pavement condition threshold was met, or a VSL change recommendation was made by the system.

Interact with System Users

The system users will interact with the VSL Management System via a web-interface. It is envisioned that the system itself will be housed on servers at the MDT Missoula District offices. The web-interface approach will allow the Operations Desk to be located in either the Missoula District offices or in Helena.

The VSL Management System user interface will allow the user to perform the following functions:

- Obtain field data for review
- Review, accept, reject or change a VSL recommendation
- Activate or deactivate VSL signs and change the posted speeds, by zone

Additionally, the system will allow users to contact field personnel directly if they want additional information or to discuss a certain situation before they decide if or how to change VSL signs. As mentioned earlier, if the center is located in Helena, a new communication connection will need to be established in order for this feature to work properly.

Implement VSL Signs

The VSL Management System will have a direct connection to the VSL signs in the field and be able to change the signs as the user directs. The management system is not designed to be fully automated.

Users must either accept or change a system recommendation and "submit" VSL sign changes manually. No VSL sign changes will be made without a human directing the system to do so.

The management system will be pre-programmed with the VSL signs by zone. The system recommendations will also be presented by zone. When a certain VSL zone is activated with a new posted speed, the system will automatically change the corresponding VSL signs. The user will not have to identify and change each VSL sign separately.

Data Logging

An internal module will log all data, recommendations, alerts, and actions taken to manage the VSL system. These logs will serve to document the conditions under which certain decisions were made for post event reviews, understanding, and staff training.

STAFFING REQUIREMENTS

The Operations Desk will operate 24/7 and perform the functions identified above. Additionally, it is essential that the field equipment and VSL Management System operate properly with a high-level of uptime. This will require the following staffing requirements:

- Four full-time Operations Desk operators to cover three shifts including holidays, sick time, and personal time. It is assumed these four operators would replace the existing road reporter positions.
- Two additional field maintenance operator positions (2 FTEs) to improve coverage of the corridor and field input
- One full-time IT/communication staff to maintain the VSL Management System and connections to field equipment
- One full-time field equipment maintenance and communication technician to ensure the sensors, VSL signs, and other equipment are operating properly

This list represents all the required staff to operate the VSL system. MDT will determine at a later time how many of these staff are new FTEs and how many can be re-positioned from existing FTEs.

FINAL CONCEPT SUMMARY AND COST ESTIMATES

The results of the concept refinement were presented to the MDT stakeholder group at a meeting on May 27, 2016. Appendix D includes the final presentation. Concurrence on the final concept was received at this meeting. This section summarizes each element of the final concept and the associated capital and O&M costs.

DATA SOURCE ELEMENT

The data source for making VSL decisions will be a combination of field operator input and sensor input.

- A heavy level of sensing was assumed to minimize reliance on field operators and support the VSL Management System. The assumptions for sensing equipment include:
    - 32 radar speed detectors
    - 6 RWIS
    - 12 pavement condition sensors (in addition to RWIS)
    - Mobile weather suites for 10 vehicles
    - Additional power and communication extensions, as necessary
- Two additional field operator FTEs were assumed to increase coverage of the corridor and improve input on road and weather conditions from the field.

DECISION/MANAGEMENT ELEMENT

The decision/management element is premised on the development of a VSL Management System with final management of the VSL system by an operator at an Operations Desk.

- The VSL Management System will interface with the field sensors and input from field operators through a connection to the 511 system to detect the need to adjust speeds, develop recommendations for speed changes, and send alerts to the operator(s).
- The Operations Desk will be located in either the Missoula District office or in Helena. If located in Helena, additional capital costs, approximately $225,000, will be incurred to provide radio communication from Helena to the field operators in the District.
- The VSL operator position will be staffed 24/7 during the winter season. When the operator is not managing the VSL system, they will have other duties. On-call staff will be available, as needed, to fulfill those other duties when the VSL operator is actively managing the system.
- The VSL operator will interact with the VSL Management System to activate, monitor, and deactivate the VSL system.

FIELD INFRASTRUCTURE ELEMENT

Field infrastructure was assumed based on conditions along the study corridor and input from other states with VSL systems.

- The corridor will be split into six zones, three in each direction.
- VSL signs will be regulatory and spaced roughly every three miles. Two VSL signs per direction will be installed to ensure the sign can be seen from each lane of travel and not blocked by large trucks. This results in 44 VSL signs.
- Due to buildup of roadside snow banks, VSL signs will be mounted on sign bridges directly over the travel lanes. In sections with a split alignment, two sign bridges, one for each direction, will be needed. This results in a total of 15 sign bridges.
- One control cabinet would be required per VSL location resulting in 12 cabinets.
- One camera per direction will be located at each VSL location resulting in 24 cameras.
- One VMS will be located at the beginning of each zone resulting in six total VMS (three existing and three new).
- Power and communications will be extended to each site, as necessary.

VSL STAFFING REQUIREMENTS

The VSL final concept will require the following staffing requirements. MDT will determine at a later time how many of these staff are new FTEs and how many can be re-positioned from existing FTEs.

- Four full-time Operations Desk operators to cover three shifts including holidays and personal time. It is assumed these four operators would replace the existing road reporter positions.
- Two additional field maintenance operators (2 FTEs) to improve coverage of the corridor
- One full-time IT/communication staff to maintain the VSL Management System and connections to field equipment
- One full-time field equipment maintenance and communication technician to ensure the sensors, VSL signs, and other equipment are operating properly

FINAL CONCEPT COST ESTIMATE

Table 8 summarizes the initial capital costs and on-going, annual O&M costs associated with the final concept. These planning-level costs are based on present (2016) dollar values. Based on input from MDT, a 2.5% annual inflationary rate should be applied to these estimates to determine future year costs. Appendix E includes the cost estimate worksheet for the final concept.

Table 8: Final Concept Planning-Level Cost Estimate (Millions of Dollars)

Capital Costs	Field Infrastructure	$6.2	**O&M Costs**	Field Infrastructure	$1.1
	Data Source	$4.1		Data Source	$0.8
	Decision/Management*	$2.7		Decision/Management	$0.7
	Total Capital Cost	**$13.0**		**Total O&M Cost**	**$2.6**

* Increases by $225,000 if VSL Operations Desk is located in Helena

CONCLUSIONS AND RECOMMENDATIONS

The Montana I-90 Lookout Pass corridor (Reference Post (RP) 0.0 to 33.4) exhibits higher than normal crash rates due to challenging terrain and weather conditions. Excessive speed is a contributor to the safety issues in the corridor. Variable speed limit systems in other states have shown to reduce speeds, narrow the distribution of speeds, and reduce crashes. This feasibility study identified and assessed several VSL concepts with stakeholders and MDT staff and determined the most likely approach to pursue, if MDT decides to move forward. The following identifies major conclusions derived during the study and recommends possible next steps to MDT.

CONCLUSIONS

Significant Implementation Challenges

The feasibility study acknowledged the challenges to implementation. These challenges do not present fatal flaws; however, they do increase the capital and ongoing operations and maintenance costs for MDT. The major challenges identified include:

- Lack of core infrastructure, namely power and communication to operate sensors and signage
- Lack of existing advance technology sensing to help understand the corridor road and weather conditions
- Lack of a management center to assemble information, make traffic management decisions, and disseminate traveler information
- Lack of operations management structure and processes

Other State VSL Systems

Four other state's VSL systems were investigated (Wyoming, Utah, Oregon, and Washington). All of these systems are effective; however, they have been implemented in very different ways and utilize varying operational approaches. The following summarizes key findings that informed the development of VSL concepts:

- Each state VSL deployment was based on their specific needs, available infrastructure, and operational culture.
- Each state depended on some form of road and weather condition information to inform VSL decisions.
- All states had some sort of data management center to assemble road conditions and provide information to decision makers (Oregon automates the decision making process).
- All states had a defined process to determine if VSL should be activated, and if so, what speed limit should be established for the present conditions.

- VSL implementation should focus on corridor-wide application and not be used as a solution for safety hot-spots.
- Each state implementation used different levels of staffing to operate their VSL systems.
- Rough VSL sign spacing guidelines was to deploy twice as many signs as they would normally have for static speed limit signs.

I-90 VSL Refined Concept Attributes

The refined concept is specific to MDT's needs on the I-90 corridor and includes the following attributes:

- Balances data collection and system management that is supported by MDT
- Combines input from strategically located sensors with input from field personnel to ensure the VSL decision maker/manager has the right level and quantity of information to make an informed decision regarding use of the VSL system
- Defines a "smart" VSL Management System that provides decision makers with the data, options, and recommendations needed for VSL operation
- The Operations Desk approach utilizes efficient use of staffing to manage the VSL system as well as perform other important and related functions.
- The Operations Desk approach also provides MDT with flexible options for future expansion into a full statewide TMC.

Planning-Level Cost Estimates

The refined concept is estimated to result in the following costs. Additional detail is provided in Appendix E.

- Capital: $13 million
- Annual O&M: $2.6 million

RECOMMENDATIONS

The following near-term actions are recommended:

- **Use Feasibility Study** – MDT should use the results of this feasibility study internally to determine next steps regarding VSL in the I-90 Lookout Pass corridor, as well as for consideration in understanding the infrastructure type and investment required for other potential corridors in the state.
- **Complete Ongoing Speed Study** – MDT should complete the ongoing speed study and implement any recommended changes in the I-90 project corridor to immediately address

safety concerns. Additional safety treatments could also be considered to address spot concerns (e.g., active warning systems on curves).

- **VSL Next Steps** – If MDT decides to move forward with VSL in the I-90 project corridor the following next steps would need to occur:
    - Conduct further analysis to determine the best location for the Operations Desk: Missoula District offices or MDT Headquarters in Helena
    - Prepare a VSL system corridor implementation plan that would define in more detail the location of sensors and signs and clarify the power and communication approaches
    - Prepare a system Concept of Operations to define data collection and management, operation desk function, communication protocols, and operational procedures (including the criteria for determining a speed limit change and what the speed should be based on various conditions)
    - Develop High-Level System Requirements to define the system levels and expected functions, inputs/outputs, and outcomes