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BRITISH COLUMBIA
Ministry of Transportation

Ministry of Transportation and Infrastructure

Fraser Valley Variable Speed Limit System
Jurisdictional Study of Speed-Harmonization Systems

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1 Executive Summary

This report provides recommended system design parameters for a speed-harmonized Variable Speed Limit System (VSLS). The report describes relevant VSLS best practices and lessons learned from a review of numerous existing systems deployed across North American and overseas. This review encompassed published government documentation, academic papers, first-hand discussions and internal experience. The content of this document is intended to guide the design and implementation of future VSLS deployed by the Ministry of Transportation and Infrastructure.

2 Introduction

As directed by the Ministry of Transportation and Infrastructure, PBX Engineering completed a jurisdictional review of existing VSLS and their methods of achieving speed harmonization. The results of this review are intended to guide the design and implementation of the proposed VSLS for a section of Highway 1, between Abbotsford and Chilliwack, which is affected by recurring congestion as well as adverse road weather conditions.

The previously-issued VSLS Concept of Operations details the Ministry's existing systems on Highway 1, Highway 5 and Highway 99. These systems recommend speed limit adjustments based on input from the road weather and traffic responsive subsystems. This report considers modifications to the existing traffic responsive subsystem to effectively manage varying traffic speeds in the presence of congestion.

2.1 Objective

The ability of speed-harmonization VSLS, in a congested highway corridor, to effectively reduce the risk to motorists associated with highly-varied speeds, has been well documented by agencies internationally. This report addresses four specific questions in relation to the development of an expanded VSLS on Highway 1 in the Fraser Valley:

1. Can the Ministry's current VSLS system play an effective role in congestion management?
2. Does the current hardware deployed in the field by the Ministry's VSLS need updating/changing (speed & queue detection sensors, sign size, sign and sensor frequency & spacing, speed by individual lane, or by all lanes, use of Dynamic Message Signs (DMS))?
3. Does the software and algorithms used to map and determine appropriate speeds by the Ministry's existing VSLS need changing/updating to support a congestion-based system? If yes, what changes should be made?
4. What are the lessons learned by other agencies? What improvements to effectiveness or modifications to their system(s) (e.g.: hardware, software, motor vehicle acts and regulations, etc.) have been planned or implemented?

In responding to these four questions, this report provides information and recommendations to the Ministry, pertaining to any changes to the existing VSLS, required to support speed harmonization and congestion management on the proposed Fraser Valley VSLS corridor. Additional consideration is given to the present configuration of instrumentation and hardware on previous Ministry deployments. Questions one through three are addressed via the Recommendations section. Question four is addressed via the Discussion of Research and Results.

2.2 Report Methodology

The methodology used in the development of this report utilized the following progression:

- Identify best practices and compare key components of speed-harmonized VSLS in numerous jurisdictions, providing an overview of pertinent aspects of successful systems.
- Provide recommendations for VSLS design for the speed-harmonized section of the Fraser Valley VSLS project.
- Identify potential changes to the Ministry's existing VSLS that may be necessary.

3 Discussion of Research and Results

3.1 Overview of Sources

The jurisdictional review carried out by PBX Engineering involved the investigation of numerous VSLS deployments by agencies throughout North America and overseas. Great utility was provided by several previously-completed jurisdictional reviews prepared by other organizations; in particular, the U.S. Federal Highways Administration (FHWA) is responsible for a detailed international study that is referenced by VSLS guides and reports published throughout the industry. In their study, the FHWA described the successes, challenges and varying approaches to traffic management and VSLS observed throughout Europe.

In addition to the review of published literature, correspondence and consultation with representatives from the Departments of Transportation in various parts of the U.S. facilitated detailed discussion of topics pertinent to the development of VSLS within British Columbia.

Key aspects of a select group of systems are shown in **Table 1** for the purpose of easy comparison. Established traffic management systems that, together, help to form an appropriate model to guide the further development of systems in British Columbia, were selected for comparison. Systems within Washington, Oregon and Virginia are compared with implementations in the UK, as well as with the existing systems currently operating in B.C.

Aspect	WSDOT	ODOT	VDOT	Highways England	B.C. MoTI
Location	Washington, USA	Oregon, USA	Virginia, USA	Great Britain, UK	BC, Canada
Deployment(s)	I5, I90	OR217	I66	M25, M42	Hwy1, 5, 99
Description	Lanes: 1 - 4 (each direction) Length: 7 miles	Lanes: 2 - 3 (each direction) Length: 8 miles	Lanes: 2 - 3 (each direction) Length: 12 miles	Lanes: 3 - 4 (each direction) Length: 23km ,17 km	Lanes: 2 - 3 (each direction) Length: 43km, 30km, 41km
Deployment Characteristics	Interstate highway. VSLS: Weather and Traffic responsive.	Urban freeway. VSLS: Weather and Traffic responsive.	Interstate highway. VSLS: Traffic responsive.	Suburban freeway. VSLS: Traffic responsive.	Rural highway. VSLS: Weather and Traffic responsive.
Speed Limits	Regulatory	Advisory	Advisory	Regulatory	Regulatory

Table 1: VSLS Jurisdictional Comparison

The information that is presented in these sections was gathered from telephone conversations, concepts of operations documentation, published lessons learned and formal reports. It should be noted that additional review of various academic sources and further publications, prepared by agencies in other nations and institutions, was used to form of the overall perspective on the state of the industry, from which perspective this report was written.

3.2 *Discussion of Jurisdictional Research*

As noted above, information on the nature of existing VSLS deployments was obtained from numerous sources. A discussion of the various approaches to speed harmonization, with respect to several categories of interest, is provided in the sections below.

3.2.1 VSL Signage

Variable speed limit signage is the primary means of communicating speed limits to motorists within a VSL corridor. It is the primary method by which the VSLS adjusts the flow of traffic in response to varying downstream conditions. The placement of VSL signs effectively divides a corridor into speed sections and dictates the sections in which speed can be controlled. VSL sign spacing and other key physical characteristics are shown in **Table 2**.

A successful speed harmonization system will impose reduced speed limits on traffic that is otherwise unaware of the upcoming congestion issue. The oncoming traffic is slowed, allowing time for the congestion condition to clear, or at a minimum, reducing hazardous changes in traffic speeds. To this end, VSL signs are typically controlled by input from nearby downstream traffic sensors.

VSL Signage	WSDOT	ODOT	VDOT	Highways England	B.C. MoTI
Sign Dimensions (mm)	1524 x 1524	Not Available	1219 x 1219	Not Available	1219 x 900
Manufacturer	Telegra	Daktronics	Ledstar	Not Available	ADDCO
Included Example(s)	Figure 1	Figure 2 and Figure 3	Figure 4	Figure 5	Figure 6
Placement	Above each lane	Above each lane	Above each lane	Above each lane	Single sign
Structure	Gantry	Gantry/Overpass	Gantry	Gantry	Davit Pole
Spacing (m)	533 - 800	1600	800	500 - 1000	2000 - 7000

Table 2: VSL Sign Comparison

The VSL sign spacing are each a result of the nature of the corresponding system. Both Oregon and Washington have rural deployments that are primarily responsive to weather, as opposed to congestion, in which sign spacing is larger. For congested areas, Highways England has designed systems based on the requirement to have a VSL sign in view at all times.

The benefits of larger VSL signs, in terms of improved visibility, have been considered by both the Ministry and WSDOT. The latter is now implementing 1524 x 1524mm signs with speed limits displayed as white images (as opposed to text) on black backgrounds, reportedly providing improved rendering of characters. With regards to signage equipment, WSDOT has noted their preference to control each sign with an individual controller with a unique IP address. Consideration should be given the merits and drawbacks of controlling multiple signs with a single controller. Furthermore, wherever possible, control equipment should be accessible at ground level. Both

WSDOT and ODOT expressed regret at not having installed catwalks on overhead gantries. In their absence, maintenance may require lane closures which have the potential to further worsen congestion.

Lastly, the issue of obstruction of sign visibility due to snow cover has been identified by the Ministry on previous deployments. The conditions observed on British Columbia's corridors have not been experienced to the same degree in other jurisdictions, likely due to different weather conditions. Sign obstruction, due to snow buildup, should be addressed in the design phase. No best practices in this regard were gained through research of other jurisdictions.

Figure 1: Washington VSL Sign and DMS

Figure 2: Oregon VSL Sign and DMS (Overpass Mount)

Figure 3: Oregon VSL Sign and DMS (Gantry Mount)

Figure 4: Virginia VSL Sign and DMS

Figure 5: UK VSL Sign and DMS

Figure 6: MoTI VSL Sign (Existing)

3.2.2 Dynamic Message Signage

The use of dynamic message signs (DMS) to support speed harmonization is seen as being crucial to promoting public acceptance of the system. Due to the nature of speed harmonization, the reason for the reduction in speed may not be immediately apparent to a motorist who is unaware of upcoming congestion. They may be required to slow down from what might otherwise be a safe speed for perceived conditions. DMS provide an opportunity to inform motorists of the reason for reduced speed limits, which in-turn results in greater compliance. Therefore, when determining placement and frequency of DMS in a VSLS corridor, their utility as tools of communication should not be underestimated.

DMS Signage	WSDOT	ODOT	VDOT	Highways England	B.C. MoTI
Dimensions (m)	Not Available	Not Available	3.8 x 2.4	Not Available	7.75 x 1.525
Included Example(s)	Figure 1	Figure 2 and Figure 3	Figure 4	Figure 5	Figure 7
Placement	Major interchanges	Entrances to VSLS corridors	Consistently spaced throughout corridor	Consistently spaced throughout corridor	Entrances to VSLS corridors
Mounting	Left side of overhead gantry	Sign pole at road shoulder and overhead gantry	Left side of each overhead gantry	Overhead gantry	Cantilever
Spacing	8 – 16km	3200m	800m	500 - 1000m	20 – 30km

Table 3: DMS Comparison

Figure 7: MoTI DMS (Existing)

The WSDOT had experience with a previous system which lacked the DMS component. This, coupled with insufficiently-sized VSL signs, led to a decidedly ineffective system. Presently, WSDOT presents both the posted speed and informative messages on their DMS, which can display 5 lines of 12 inch characters. At a minimum, agencies typically provide information on upcoming traffic conditions or incidents. The M42 system in the UK provides additional information about congestion on surface streets that connect to the VSLS corridor, so that motorists can adjust their travel plans if desired. Virginia complements the VSL sign by stating when reductions in speed are recommended (due to congestion) and conversely when it is safe to resume the normal speed limit (after traffic begins to flow freely once again). ODOT DMS identify the reason for the recommended reduced speed, be it due to weather, congestion, or an upcoming traffic queue. When specific information relating to traffic incidents is available it can be displayed via DMS as is the case in Virginia and the UK.

Typical of all surveyed agencies is the tendency to co-locate DMS with VSL signs when possible, to make efficient use of structures. In cases where DMS and VSL signs are both spaced with the same frequency, placement of DMS becomes relatively trivial. In other cases, where VSL signs are not always accompanied by DMS, strategic placement is necessary. Examples of this are as in Washington and Oregon, where DMS are placed at major interchanges and entrances to the VSLS corridor.

As previously noted in regard to VSL signs, gantry catwalks are regarded as being highly beneficial for maintenance and, wherever possible, sign control equipment should be accessible from ground level.

3.2.3 Traffic Sensors

Traffic sensors provide data that are the basis for the speed harmonization algorithm. Traffic sensors can detect the presence of passing vehicles and determine vehicle speed and classification as well as traffic volume and occupancy. Data from these sensors are used to identify and calculate severity of congestion at a given location.

The placement of traffic sensors affects the algorithm's ability to detect congestion; congestion can only be detected where sensors are installed, so strategic placement is a key consideration. A strong understanding of the locations within a corridor where recurrent congestion poses an issue will lead to a system that can consistently detect and respond to such events. Furthermore, frequent placement of sensors throughout a corridor increases the chances that an incident or non-recurring congestion condition can be reliably detected.

Traffic Sensors	WSDOT	ODOT	VDOT	Highways England	B.C. MoTI
Type	Loop	Loop/Radar	Radar	Loop/Video	Radar
Approx. Spacing	533 – 800m	800 – 1600m (congested areas) less frequent in rural areas	533m	500m	2 - 7km

Table 4: Traffic Sensor Comparison

Analyzing the effectiveness of a speed harmonization system can be facilitated by the measurement of travel times before and after the system implementation. In addition to conventional loop and radar-based traffic sensors, the ODOT deployment makes use of Bluetooth sensors to measure travel times as a means of gauging the effectiveness of the system. WSDOT has noted difficulty in quantifying the effectiveness of their speed harmonization algorithm.

3.2.4 Speed Harmonization Algorithm and ATMS

The primary task of the Automated Traffic Management System (ATMS) speed harmonization algorithm is to facilitate the reduction of speed limits (in response to current conditions) in a manner that reduces or eliminates significant and abrupt changes in actual vehicle speeds as experienced by motorists. The primary objectives are to reduce the risk of motor vehicle incidents caused by abrupt braking, increase traffic flow and to provide consistent travel times for motorists. This also includes the goal of accounting for actual vehicle speeds when determining a new speed limit, in order to limit unnecessary speed deviations. To this end, the algorithm will need to accomplish the following:

- Interpret traffic conditions in real time, identifying congestion when present
- Apply optimal speed reductions to appropriate VSL signs, imposing speed reductions gradually
- Display relevant information on appropriate DMS

Before speeds are posted, the algorithm must ensure all reductions in speed are imposed gradually as a motorist travels along the corridor. A basic example of this concept of cascaded speed adjustment is as follows:

With no speed reductions in effect, congestion is detected at a particular location. VSL sign "n" is the next upstream sign in advance of the identified traffic condition. If this condition warrants a significantly reduced speed at VSL sign "n", the next upstream VSL sign, "n-1", should display a speed greater than that of VSL sign "n", but less than the speed displayed by the next upstream VSL sign, "n-2". A motorist travelling along the corridor will encounter a marginally reduced speed at VSL sign "n-2", a further reduced speed at VSL sign "n-1" and, finally, the fully reduced speed at VSL sign "n".

The above approach smooths out dramatic speed reductions and helps to avoid creation or relocation of traffic shockwaves. This part of the algorithm should be applied before speeds are posted to ensure an effective and proactive system response.

Additional design considerations may become relevant depending on the application. The ability to use the shoulder as an additional running lane and individual control of per-lane speeds are two possibilities that add complexity to a system, but which may be warranted depending on the severity of the congestion issues observed in the area.

System Attribute	WSDOT	ODOT	VDOT	Highways England	B.C. MoTI
Per-Lane Control	Higher speed in HOV lane permitted	None	Not determined	Per-lane speed all lanes	None
Shoulder Utilization	None	None	Dynamic shoulder use	Dynamic shoulder use	None
Speed Detection	85th percentile speed	85th percentile speed	Calculated average speed	Not determined	85th percentile speed
System Autonomy	Automated (Operator suggestion and override capabilities)	Automated (Operator suggestion and override capabilities)	Automated (Operator suggestion and override capabilities)	Automatic operation based on manually selected, pre-defined operational regimes	Automated (Currently Operator required to accept all recommended speeds)
Communications	Fibre	Fibre	Fibre, cellular, VPN	Not determined	Cellular, wireless Ethernet

Table 5: System Comparison

As previously stated, the operation of a speed-harmonization system relies on traffic sensors to provide data on the state of traffic flow. A value for traffic speed can only be inferred, as direct measurement is not possible. It is typical for a VSLS algorithm to continuously compile individual vehicle speed data over a period of time and calculate the 85^{th} percentile speed as the representative traffic speed. This value evolves over time as general traffic speed varies and is an effective way to determine a value to use in place of average traffic speed. The determination of this 85^{th} percentile speed allows the opportunity for the VSLS to set the speed limit based on actual traffic speeds, which can help reduce speed deviation and improve flow.

Depending on whether the VSLS includes a subsystem that provides input from road weather sensors, the more conservative of multiple proposed speeds is typically chosen to apply to a given section. This is often done automatically, with input or override from operators accepted, but not constantly required; the BC VSLS deployments currently differ from others in this regard, with operator acceptance required for all speed changes. We note that this requirement may be removed in the future, as the system is capable of running fully autonomously. A speed-harmonization system benefits from its ability to respond, with minimal delay, to changing traffic conditions and minimal reliance on operators can certainly improve the effectiveness of the system. As noted by the VDOT, VSLS systems should be constantly logging auditable data pertaining to the speed values posted, time and date, sensor data and any other relevant information.

The response to detected congestion condition varies across VSLS implementations, but the way a system responds is invariably related to, or limited by, the frequency of VSL signage and DMS within the corridor. For instance, in Washington, regularly spaced gantries are grouped in order to provide a coordinated response to a detected condition. In that case, each step of the graduated speed reduction is applied to a pre-determined set of gantries, dependent on where the issue is located. In the UK, notification of incidents or congestion is provided at least 1 mile upstream of the condition.

While in most cases, the speed on a given VSL sign is dependent on downstream traffic sensors, ODOT identified that any traffic sensors that may be co-located with the VSL sign should also factor into the proposed speed for that sign. Additionally, for ODOT's rural deployments in which speeds are affected primarily by input from weather sensors, there are cases where different speeds are posted for trucks versus regular traffic.

In existing VSLS implementations, certain limitations are typically placed on the rate of change of posed speeds. The imposition of these limitations may be driven by regulatory groups or they are otherwise instrumental to the success of the VSLS. As is the case in the ODOT deployment, the minimum elapsed time to maintain a displayed speed limit is larger when the speed is to be increased, than when the speed is to be decreased (i.e. speed limit reductions are allowed to occur more rapidly than speed limit increases). Minimum display periods of 2 minutes, prior to reducing speed, and 3 minutes, prior to increasing speed, are used by the ODOT VSLS to prevent speed limit oscillation. Additionally, limits are typically placed on the maximum speed increment by which subsequent VSL signs should differ; 10 mph is the limiting value used by VDOT.

3.2.5 Communications Infrastructure

As listed in Table 5, different communications solutions have be employed, with the most reliable being fibre (Information on the means of communication for VSLS in the UK was not available). Experiences in Oregon, Virginia and British Columbia encourage the use of fibre optic communications for reasons including increased bandwidth for CCTV and improved reliability.

3.2.6 Public Outreach and Enforcement

Any new VSLS must be trusted by the public in order to be successful in meeting its objectives. To that end, the public must be made aware of its purpose in order to manage their expectations. A speed-harmonization system alone cannot solve the problem of an increasing population making use of relatively static transportation infrastructure, but it can improve conditions and increase safety. If the goals of a system are not made clear, members of the public may lose confidence or become frustrated with it, leading to non-compliance, which will reduce the effectiveness of the system.

As discussed in previous sections, messages provided through DMS have been used effectively to inform and educate motorists on the road, but additional proactive public outreach in the early stages of a project can be highly beneficial. For instance, WSDOT noted certain issues with the media's use of the phrase speed "harmonization" in reference to one of their newer VSLS projects. The meaning of term was seemingly unclear in reference to the benefits such a system was meant to provide. Use of the alternative term, speed "smoothing", was deemed more effective as it better described what the system was intended to accomplish.

Closely-related to the subject of public compliance is the matter of speed limit enforcement. Depending upon the nature of the system, i.e. regulatory versus advisory, different approaches can be taken to citing infractions. In the UK, the M42 VSLS randomly activates speed cameras to cite drivers travelling a specified percentage beyond the posted limit. VDOT has stated that CCTV will not be used to enforce speeds set by their advisory system, while the advisory speeds posted in Oregon are presumed by authorities to be applicable in court as they represent safe speeds for conditions (though there has been no precedent set for this).

Priority should be placed on promoting public acceptance through early project notifications and media relations, while appropriate enforcement strategies should be explored according to the challenges faced in the congested corridor and the objectives of the VSLS.

3.2.7 System Maintenance

Experience with ongoing maintenance activities and challenges experienced in the previous VSLS deployments in British Columbia, lead to potential design enhancements for future projects. The following considerations complement the results of the jurisdictional review discussed in this report:

- Prevention of snow buildup on signs:
  - Major visibility concerns arise when snow obscures signals and signage.
- VSLS communications:
  - The cellular network employed by the current B.C. VSLS has experienced multiple connectivity issues. These include local issues due to poor signal quality as well as carrier-caused system-wide outages. A fibre-optic communications backbone is seen as a valuable improvement that would greatly improve VSLS reliability. Additionally, a congestion-based system may be subject to a higher bandwidth requirement due to higher density of signs and more frequent speed changes. A non-subscription communications system would reduce yearly operating costs.
- Protection of poles and associated equipment:
  - Damage to instruments and equipment due to collisions or traffic incidents is costly and will adversely affect VSLS performance. Civil designs that protect equipment and system integrity should be a priority.
- Calibration of instruments:
  - As time goes on, the need to ensure accurate data collection and equipment operation is imperative. Additionally, for road weather sensors, the changing seasons can affect accuracy. A robust calibration schedule would improve overall system reliability.
  - Pavement condition sensors should be positioned and interpreted so that they do not indicate prematurely good conditions. Data should be compared with other sensors to determine if return to higher speed limits is warranted. Where applicable, segments should include road weather data from the opposing direction to ensure consistent application of reduced speeds.
- Inventory of spare parts:
  - Delayed corrective maintenance due to lack of spare materials will adversely affect VSLS performance and public perception of the system.
- Standard materials:
  - Standardized materials should be used wherever possible for all enclosures and common components. This will help to facilitate rapid deployment as well as reduce the time needed for replacement or maintenance.

4 Recommendations

4.1 Proposed Fraser Valley Speed Harmonization System

The section of Highway 1 through the Fraser Valley from Abbotsford to Chilliwack consists of approximately 30km of primarily two-lane divided highway. There are approximately 8 - 10 interchanges along this section, with various potential sources of congestion. Table 6 lists high-level recommendations for the design and deployment of a speed-harmonized VSLS, based on industry practices and lessons learned through the research conducted for this report. Specific recommendations are detailed further in the following sections.

VSL Sign Spacing	1000m
Speed Reduction Increment	Maximum 20km/h.
Signage Update Increment	2 - 3 minutes
DMS Placement	• Major interchanges • Entrance to VSLS corridor • Mounted with VSL signs where practical
DMS Sign Spacing	2 - 3 km
Traffic Sensor Type	Radar
Traffic Sensor Spacing	500m
Differential Lane Control	None
Shoulder Utilization	Not considered in scope for this project
Communications	Fibre
System Autonomy	Fully-automatic operation for congestion-based speeds

Table 6: Fraser Valley Congestion Management Recommendations

4.1.1 VSL Signage

Frequent presence of VSL signage (as noted in Table 6) is warranted for the purposes of speed harmonization. Providing effective and timely response requires that relatively frequent minor speed adjustments be communicated to motorists.

A significantly larger sign than previously deployed by the MoTI should be used for increased visibility. The Ministry should consider the installation of an overhead and shoulder mounted sign to provide appropriate line-of-sight for traffic in both lanes.

Flush mounted signs that discourage snow buildup are recommended, as is further investigation into potential solutions to the issue of snow clinging to signage..

4.1.2 Dynamic Message Signage

Significant consideration should be given to the deployment of the DMS component of the overall system. More frequent DMS placement is recommended to promote driver awareness of the system and to advise the rationale for reduced speeds. Strategic placement of DMS at major interchanges and otherwise regularly spaced DMS is appropriate. Co-location of DMS with VSL signage should be explored as a cost savings initiative.

In addition, consideration should be given to the concept of placing smaller, full-colour DMS adjacent to the VSL signs in addition to larger, conventional DMS at the corridor entrances and major interchanges. These smaller DMS can be used to provide location-specific rationale for reduced speeds and potentially act as a secondary VSL sign.

For VSL signs, dedicated controllers are not required for operational reasons. A separate controller per sign does provide a level of redundancy, by eliminating a single point of failure. However, this would also increase the space and power required within the control cabinet.

4.1.3 Traffic Sensors

Multiple radar traffic sensors are recommended for each speed section. Placement every 500m is recommended for adequate resolution and detection of localized traffic conditions. If sufficient detailed information is available as to the location and length of congestion problem areas, consideration may be given to providing higher frequency of radar sensors in these areas and less in others.

Further investigation is recommended to determine additional means of evaluating the effectiveness of speed harmonization. E.g. Bluetooth detection systems could be deployed to collect travel time data before and after implementation.

4.1.4 Speed Harmonization Algorithm and ATMS

A system with the ability to function automatically and without operator acceptance is recommended. Manual acceptance of congestion-related speed limit reductions, in every case, is likely to hinder the system's agility. Operator suggestion and override capabilities should be maintained, but the necessary level of required oversight requires further consideration and input from the Ministry from both operational and legal perspectives.

With frequent input from both traffic and road weather subsystems, speed harmonization (or smoothing) should be applied regardless of which subsystem recommends the speed. A minimum period of time for each displayed speed should be applied to both DMS and VSL signage. Increases in speed should be updated more slowly than decreases in speed. Notwithstanding, several minutes of delay is adequate in both cases. Further consideration for selecting specific values is recommended.

A maximum speed step should be imposed for speed reductions from sign to sign. A step of 20km/h is recommended for initial deployment. Further investigation of the effectiveness of the step value should be further considered for different system scenarios and VSL sign spacing.

The use of individual lane control is not recommended. The implementation of such functionality would unnecessarily increase system complexity and is unwarranted on this cross section. While other agencies have the theoretical ability to control individual lane speeds, they have not done so in practice except for HOV lanes. Due to the nature of traffic congestion not being equivalent in opposing directions, a directional speed differential should be allowed to exist if produced by the VSLS.

Configuration parameters governing operation of the algorithm employed to achieve speed harmonization should provide sufficient latitude to adjust to the actual placement of all field equipment (sensors and signs). Configuration parameters should be carefully thought out with respect to scope (corridor-wide versus per-segment, etc.) in order to effectively optimized system operation.

4.1.5 Public Outreach and Enforcement

To prepare the public for the new system and to ensure expectations are managed, media relations consultation should be explored. A proactive approach should be taken in regards to explaining the impacts the new system will have on regular users of the Fraser Valley corridor and the reason for it. Focus should be placed on the potential to improve safety, traffic flow and consistency, rather than overall reduction in travel times. As previously stated, DMS placement and message content will play a significant role in improving public acceptance of the system and compliance as a whole. Public outreach could include information related to plans of enforcement of speed limits on the new VSLS corridor in the interest of transparency.

4.1.6 Communications Infrastructure

The network infrastructure for the proposed Fraser Valley speed-harmonized VSLS will require a significantly increased level of communication, between the ATMS and field equipment, when compared to the Ministry's existing VSLS corridors. Speed harmonization requires a much higher density of VSL signs, traffic sensors and DMS.

In order to function properly, it also requires more frequent upload of traffic data and more frequent adjustments to speed limits. Additionally, the very nature of speed harmonization itself means that each speed limit change will require posting of speed messages to multiple VSL signs and corresponding verification. The frequent transfer of information to and from the traffic sensors, VSL signs, DMS and PTZ cameras, needed to achieve the desired functionality, requires sufficient bandwidth and reliability that is best provided by a fibre-optic backbone.

Table 7 identifies key points, for the Ministry to consider, regarding the installation of a fibre optic communications network for the speed-harmonized section of the proposed Fraser Valley VSLS corridor. The approximately 30km speed-harmonized section, which is the subject of this report, is referred to in the table as the "western section". The term "eastern section" refers to the approximately 50km section that will not be subject to congestion management and will function essentially like the Ministry's existing three VSLS corridors. Each implementation option is described along with the corresponding advantages and disadvantages.

Timely response to rapidly-changing traffic patterns requires high speed communications that are not subject to bandwidth limitations or service interruptions inherent in wireless networks. Furthermore, a partially implemented system associated with delayed fibre installation is not recommended, due in part to the negative perception that may result from visible construction with limited observable benefits.

Operation of the speed-harmonized section of the VSLS would be considerably more challenging and expensive to operate without a sufficiently fast and robust communications infrastructure. Operational costs aside, the sub-optimal system performance and reliability that would result from an attempt to implement wireless communications on this corridor pose a risk to the public perception of the system. As such, one of the key considerations is the resulting optics of the method of implementation. As described elsewhere in this report, public trust in, and acceptance of the VSLS is paramount in achieving compliance and a resultant successful implementation.

Decision	Decision Overview	Resulting Optics	Advantages	Disadvantages
1. Fibre Installation Approved.	a) Fibre infrastructure installed prior to system activation.	• The public observes construction, followed by system activation.	• Optimal performance of system(s), upon activation. • No temporary communication provisions necessary. • No additional operational costs that would be due to use of a cellular network. • Public perceives system benefits immediately following construction. • System addresses congestion issues from time of activation. • No extensions to project timeline.	• Greater initial cost.
2. Delayed Fibre Installation Approved.	a) Construction and activation of both eastern and western sections. Western section implemented using temporary cellular network.	• The public observes construction, followed by the activation of the full scale system (congestion management and weather responsive), as advertised.	• Initial cost savings due to budgeting for fibre installation. • Public perceives system benefits immediately following construction. • System addresses congestion issues from time of activation.	• Sub-optimal system performance due to insufficient and unreliable network. • Increased operational costs due to use of a cellular network. • Increased project costs due to setup and maintenance of temporary cell network. • Project timeline extended.
	b) Construction and activation of eastern section. Construction of western section, but delayed activation until fibre is installed.	• The public observes construction, followed by the activation of a reduced system (no congestion management day one).	• Initial cost savings due to budgeting for fibre installation. • No temporary communication provisions necessary.	• Sub-optimal and potentially unsafe system performance due to lack of active congestion management subsystem. • Public perceives only limited system benefits following construction. • Initial system does not address congestion issues. • Project timeline extended.
	c) Construction and activation of eastern section. Delayed construction and activation of western section, after installation of fibre infrastructure.	• The public observes two distinct construction projects. First, the construction and activation of the eastern section (primarily weather responsive system), followed by the construction and activation of the western section (congestion management and weather responsive).	• Initial cost savings due to budgeting for fibre installation. • Optimal performance of each section upon activation. • No temporary communication provisions necessary. • Public perceives benefits of each section following construction.	• Initial system does not address congestion issues. • Project timeline extended.
3. Fibre Installation Denied.	a) System designed and constructed with cellular network.	• The public observes construction, followed by system activation.	• Initial cost savings due to lack of fibre installation. • No temporary communication provisions necessary. • Public perceives system benefits following construction. • No extensions to project timeline.	• Sub-optimal system performance due to insufficient and unreliable network. • Increased operational costs due to use of a cellular network.

Table 7: Fibre Installation Options

4.1.7 System Maintenance

Sign control equipment should be accessible at ground level, whenever practical. Where applicable, catwalks should be considered to permit maintenance over live traffic. Adequate protection of poles, sensors and cabinets should be utilized to prevent costly repairs and downtime affecting system integrity and/or public perception.

The use of PTZ cameras to remotely confirm sign operation in real time would provide confirmation of visibility and system operation.

4.2 Revisions to Previous MoTI Deployments

The Ministry's present VSLS deployments on Highway 1, Highway 5 and Highway 99 are influenced by both traffic responsive and road weather subsystems. Equipment is placed throughout the corridors in a manner which supports these subsystems, but would not be ideal for congestion management. To achieve the intent of the recommendations of the previous sections, adaptation of the current VSLS design to achieve speed-harmonization functionality would include the following:

- Placement of VSL signs at a higher frequency
- Placement of traffic sensors at a higher frequency
- Use of larger VSL signs
- Use of multiple VSL signs per structure
- Placement of DMS at a higher frequency – these could be smaller than the typical gateway DMS
- Addition of DMS messaging content and functionality specifically targeted to congestion-related operation
- Addition of speed-harmonization logic to the existing ATMS – this is expected to include speed-step logic and control of upstream sign speed (may occur as part of the traffic subsystem or just prior to DMS control, depending on whether or not speed-step logic will be applied to road-weather and/or operator speeds)
- Improvement of network infrastructure to handle higher frequency of communications
- Review and revision to a number of existing configuration parameters such that appropriate fine-tuning can be adjusted with the required scope
- Enhanced promotion of public awareness

4.3 Additional VSLS Recommendations

We note that PBX Engineering and the Ministry have compiled further recommendations that are beyond the scope of this report. These recommendations should be considered for new VSLS deployments as well as for any updates to existing VSLS.

5 Next Steps

PBX will present the findings of the study to the Ministry on January 23, 2017. Subject to acceptance of the recommendations, we will proceed with the preliminary design of the Fraser Valley VSLS system. This will include the following:

- Review of as-built Software Design Documentation
- Development of a revised concept of operations
- Preparation of revised software functional requirements
- Design for equipment placement
- Specification of major components
- Preparation of documentation for material procurement
- Civil electrical design

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