Variable Speed Limits Framework on a Pilot Study on Alberta Highways

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ABSTRACT

International research has shown that the Variable Speed Limits (VSL) system is a successful traffic engineering application used to manage traffic conditions during congestion, incidents, road construction, and inclement weather. VSL has been implemented in a number of jurisdictions throughout the world to improve safety and traffic efficiency on the road network. However, there has been limited application of VSL in Canada and the US, primarily owing to the legislative enforcement restrictions.

Alberta Transportation (AT) has recognized the need to gain experience in the use of VSL and determine its effectiveness in the Alberta highway environment. This paper is aimed at developing a comprehensive framework for a variable speed limit pilot project and consists of a literature review, development of a project framework, a strategy for evaluating project benefits, and future maintenance and operation requirements.

The comprehensive literature review identifies the best practices, guidelines and technical research work on the application and evaluation of VSL in Canada and internationally. Based on the literature review, a site selection criterion is developed which considers collision history, minimum volume threshold, minimum speed, congestion, and weather conditions. A criterion is also developed for reducing the posted speed limited and an evaluation strategy is developed to predict the benefits associated with the speed reduction. A set of recommendations for the maintenance and operations of the VSL system under the pilot project initiative are developed as well as motorist education strategy to increase speed compliance with the VSL zone.

Introduction

International research has shown that the Variable Speed Limits (VSL) system is a successful traffic engineering application used to manage traffic conditions during congestion, incidents, road construction, and inclement weather. VSL has been implemented in a number of jurisdictions throughout the world to improve safety and traffic efficiency on the road network. However, there has been limited application of VSL in Canada and the United States (US), primarily owing to the legislative enforcement restrictions.

The Alberta Traffic Safety Plan identified the use of Intelligent Transportation Systems (ITS) as one of the key measures in reducing collisions on Alberta roads. More recently, the Methods for Reducing Collisions on Alberta Roads project documented the benefits, applications, and legislative requirements for using VSL in Alberta.

Literature Review

Overview of International VSL Initiatives

Variable Speed Limits (VSL) have been trialled in the US and in European countries since the 1960s and since the mid 1980s in Australia. VSL is deployed as a traffic management tool with the aim of producing benefits in safety, traffic operations during congestion, incidents, and inclement weather. This chapter reviews the available literature on the applications, international best practice, public education, and issues around the evaluation and legislative enforcement of VSL.

The key VSL initiatives in the US have been undertaken in Tennessee, Washington, Missouri, New Mexico, Arizona, Nevada and the New Jersey Turnpike. According to the Federal Highway Administration (FHWA), the New Jersey Turnpike consists of 120 VSL signs over 238km (148miles). The speeds vary from 105 km/h to 48 km/h (65-30 mi/h) and the system is based on mean speed. State Police enforces the reduced speed limits by issuing summonses to those motorists found to be in violation.

The Washington State Department of Transportation (WSDOT) Maintenance Office is responsible for operation and monitoring of the VSL system implemented on the Snoqualmie Pass which is 3,200 feet above sea level and is often subject to ice and fog (**Figure 1**). The decision to reduce the speed limit is based on feedback from multiple weather stations, snowplough operators, and State Police patrol. Although there has been no formal evaluation, WSDOT has observed motorists slowing down when the VSL system is in use [1, 2].

Figure 1: VSL on I-90 – Snoqualmie Pass, Washington [1]

In the United Kingdom (UK), introduction of VSL has led to significant traffic flow and safety benefits for the road users and the Highways Agency. The UK trial on the M25 (**Figure 2**) combines the speed control system with a rigorous enforcement system [3]. The system has been installed on a 20km stretch of the motorway west of London. It is equipped with Variable Message Signs (VMS) to warn drivers of the incidents, queues or congestion ahead. The Controlled Motorways scheme has been extended to cover interchanges of M25/M4 and M25/M40 and the performance has been monitored since its implementation in 1995. The Highways Agency has observed traffic speed harmonization, reduction of shockwaves, delay in onset of flow breakdown, and advanced recovery from congested conditions.

Figure 2: VSL on M25, UK [3]

VSL systems have been deployed in various parts of Australia since 1990s. In New South Wales, key VSL installation locations include the F6 Tollway, M4 Motorway, F3 Motorway, and the New England Highway in New South Wales, Western Ring Road, Westgate Bridge in Victoria, Gateway Bridge in Queensland, the Adelaide-Crafers Highway in Adelaide, and the Tasman Highway in Tasmania. In most cases, the VSL forms part of a wider network management system and is integrated with other ITS applications such as wet weather, fog, congestion, and incident management. In a unique application on the Westgate Bridge in Victoria and the Gateway Bridge in Queensland, the advisory speed is regulated based on the prevailing wind speed. The VSL system, in most cases, is linked to the Traffic Management Centres (TMC) to manage, monitor and control the system as required.

The literature review indicates that VSL applications in Canada are limited owing to the legislative enforcement constraints. The only documented VSL application has been identified on the Wayne Gretzky Drive in Edmonton, Alberta as part of the Edmonton River Crossing Integration ITS Deployment [4].

In Alberta, a reduction in posted speed limit from 90 km/h to 70 km/h is put into operation each year along a section of the Trans Canada Highway (TCH) near the Lake Louise area [5]. Additionally, some research has been undertaken to establish potential benefits of VSL implementation on Canadian roads. In 2005, Steel et al. evaluated the potential application of VSL on the TCH between the Castle Mountain Interchange and the Alberta/British Columbia border within Banff National Park [6]. The study outlines the information required for VSL applications and provides recommendations on legislative constraints that may need to be addressed within the province of Alberta.

The ITS Lab at the University of Alberta is currently undertaking a field operation test of VSL implementation on the Whitemud Drive corridor in Edmonton. The project, supported by the Alberta Traffic Safety Fund, is aimed at improving road safety. AECOM conducted an interview with Dr. Tony Qiu and his research team from the University of Alberta to learn more about their ongoing research efforts on the VSL study in Edmonton. Dr. Qiu mentioned the following benefits from implementing a VSL system:

- Increased traffic mobility;
- Reduced travel time;
- Improved traffic safety;
- Reduced CO_2 (Carbon Dioxide) emissions.

The research team is developing an algorithm for speed selection which will be based on the following traffic parameters:

- Traffic Speed;
- Traffic Volume;
- Weather Information; and
- Vehicle Classification.

The data is dynamically collected from the existing equipment in place (loop detectors, cameras, etc.) and is made available from the TMC.

Benefits and Evaluation Methodology

Motorway strategies in general and VSL in particular have been evaluated through both field tests and simulation experiments. The field experiments tend to focus on the impacts of VSL on individual traffic variables such as traffic flow distribution, mean speed, and mean headway. The experiments found that a dependence on the traffic variables alone obstructs the evaluation of impact from other external factors [7]. Traffic micro-simulation is suggested as an alternative tool to evaluate the performance of dynamic traffic controls. An appropriately calibrated and validated traffic simulation model is suggested to be particularly well-suited in evaluating ITS strategies owing to the detailed representation of the traffic control system and driver behaviour. Castle [8] reported results from a micro-simulation study in which a PARAMICS model was developed to evaluate benefits from the VSL scheme deployed on the M4 motorway in the UK. The study found that deployment of VSL helped in reducing journey times under severe flow breakdown and congestion, but the benefits were negligible under marginal traffic conditions.

Hellinga and Allaby [9] evaluated Impacts of a potential VSL strategy implemented on an 8km section of the eastbound Queen Elizabeth Way (QEW) located near Toronto, Canada. The evaluation framework presented in the research consisted of a microscopic simulation model (PARAMICS) combined with a categorical crash model. The results indicated significant safety improvements during congested periods, but net reduction in safety during uncongested conditions. Additionally, implementation of VSL led to increased travel times for all traffic scenarios considered in the study.

In Missouri, Bham et al. [10] conducted online surveys to understand the public and law enforcement opinions on the I-270/I-255 VSL project. Such surveys are recommended in the post-implementation period to gauge the level of awareness, satisfaction, and effectiveness of the system amongst the users and law enforcement officials. The surveys helped in identifying a wide-spread dissatisfaction with the VSL system within the public and law enforcement officials.

ITS Canada and DELCAN prepared a framework for evaluation of Canadian ITS projects for Transport Canada in 2007 which recommends a four-step evaluation process entailing: evaluation planning, data collection, data analysis, and recommendations. The report addresses the issue of limited data availability and explains the application of traditional economics tools in evaluating ITS programs.
The limited availability of literature indicates that in general, the impact and effectiveness of VSL systems have not been extensively studied. The most comprehensive evaluation of an operational VSL system was carried out by the Highways Agency on M25 and M42 in the UK.

The benefits and economic evaluation of VSL applications in various jurisdictions are summarized in **Table 1**.

Table 1: Summary of reported benefits

Benefit Classification	Project Location	Project Objective	Reported Results
Safety	Autobahns, Germany	Traffic safety and performance improvement.	20-30% reduction in crash rates.
	M4, F3, & the Adelaide-Crafers Highway, Australia	Reduction of rear-end crashes, incident, queue management, and safe traffic operations in adverse weather conditions.	11-24% reduction in crash rates, 70% reduction on F3 in the first month of installation.
	M25, UK M42, UK	Safety and capacity enhancement.	M25 - 15% reduction in injury accidents, 20% reduction in damage only accidents for every injury accident, and 30% reduction in accident rates and costs. M42 - Personal Injury Accidents (PIA) reduced from 5.08 per month to 1.83 per month.
	I-270/I-255, St. Louis, Missouri	Prevent traffic flow breakdown, reduce congestion and delay, and improve safety.	11% reduction in total crashes and 3% decrease in rear-end crashes.
	Queen Elizabeth Highway, Toronto	Evaluation of a proposed VSL program using micro-simulation (PARAMICS).	Significant safety improvements during congested periods, but net reduction in safety benefits during uncongested conditions.
Traffic Flow and Congestion	M25, UK M42, UK	Safety and capacity enhancement.	M25- Motorists were more inclined to keep to their lane and keep to the inside lane. Total throughputs during the 5- hour peak periods, between J15-16 increased by 1.5%. M42- Capacity increased by an average of 7-9%.
	A9, Germany	Traffic safety and performance improvement.	Mean traffic flow increased by 3% in comparison to adjacent freeways without VSL application.
Travel Times	M25, UK M42, UK	Safety and capacity enhancement.	M25- Decrease in average travel time during 2001 and 2002. M42- Decrease in average travel times by up to 24% in the northbound direction and 9% in the southbound direction. Variability of journey times reduced by 22%.
Environment	M25, UK M42, UK	Safety and capacity enhancement.	M25 - Emissions reduced by 2% to 8%, depending on individual pollutant considered. Weekday traffic noise adjacent to the scheme has been reduced by 0.7 decibels. M42 - Emissions reduced by 3% to 10%, depending on individual pollutant considered. Minor reduction in noise levels have been observed with an estimate of between 1.8 to 2.4 dB (A).

VSL Operational Principles

Criteria for Location Selection

The literature review indicates that VSL application is deemed necessary under the following circumstances:

- History of crashes;
- Congestion;
- Construction / Work-zone;
- Adverse weather conditions (ice/snow/fog).

In addition to the above factors, road authorities in the UK and Australia also consider threshold traffic volume as one of the criteria for implementing variable speed control. Smulders reported that it was not appropriate to deploy VSL on a two-lane facility with traffic volumes below 3,000 vph [11]. The Roads and Traffic Authority in New South Wales, Australia uses VSL to reduce speed limits to 70 km/h when traffic volume reaches 1,800 vph [12].

An assessment of ITS needs for Highway 2 between Edmonton and Calgary, undertaken by Delcan in 2004, detailed the following findings [13]:

- Peak period congestion is prevalent on the Deerfoot Trail section (especially between Southlands Drive and 32 Avenue NE);
- Weather-related collisions and animal hits contribute to over 50% of the collisions that occur within the rural section of the corridor;
- Bridge decks and grades (e.g. Coulees, Antler Hill etc.) are identified as primary locations of collisions during winter months; and
- Closures of Highway 2 are a frequent occurrence (4 to 6 times a year).

Based on these observations, VSL was recommended as one of the ITS deployments on concerned sections of Highway 2. A similar assessment of key highways and roads would indicate the preferred site locations for the VSL pilot project in Alberta.

Selection of Speed Limit

In some of the early applications of VSL, the speed limits were regulated based on pre-determined values calculated for different weather conditions [1]. However, with advent of new technology, this practice has been replaced with use of complex algorithms which compute a safe travelling speed on the basis of real time traffic data, weather information, and incident detections [12].

A majority of VSL systems are based on algorithms that dynamically adjust the speed limit as per the available operational data. In the US, typically the algorithm adjusts the speed limit to equal the mean (or 85^{th} percentile) traffic speed in cases of high traffic demand. This helps in reducing the speed differences without significantly reducing the average speed. In the UK and Australia, the algorithm is based on the relationship between the maximum rate of service of a roadway and the corresponding mean speed of the traffic. This approach also considers weather information and detects queuing or slow moving traffic to provide advance warning to drivers.

Literature review indicates that the selection of a volume trigger is complex and that a further calibration of any algorithm to local traffic flow variance and driver behaviour is essential.

Rules of Speed Changes

Literature review indicates that it is critical to introduce gradual speed changes to avoid driving stress. Lennie explains that it could be confusing and unsafe for drivers if introduced to frequent speed changes within a short distance [14]. This position is backed by the minimum speed zone lengths in the Manual for Uniform Traffic Control Devices (MUTCD).

In the US, variable speed limits are generally changed in five to ten mph increments. The UK M25 system has been designed to ensure that the motorists are not required to reduce speed by more than 32 km/h (20 mi/h) at any one sign. The VSL signs on the Western Ring Road system in Melbourne regulate speed in increments of less than 20 km/h. Road authorities in NSW and South Australia have developed guidance for speed limit changes under an incident scenario. For the safety and logic rules of speed changes, practitioners recommend using expert reviews to fine tune the algorithms gradually during operation [12].

Enforcement and Legislation

The likely success of any VSL scheme, to a large extent, depends on the enforcement of the displayed speed limit, as evidenced in the case of the speed-camera-enforced VSL on the UK motorways. In the US and Canada, the absence of judicial enforcement has been a major constraint in the deployment of VSL system on a larger scale. Practitioners believe that there is a need for an enforcement system to ensure that the VSL systems perform as designed. Overseas experience indicates that the best results are achieved through unattended (automatic) enforcement.

A report by the National Cooperative Highway Research Program (NCHRP) examined the impact of judicial decisions and enforcement on the likely success of VSL [15]. The report concluded that enforcement is an integral part of the VSL system. Any legal issues arising from the creation and enforcement of a proposed VSL should be no different from violations of prima facie speed limits and other maximum speed limit violations. Literature suggests that a visible enforcement system, such as the automated speed enforcement system in the UK, has a powerful influence on driver behaviour.

The Opus Report [5] and Steel et al [6] have identified the need for stringent enforcement provisions through appropriate amendments to the Alberta Traffic Safety Act. Although the Traffic Safety Act does not explicitly address the prescribing of VSL, it is expected that a similar process to that outlined in Part 5, Division 1 of the Act would be adopted for the governance and application of VSL in Alberta.

Public Education

Literature review indicates that public education and stakeholder engagement at the onset and on an ongoing basis is critical to the success of a VSL scheme. A prior-to-launch information strategy is essential to ensure that drivers approach the scheme with a positive frame of mind and that they are able to negotiate the VSL in a safe and comfortable manner. This may also assist in achieving higher compliance numbers and acceptability from the members of the public.

The public education program may include a prior-to-launch public information strategy and a continuing public information strategy, incorporating such media as newspaper, radio and television advertisements, rewarded questionnaires, websites, fact sheets, integrated VMS or a government mail-out [12].

VSL Site Selection

Genera Principles

The site selection process is based on the analysis of the factors identified in the Literature Review, namely:

- History of collisions;

- Congestion;
- Adverse weather conditions; and
- Traffic volume.

Table 2 summarizes the general guidelines on the application of the above mentioned criteria in the VSL site selection process. These guidelines are further detailed in the subsequent sections and applied to develop a list of potential sites for the VSL pilot project in Alberta.

Table 2: General site selection guidelines

Criteria	Assessment	Suggested Threshold
	Primary Criteria	
Collision	The average collision rate should be compared to the provincial average crash rate on similar type of highway segments. Additionally, critical crash rate for all locations should be calculated and compared to the actual collision rate.	Provincial average collision rate for similar highway segments. And / Or Critical crash rate
Congestion / Level of Service (LOS)	Peak Hour LOS (based on Density (pc/km/ln) should be evaluated for each location.	LOS E or worse
Adverse Weather Conditions	The prevailing road surface conditions corresponding to the collision data should be analyzed.	Snow/Ice/Wet/Slush are the prevailing surface conditions in at least 50% of the collisions
	Secondary Criteria	
Length of Segment	All short-listed VSL corridors should be evaluated for free flow traffic operations.	Length of segment (uninterrupted traffic flow) ≥ 3km.
Speed Limit	Posted speed limit data for all locations should be analyzed.	Maximum Speed Limit ≥ 90 km/h
Monitoring and Maintenance	Proximity of the Alberta Transportation offices or Traffic Management Centre to the VSL site will help in monitoring and maintenance of VSL operations.	Short listed sites should be re-ranked based on their relative distance to the AT offices or TMCs.
ITS Integration	Any existing DMS/VMS signs, CCTV cameras, loop detectors, and any other ITS equipment in the vicinity of the short-listed sites should be identified.	Preference may be given to sites where existing ITS equipment may complement the VSL implementation.

All potential sites should satisfy two or more of the primary criteria identified in Table 2. A weighting system may be applied to the primary criteria based on the severity of the problem. Such a weighting system is proposed and applied to the site selection process for the VSL pilot project

VSL Pilot Project Site Selection

The department's TIMS Reporting Application was used as the source of data for this analysis. It was found that the available time period which corresponds to all the required data parameters is from 2007 to 2009. To ensure that the data refers to the same section of the highway, a parameter 'Location' was developed as a combination of the highway name, control section number, and the first two letters of the district name.

A review of VSL initiatives indicates that the system is best suited for divided highways with speeds of 90 km/h or higher. Therefore, the focus of this exercise was on analyzing the available data for the divided highway network in Alberta with speeds of 90 km/h or higher.

A staged approach was taken in analysing the data by first looking at the collision, congestion, and surface condition parameters separately, as well as identifying sites that fail two or more parameter.

Collision

In order to rank locations based on collisions, three criteria may be used: collision frequency, collision rate (exposure), and collision severity. Collision frequency tends to bias the selection process in favour of high volume roadway sections. Collision rates overcome this bias by accounting for the differences in traffic volumes (exposure) and therefore are normally considered better indicators of risk than collision frequencies alone.

Collision rate for each roadway segment is expressed in terms of collisions per million vehicle-kilometres (MVK) and was calculated as below:

$$R = \frac{A \times 10^8}{365 \times V \times L}$$

Where,
R = Collision rate for a roadway segment
A = Average number of reported collisions
V = Annual average daily traffic (AADT) volume
T = Time period of analysis (years)
L = Length of the segment in km

Ranking locations by collision rates rather than frequency is generally a better methodology but may result in a bias in favour of low volume locations that have relatively few collisions but a high collision rate. To correct this bias in the ranking process, AECOM took into account two other factors: AT's average collision rate, and the critical collision rate. The AT average collision rate (Ra) for all highway segments in Alberta is 0.544 MVK.

The critical collision rate method applies a statistical test to account for the random variation associated with collision frequency and determine if the collision rate at a location is significantly high when compared to other locations. The critical collision rate was calculated for each road segment using the following equation:

$$Rc = Ra + K\sqrt{\frac{Ra}{m}} + \frac{1}{2m}$$

Where,
Rc = Critical collision rate
Ra = average collision rate for all locations (0.544 MKV)
m = millions of vehicles entering road segment (AADT x $365/10^6$)
K = constant corresponding to level of confidence (K = 1.282 using 90% confidence level)

All locations with a collision rate (R) higher than the AT average collision rate (Ra) are identified as well as location that have a higher collision rate than the critical collision rate (Rc). Those locations with R > Rc will be given extra consideration in the final selection process based on the safety concerns associated with them.

Congestion

One measure of congestion is level of service. The Alberta Infrastructure Highway Geometric Design Guide defines level of service (LOS) criteria for multi-lane highways in terms of density. Density (passenger cars / km / lane) expresses the degree of maneuverability in a traffic stream and quantifies the proximity to other vehicles. AT density boundary values corresponding to LOS A – F are as follows:

- LOS A: Density ≤ 7
- LOS B: 7 < Density ≤ 12
- LOS C: 12 < Density ≤ 19
- LOS D: 19 < Density ≤ 26
- LOS E: 26 < Density ≤ 42
- LOS F: Density >42

As per the guidelines, Peak hour LOS was calculated for the sites based on densities and locations having LOS D or worse were identified. Peak hour was assumed to be 12% of AADT and density was calculated as follows:

$$D = \frac{AADT \times 0.12}{L \times N}$$

Where:
D = Density (pc/km/ln)
L = Length of the segment in km
N = Number of lanes

Surface Conditions

The data obtained from the TIMS Reporting Application classified collisions by three surface conditions: dry, slush/snow/ice/wet, and unknown. In order to rank locations by surface conditions, AECOM recalculated the surface condition percentages based only on the known surface types. Locations with 50% or more collisions occurring on slush/snow/ice/wet surface conditions were identified

Site Selection Weighting Criteria

In order to rank the sites based on the three criteria discussed above, a weighted methodology is proposed as follows:

Collision:

- A score of 1 is give if site collision rate (R) is greater than the average collision rate (Ra) but less than the critical collision rate (Rc)
- A score of 2 is give if site collision rate (R) is greater than the critical collision rate (Rc)

Congestion:

- A score of 1 is given if LOS = D
- A score of 1.5 is given if LOS = E

- A score of 2 is given if LOS = F

Surface Condition:
- A score of 1 is given if the % slush/snow/ice/wet is greater than 50%

Table 3 identifies all site locations meeting 2 or more of the criteria (thus having a score of 2 or higher).

Table 3: Weighted Site Selection Ranking

Location	Collision		Congestion		Surface Condition		Total Score
	Collision Rate	Score	Peak Hour LOS	Score	% Slush / Ice / Wet	Score	
63:11:FO	0.99	2	F	2	53%	1	**5**
16:18:ST	1.77	2	F	2	48%	0	**4**
2:24:RE	0.63	1	E	1.5	52%	1	**3.5**
16A:16:ST	0.73	1	F	2	47%	0	3
2:32:ST	0.48	0	F	2	55%	1	3
2:34:ST	0.49	0	F	2	53%	1	3
216:4:ST	0.19	0	F	2	64%	1	3
2A:8:CA	0.6	1	F	2	28%	0	3
1:10:CA	0.66	1	D	1	40%	0	2
1:2:CA	0.75	1	B	0	61%	1	2
1:22:LE	0.84	1	A	0	52%	1	2
16:14:ST	0.74	1	D	1	48%	0	2
16:26:VE	0.59	1	A	0	51%	1	2
2:22:RE	0.43	0	D	1	54%	1	2
2:30:ST	0.37	0	D	1	64%	1	2
43:10:GR	0.71	1	A	0	53%	1	2
43:12:GR	0.79	1	A	0	58%	1	2
43:14:ED	0.58	1	A	0	59%	1	2
43:18:ST	0.56	1	A	0	56%	1	2
43:22:ST	0.55	1	C	0	50%	1	2

From Table 3, all locations with a total score of ≥ 3 are identified as candidates for further analysis based on the following criteria:
- Length of highway segment with free traffic operations within the identified VSL corridor;
- Distance to the nearest AT / TMC (for purposes of maintenance and monitoring); and
- Existing RWIS and DMS/VMS equipment within the section.

In order to identify the location of VSL corridor within the highway control section, distribution of collisions along the control sections for the three year period (2007-2009) were plotted. The segment of the control section with maximum number of collisions corresponded to the VSL corridor location. Google Maps was used to determine the length of the highway section with free flow operations for each site based on the location of the VSL corridor within the highway control section.

The free flow segment length within the identified VSL corridor is compared to the minimum section length (3 km) criteria detailed. Since this is a key aspect of the VSL system implementation, locations that do not satisfy this criterion were not considered for further investigation. However, the only exception to this is location 2:32 (Stony Plain), which is recommended for consideration due to its strategic significance as a key access/egress route to the Edmonton International Airport. The following locations are recommended for the VSL pilot project in Alberta:

63:11 (Fort McMurray)
- Sufficient segment length with free flow traffic operations
- Existing RWIS and DMS / VMS equipment
- Proximity to AT / TMC

2:32 (Stony Plain)
- Proximity to the Edmonton International Airport makes this location strategically important
- Existing RWIS and DMS / VMS equipment
- Reasonably close to AT / TMC

2:24 (Red Deer)
- Sufficient segment length with free flow traffic operations
- Existing RWIS equipment
- Proximity to AT / TMC

VSL Corridor Location

As per AT's recommendation, Highway 2:32 (southbound) is selected for the pilot VSL project. **Table 4** details the collision statistics on the southbound lanes of Highway 2:32 for a three year period (2007-2009). It is indicated that 98% of the total collisions in the southbound direction have occurred within the first 15 km of the control section.

Table 4: Distribution of Collisions on the Southbound Lanes of Highway 2:32

Distance from the start of the control section (km)	Number of Collisions	% of Total Collisions in the Southbound Direction
0-5	79	27%
5-10	130	44%
10-15	81	27%
15-21.39	7	2%

Based on the above information, the pilot VSL project is proposed to be deployed along the 15 km corridor of Highway 2:32 (southbound) with the following start and end points:
- Start Point – 6 km (approx.) south of Highway 2 / Anthony Henday Drive interchange
- End Point – Highway 2 / Highway 39 interchange

VSL Implementation Framework

The key components of the implementation framework for the pilot VSL project in Alberta are identified as follows:
- Infrastructure requirements;
- Functional considerations;
- System architecture; and

- Maintenance.

Infrastructure Requirements

The ITS Architecture for Canada provides a unified framework for integration to guide the co-ordinated deployment of ITS programs. The Architecture describes interaction among physical components of the transportation systems including travellers, vehicles, roadside devices, and control centres. It also describes the information and communications system requirements, how data should be shared and used, and the standards required to facilitate information sharing.

The ITS Architecture for Canada includes a service package for Variable Speed Limit and Enforcement. The infrastructure requirements for the pilot VSL project in Alberta were based on the suggested equipment and architecture flows detailed in this package. **Figure 3** shows the components of the VSL and Enforcement service package.

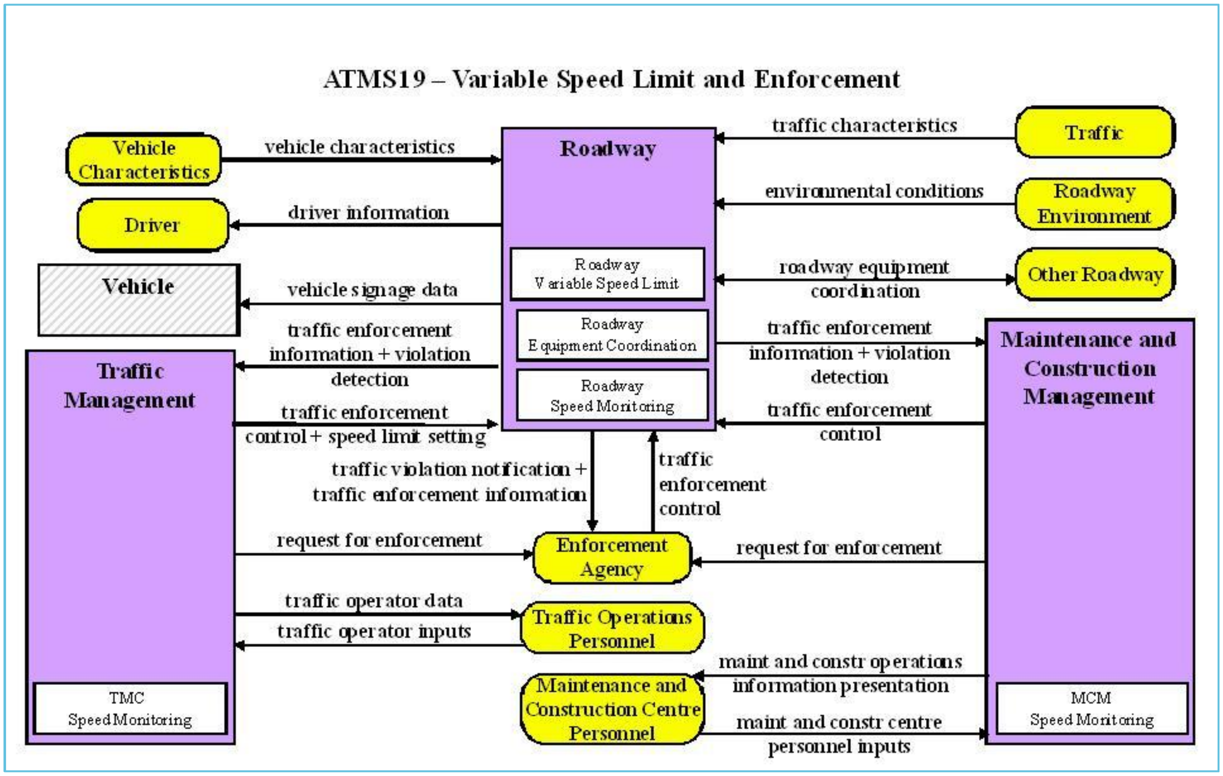

Figure 3: ITS Architecture for Canada - VSL Service Package

Based on the VSL Service Package, the following infrastructure components were identified for the pilot VSL project:

- Roadside detection (speed monitoring, environmental monitoring);
- Variable speed limit;
- Traveller information;
- Traffic management centre and control system; and
- Communication system.

Roadside Detection

Two types of speed monitoring are proposed for the pilot project: vehicle detection sites and closed-circuit television cameras. Vehicle detection sites provide vehicle speed and traffic flow information to the VSL control system. The literature review indicates that the vehicle detection sites are located, approximately, every 500 metres along the freeway. Low light, PTZ (pan-tilt-zoom) cameras are recommended for the pilot project to verify the event causing the change in speed.

The Government of Alberta has installed 76 RWIS stations on major Alberta highways for real-time weather condition information at and near the road surface. This allows the highway maintenance personnel to predict icing conditions and respond more proactively. Road weather information is a key factor in regulating the highway section speed. For the pilot VSL project, integration of existing RWIS stations, near the study area, with the VSL system was recommended.

VSL Signs

The literature review indicates that there are two categories of VSL signs: electronic illuminated and static. Electronic illuminated signs are mounted by the side of the road in place of the regulatory speed signage. They are also mounted on a gantry over the relevant lanes. The most common method of illumination involves the use of high intensity LEDs. Static signs are usually mounted with flashing beacons or a flashing annulus to highlight the sign when the VSL is applicable.

For the pilot VSL project in Alberta, the 600 mm x 900 mm Maximum Speed sign (RB-1, Manual of Uniform Traffic Control Devices for Canada), are recommended to be used as a template. Figure 4 illustrates an example of VSL sign placement and detection along Highway 2.

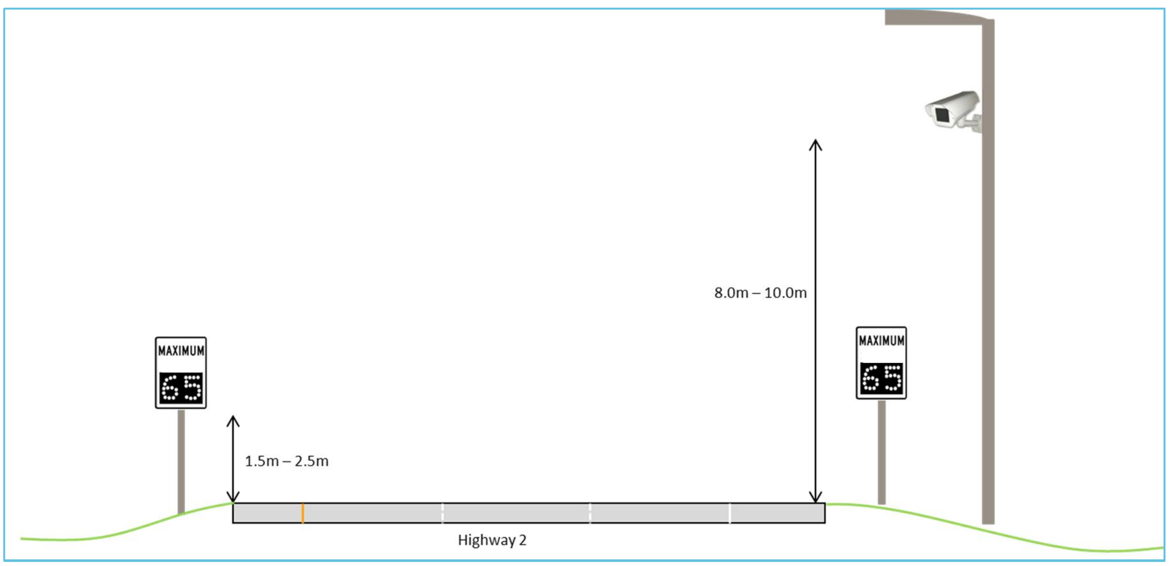

Figure 4: VSL Conceptual Cross Section

Traveller Information

The literature review suggests that the VSL systems experience a higher compliance rate when the reason for speed change is communicated to the road-users. Dynamic message signs are an effective means of communication with the travelling public. For the pilot VSL project, indicative locations of the DMS are identified and integration of any existing DMS into the pilot VSL system is recommended.

Traffic Management Centre and Control System

The roadside control system are responsible for the processing of the traffic and weather data, computation of the VSL algorithm, control of variable speed limit signs, and communication with the control centre or the TMC. Typically, roadside stations are deployed at regular intervals along a VSL corridor. The TMCs use the information from the roadside stations to compute the speed limit(s) required for optimal operation along the corridor.

Communication System

In a VSL system, communication systems link the detector stations, VSL signs, and roadside stations to the control centre or the TMC. The communication links may include dial-up ISDN (Integrated Services Digital Network), dial-up PSTN (Public Switched Telephone Network), DDS (Dataphone Digital Service), fibre optic cable network or wireless-based network. The communications systems should be designed and equipped with an uninterruptable power supply (UPS) to minimize disruption during power outages.

Functional Considerations

The key functional aspects of a VSL system are: selection of speed limit, rules of speed changes, and signage placement and mounting.

Typically, an automated speed selection system with manual overrides is recommended for a VSL system. The algorithm is designed to consider all inputs gathered by the sensors to determine the appropriate speed limit, duration times and change intervals.

Literature review indicates that it is critical to introduce gradual speed changes within a VSL system in order to allow the drivers to adjust the vehicle speed in a safe manner. For the VSL pilot project, it is recommended that the increment of speed change be restricted to a maximum of 20 km/h. The lower limit of the reduced speed is a function of the traffic volume, level of congestion, weather conditions etc. A review of international VSL initiatives indicates that the variable speed limit ranges from a maximum corresponding to the posted speed limit to a minimum of 50 km/h.

The recommended practices for Placement of Signs [16] developed by Alberta Transportation provides guidance for location and placement of regulatory speed signs. These guidelines are recommended for use in identifying the location of VSL signs in the pilot VSL project. Literature review suggests that VSL systems in other jurisdictions have generally been spaced between 500 m and 3000 m. VSL signs can be positioned either side of the road or mounted directly over the lanes. When there are three or more travelling lanes in one direction, VSL signs are installed over the highway on a gantry or single mast. VSL signs should also be mounted overhead where traffic volumes are high and the proportion of heavy vehicles is high. Where there are less than three lanes, it may be appropriate to consider side-mounted VLS signs. The sign mounting height should be between 1.5 m and 2.5 m from the road surface to the bottom of the sign. Typically, VSL signs are angled downward at 15 degrees to reduce deterioration in visibility experienced when LEDs are subject to direct sunlight.

Figure 5 presents the indicative locations of the VSL signs, RWIS, and the DMS (proposed and existing) for the pilot VSL corridor on Highway 2:32 (southbound).

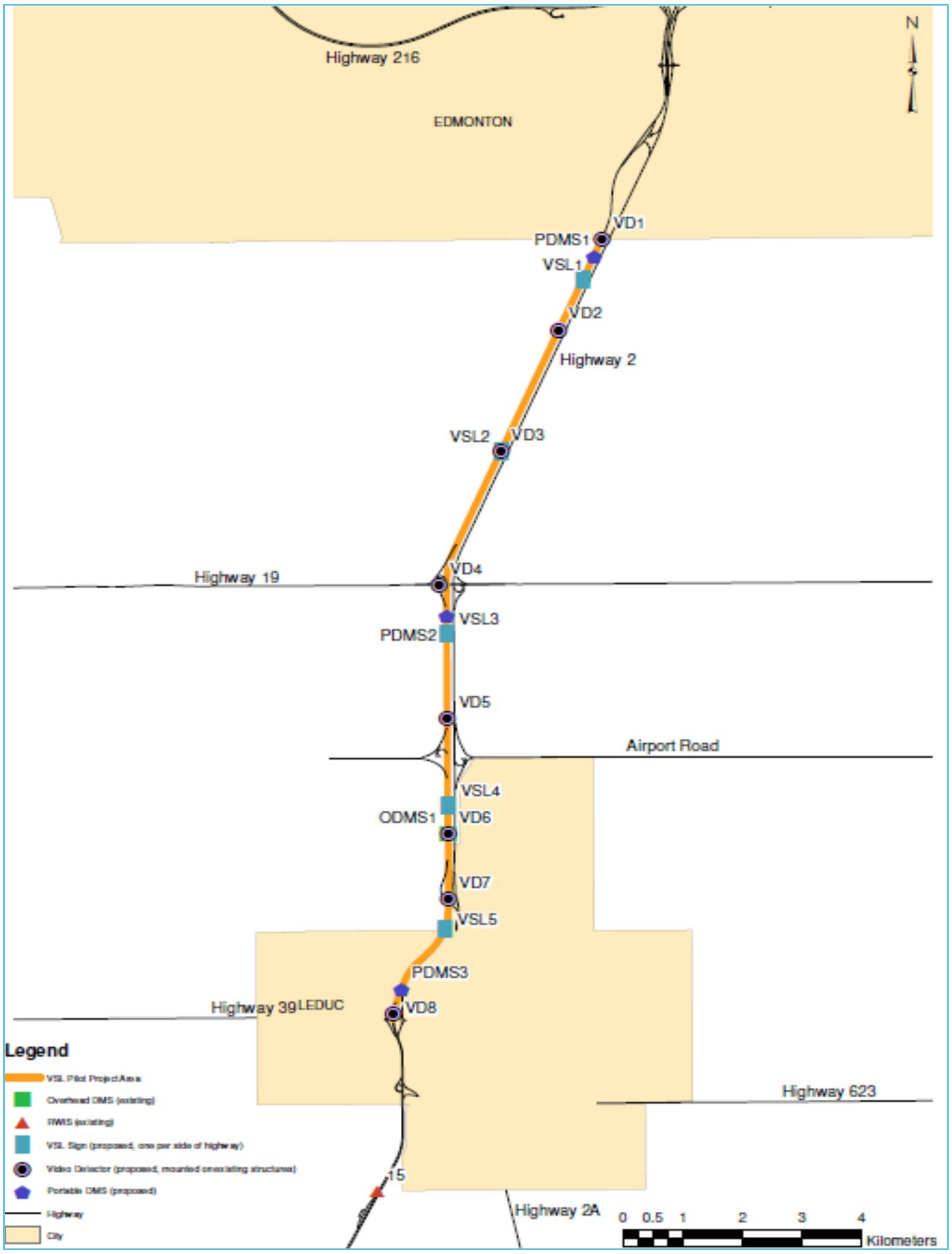

Figure 5: VSL Pilot Project Area

Public Education Strategy

Literature review indicates that public education is needed for the successful implementation of a VSL system. A prior-to-launch information campaign and initial publicity at the commencement of the VSL program may assist in addressing speed compliance and possible public scepticism about the system.

Any additional speed enforcement must be complemented by focused public information and education campaigns. Research shows that compliance with, and support for, traffic laws can be increased through aggressive, targeted enforcement combined with vigorous public information and education program. This approach has been successful in addressing impaired driving, occupant protection, red-light running, and commercial motor vehicle safety issues. Public information and education also contribute to public support for speed management by increasing the awareness of the consequences of speeding.

The public education program may include a prior-to-launch public information strategy and a continuing public information strategy, incorporating such media as newspaper, radio and television advertisements, rewarded questionnaires, websites, fact sheets, integrated VMS/DMS or a government mail-out.

The public education strategies outlined in the Alberta Traffic Safety Communication Plan [17] are used as guidelines for communicating the key benefits of the pilot VSL project to the audience. The recommended communication vehicles include: broadcast (radio, TV), e-marketing (social media, YouTube, etc.), place-based communications (arena/stadium venues during key events, cinema movie preview advertising), and print (newspaper advertising, Q&A, key messages, media notices and news releases).

Enforcement

A robust enforcement system is an integral part of the VSL control system. Overseas experience indicates introduction of VSL within the legislations to support efficient and effective enforcement and prosecution. In the UK, the VSL systems on the motorways have been included in the Motorway Regulations by the Secretary of State for Transport, making them legally enforceable. Since 1995, separate Motorway Regulations have been introduced as the VSL system has expanded. The latest Regulation came into force in February, 2012 making variable speed limits legal on M25 between Junctions 2 and 3 [18].

The government of Queensland, Australia, introduced VSL as a regulatory speed sign in the Transport Operations Regulation, 1999 [19]. The same is also included in the New South Wales Road Rules (Part 3, Rule 21), 2008.

In Virginia, under the Code of Virginia, Title 46.2, Motor Vehicles, Chapter 8, Regulation of Traffic, Section 46.2-881, the law authorizes the Commissioner of Highways to establish and indicate VSL on roadways when considered appropriate [20]. The Code deems it unlawful for any driver to exceed the maximum speed limit indicated on the VSL sign.

In the context of a pilot VSL project in Alberta, it is recommended that VSL be recognized as a regulatory speed limit sign within the following documents:

- Use of Highway and Rules of the Road Regulation, Alberta Regulation 304/2002 (Part 1, Division 1);
- Driver’s Guide to Operation, Safety and Licensing (Cars and Light Trucks); and
- Traffic Safety Act (Part 5, Division 1).

A pictorial representation of the standard VSL sign is recommended for inclusion in the Driver’s Guide to Operation, Safety and Licensing in order to educate the new and unfamiliar drivers.
In summary, any legal issues arising from the creation and enforcement of the proposed VSL system should be no different from the legal issues that are considered by courts where violations of prima facie speed limits and other fixed maximum speed limits are processed.

VSL System Evaluation

The VSL system evaluation, typically, entails a comparative analysis of key measures of effectiveness for the 'before and 'after' VSL deployment period. For a valid evaluation, it is advisable that the assessment periods be comparable (with regard to seasonality and sample size) for the two scenarios. The following are identified as the measures of effectiveness for evaluating the benefits of the pilot VSL project:

- Traffic Flow and Congestion;
- Safety;
- Journey Time Reliability;
- Environment; and
- User Feedback.

Traffic Flow and Congestion

Literature review suggests that the average peak 15 minutes flow is a good indicator of the effects of the VSL system on the capacity of the highway segment. It is recommended that the data be collected for comparable periods of time (same months of the year) in order to negate the seasonal variation of the traffic.

It should be noted that the background traffic growth on the highway may lead to an undervaluation of the system benefits in the post-VSL period. Any increase in the peak 15 minutes traffic flow greater than the annual average traffic growth on the concerned highway segment will indicate a positive effect of the VSL system on the capacity of the highway segment. A highway density based Level of Service calculation has been presented in this study. A similar approach may be taken in evaluating the effects of the pilot VSL project on traffic congestion.

Safety

As discussed earlier, collision rate is a commonly used performance measurement in safety assessments and provides an equitable method to compare 'before and 'after' conditions. It is a recommended practice to include at least three years of crash data in any safety assessment. If there is a deviation from this practice then care should be taken in deriving conclusions on the role of VSL on safety of the highway segment.

A decrease in the collision rate will indicate a positive impact of the pilot VSL project. If budget and time permit, a detailed statistical crash analysis using the Conventional Prediction methods (Naive and Empirical Bayesian) is recommended for providing strength to results from the collision rate method.

Travel Time Reliability

Congestion results in a significant variation in the journey times on a heavily used highway segment. Although the introduction of VSL may increase the overall travel time, it is evidenced that the system has potential to reduce the travel time in congested traffic conditions. This helps in reducing the variability in journey times or increasing its reliability.

The travel times may be calculated from the information collected by the loop detectors on the highway segment. The variability of travel times is represented by the standard deviation of travel time over the observed period. Typically, travel times are compared on a month to month basis discarding any unusual traffic conditions caused by accidents, holidays, sporting events etc.

A decrease in the average travel time and variability of travel time will indicate positive impacts of VSL, especially in recurring and non-recurring congestion periods.

Environment

Environment studies ‘before’ and ‘after’ the VSL deployment are recommended to investigate the effect of VSL on vehicle emissions and air quality. Concentrations of the following pollutants should be monitored near the VSL study area:

- Carbon Monoxide (CO);
- Oxides of Nitrogen (NOx);
- Hydrocarbons (HC); and
- Particulate Matter (PM).

Any reduction in the concentrations of the above pollutants may indicate a positive impact of the VSL system. However, in order to draw an accurate conclusion, the analysis should consider the impacts of any change in the fleet composition (newer cars) and / or any other mitigation measures that may positively impact the air quality.

Additionally, noise surveys alongside the pilot project site for the ‘before’ and ‘after’ scenarios are recommended to establish the influence of VSL on traffic noise levels around the study area. The standard approach for noise level and air quality assessments should be followed for these analyses.

User Feedback

The success of any VSL system relies heavily on public acceptance / compliance of the system. It is beneficial to gauge the public opinion of the system so as to identify any deficiencies from a road users’ perspective. The methods used for the user feedback may include: public user surveys, roadside interview of drivers, postage questionnaire survey, manual observation of road and weather conditions, and field experiment for legibility distance.

Literature review indicates that the public user survey is the most popular and effective method to test the impacts of driver attitude and behaviour. The survey may include specific questions aimed at providing an understanding of the driver attitude towards:

- Congestion – Levels of congestion experienced during the ‘before’ and ‘after’ scenarios.
- Safety – Concern for safety in using the concerned highway segment.
- Enforcement – Awareness of the enforcement measures in place.
- Driver information and signage – Adequacy of the amount and placement of information and signage.

The results from each evaluated aspect of the VSL system must be reviewed holistically to derive conclusions on the system benefits. The success of the system will be indicated by the accomplishment of the objective(s) that were set before the system implementation. For the pilot VSL project in Alberta, the results from the evaluation are expected to be used towards developing a more successful system that would potentially be used as a model template for any future VSL projects in the province.

Conclusion

In this paper, results are presented from a study undertaken to develop a framework for VSL deployment on Alberta highways. The research was focussed on three main phases of the pilot project: site selection, implementation, and evaluation. The paper discusses the legal issues around VSL enforcement and recommends changes in the relevant legislations to ensure lawful compliance of the system. The research recognizes the significance of public education and feedback in developing a robust VSL system that is easy to follow and addresses the traffic issues from a road-user's perspective.

Unlike its wide acceptance in other parts of the world, VSL is yet to be regarded as a key active traffic management strategy in North America. The study discussed in this paper is first of its kind in Canada to develop a comprehensive framework for VSL deployment. The framework described, for the pilot project, has the potential to serve as a template for future VSL initiatives.

It is envisaged that the evaluation of the pilot VSL project in Alberta would form the basis of future research. The outcome of the evaluation would play a major role in deciding the future of VSL system in Alberta.

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