Development of a Safety Improvement Strategy at a Truck Rollover Prone Location

By

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Paper prepared for presentation at the
Intelligent Transportation Systems as a Tool for Improving Road Safety
Session of the 2008 Annual Conference of the Transportation Association of Canada
Toronto, Ontario

ABSTRACT

The rural section of Highway 1 (Trans Canada Highway) known as 'Marshall Mountain' located in British Columbia's Fraser River Canyon has been identified as a truck rollover prone location. Previous studies have recommended improvements to warning signage and delineation. While the frequency of rollover incidents has been reduced in recent years, the occurrence of occasional rollover incidents persist and the location continues to be perceived as being problematic.

The specific location is found at the end of a significant downgrade and on a horizontal curve. A secondary concern is the proximity of the Canadian Pacific Railway (CPR). At the critical section of the curve, the CPR line is approximately 10m (horizontally) from the highway. Due to the proximity of the railway, several rollover incidents have resulted in a blockage or damage to the railway. Any debris or wreckage resulting from a truck rollover incident presents a serious risk to rail traffic. The possibility of a train collision and/or derailment remains a significant concern. While the truck rollover issue on the highway represents a significant problem, the secondary issue of railway impacts serves to exacerbate an undesirable situation.

In 2006, the Ministry of Transportation engaged Urban Systems Ltd. to conduct a review of previous studies, complete an investigation of historic rollover events and site characteristics, and develop a recommended improvement strategy. While a multitude of contributing factors was identified, the primary issue was found to be excessive speed. Due to unique geometric conditions, static warning signs were not effectively conveying roll risk to truck operators.

Taking into account the context of the location, a phased improvement strategy was developed with the goal of reducing the frequency and severity of truck rollover incidents at this location. This strategy used a phased approach with a progressive suite of safety enhancements, each building upon the last. A significant component of the recommended strategy was the use of an Automatic Truck Rollover Warning System (ATRWS). This type of Intelligent Transportation System (ITS) is specifically designed to complete a real-time assessment of rollover risk and to provide relevant information to approaching truck operators.

1.0 CONTEXT

The rural section of Highway 1 (Trans Canada Highway) known as 'Marshall Mountain' located in British Columbia's Fraser River Canyon has been identified as a truck rollover prone location. by the Insurance Corporation of British Columbia (ICBC) in the document entitled "*Safety Review of Truck Rollover Prone Locations in British Columbia"*. While statistical evidence of the collision history at this location is inconclusive, at least 10 truck rollover incidents have been observed and documented by varying sources between 1996 and 2006. Several of these incidents are known to have occurred where either the truck and/or its load has fallen onto the adjacent railway tracks causing an interruption of railway activity and presenting a hazard to passing freight trains.

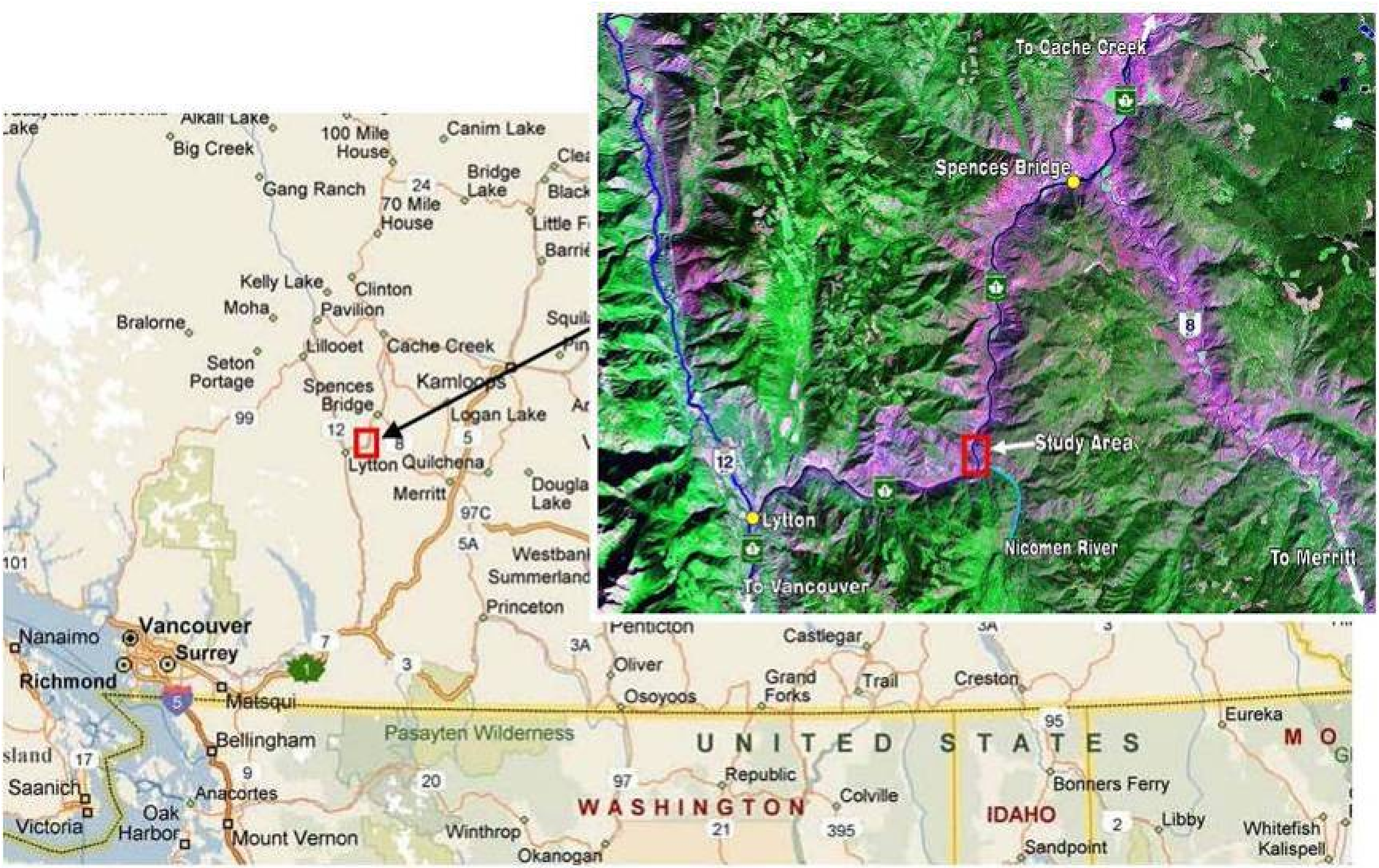
Previous studies have investigated the issues at this location and recommended improvements to warning signage and delineation. While the frequency of rollover incidents has been reduced in recent years, the occurrence of occasional rollover incidents persist and the location continues to be perceived as being problematic.

In 2006, the Ministry of Transportation engaged Urban Systems Ltd. to conduct a review of previous studies, complete an investigation of historic rollover events and site characteristics, and develop a recommended improvement strategy. The purpose of this Project Scope Development Study was to undertake a more thorough and specific investigation of this site, considering the factual data and contributing factors in an effort to develop the scope of a potential upgrade project. Specific effort was placed upon seeking to balance the order of magnitude of the potential solution with that of the problem identified. This assignment was intended to apply a unique approach to developing an appropriate range of solution(s) based upon a clear understanding of the problem (within the context of the information available) and the development of responsive and reasonable project candidates. Accordingly, consideration of funding requirements and 'business case' fundamentals were a pivotal element.

1.1 Study Area

Highway 1 is primarily a two-lane undivided rural highway located in British Columbia's Fraser River Canyon between Spences Bridge and Lytton. Passing lanes and auxiliary truck climbing lanes exists at several locations along this segment. The posted speed limit is 90 km/h; however advisory speed zones exist to address grades and curves as the highway follows the slopes of the Thompson River. The specific location known as 'Marshall Mountain' (also referred to as 'Thompson Siding') is located approximately two kilometers north of the Nicomen River, as illustrated in **Figure 1.1**.

Figure 1.1: Study Area



1.2 Highway 1 Performance

Historic highway performance trends and indices are reviewed in this section to establish a 'benchmark' for how this section of Highway 1 is being used.

1.2.1 Traffic Characteristics

Traffic volume data from Ministry of Transportation count stations show average annual traffic volumes (AADT) and summer average traffic volumes (SADT) to be approximately 3,800 and 5,700 vehicles per day respectively. The 2001 ICBC statistics indicated that trucks represented approximately 53% of total traffic on Highway 1 between Lytton and Spences Bridge. Typical cargo includes finished lumber carried on various configurations of flatbed tractor trailers.

1.2.2 Safety Characteristics

The Ministry of Transportation's Highway Accident Summary (HAS) data in this area appears to be limited and generally inconclusive. Due to a known number of unreported incidents and inconsistent location identification, the frequency of truck rollover incidents appears to be significantly under-represented.

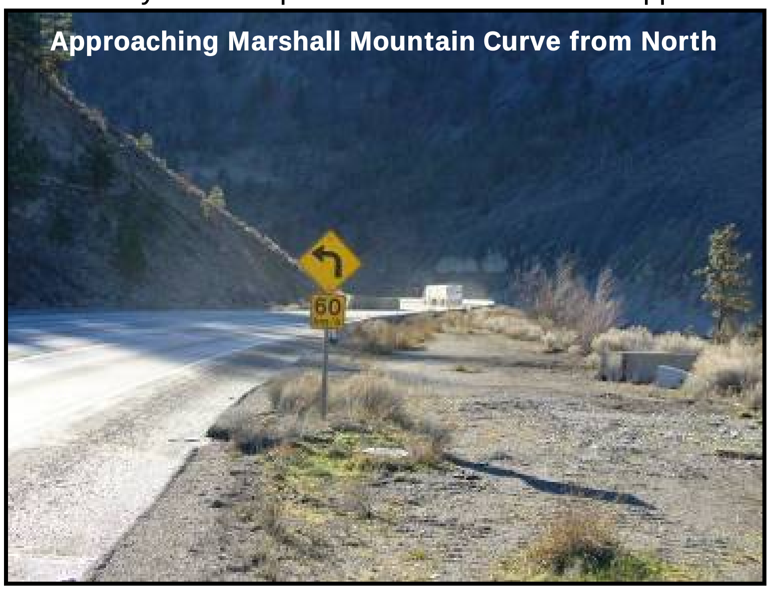
The HAS data indicates only a single occurrence in the critical area between LKI 18.5 and 18.7 (the 'apex' of the curve), although it would seem that several truck rollover incidents have possibly been incorrectly located in the HAS database between LKI 19.0 and 19.2. By combining reports provided by the RCMP and documented rollover incidents provided by the Ministry of Transportation, 10 truck rollover incidents from 1996 to 2006 can be identified in the critical curve area. Previous work undertaken by ICBC estimated that 16 truck rollover collisions occurred between 1990 and 2001.

2.0 PROBLEM RECOGNITION

Based upon the available information, this section establishes the focal problem to be addressed as part of an improvement project in the area. It also outlines a number of related ancillary issues to be considered in the solution. Note that this report is prepared from the perspective of the BC Ministry of Transportation. As a result, the analysis is focused upon what the Ministry of Transportation can affect; highway geometry and operations.

2.1 Primary Issue

While HAS database collision statistics in this area are inconclusive, the number of documented truck rollover incidents reported by the Ministry of Transportation and the RCMP support the conclusion of work undertaken by ICBC, indicating that this location is a 'Truck Rollover Prone Location'. The curve is located at the bottom of a 7% downgrade and has a 200m radius. Travel lanes through the curve are approximately 3.6m with 2.0m paved shoulders. While the regulatory speed limit of the highway corridor is 90 km/hr, the critical curve has a design speed of 80km/hr and a posted advisory speed of 60 km/hr. The majority of truck rollover incidents occur in the southbound direction, at the end of the 7% downgrade.

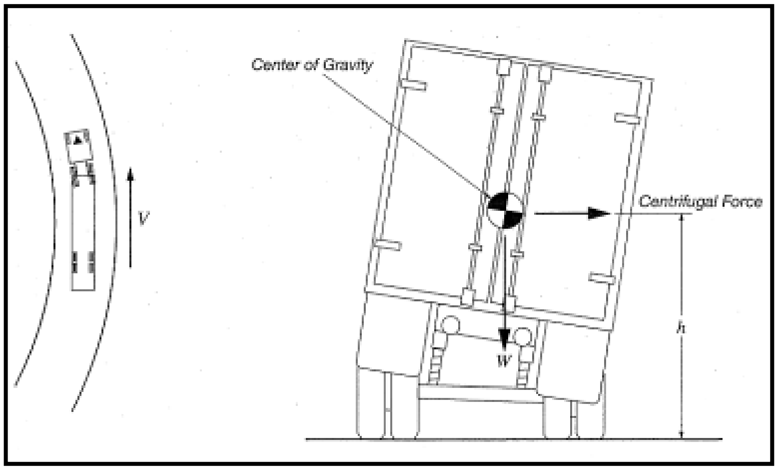


Through a site visit conducted during this assignment, as well as a review of previous studies, several concerns can be identified at this location.

- A 200 m curve radius (southbound left curve) at the bottom of the 7% downgrade and just after a southbound passing zone.
- Limited lane width and shoulder width through the corner to accommodate the wheel tracking of trucks.
- Static warning signage is unclear and ineffective as the curve is immediately preceded by a right turn, which contributes to reduced warning and confusing warning sign placement.
- A crest vertical curve exists at the beginning of this section (southbound), limiting the sight distance to the curves.
- The placement of warning signs in advance of the first curve, in combination with the effect of the crest may indicate to drivers that the curve to right is the hazard.
- The relatively long downgrade following the first curve may encourage drivers to resume speed in advance of the true hazard, at the critical second curve to the left.

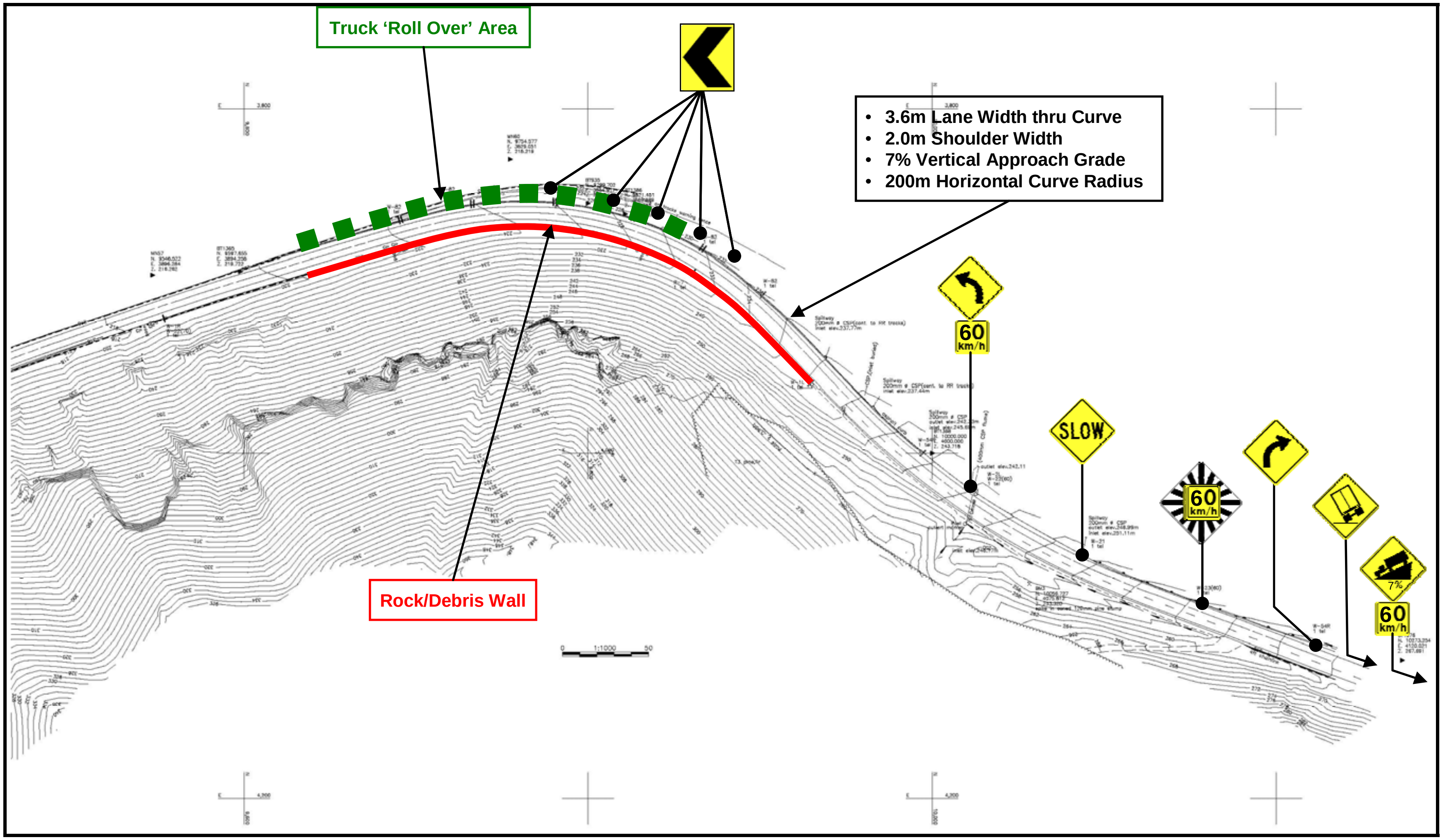
This subtle combination of lower order geometry often contributes to excessive speed for the conditions and a potential loss of control. Collision records indicate that many rollover incidents occur during clear and dry road conditions suggesting that poor weather or light conditions is not a primary contributing factor. Both HAS and RCMP data list excessive speed as a primary contributing factor.

The mechanics of a truck rollover can be summarized in the calculation of Rollover Threshold Speed. According to ICBC, the rollover threshold speed of this curve is 118 km/hr. As this speed is significantly higher than the posted advisory speed of 60 km/hr it can further be reasoned that excessive travel speed is <u>the</u> primary contributing factor to collision events at this location.



The existing advance warning sign placement is illustrated in **Figure 2.1**. A total of six static warning signs are currently placed in advance of the critical curve. The relatively high number of warnings over a short distance (approximately 560m) may be contributing to reduced compliance levels as the existing sign placement does not adequately communicate the specific location and magnitude of the hazard. In particular, the Truck Rollover Warning (W-324) sign is placed in advance of the first curve to the right. This would seem to indicate that the first curve is the critical curve, as opposed to the actual rollover prone location which follows on the curve to the left. The 60 km/h advisory speed warning is also displayed in three separate locations (including a W-23 starburst), and is further reinforced by a ‘Slow’ (W-21) warning sign. The number of advisory speed warnings over a relatively short distance may be reducing the conspicuity of the critical truck rollover warning message.

Figure 2.1: Existing Site Characteristic



2.2 Secondary Issues

A number of related issues and considerations exist at this location, which were noted for potential inclusion in the solution.

2.2.1 CPR Railway

Due to the proximity of the CPR railway at this location, several truck rollover incidents have resulted in either the entire truck or its load affecting traffic activity on railway line. At the critical section of the curve, the CPR line is approximately 10m (horizontally) from the highway. A standard roadside barrier wall is in place along the entire curve; however this configuration does not offer protection in the event of a direct truck collision. At least one event is known to have resulted in the entire truck breaching the barrier and landing on the railway line itself. In other cases the rolled truck stayed on the highway, while its load spilled over the barrier and onto the railway line.

Truck Rollover Incident – April 16, 2005

Any debris or wreckage resulting from a truck rollover incident presents a serious risk to rail traffic. While CPR has installed detection sensors to warn oncoming trains when foreign objects block the tracks, sufficient warning may not always be provided. The possibility of a train collision and/or derailment remains a significant concern. Blockages of the rail line represent a significant cost to the CPR and its users. The time required to investigate, clear, and repair the railway after these events results in lengthy closures with associated costs to CPR (anecdotally estimated to be in the range of $1 Million per day). While the truck rollover issue on the highway represents a significant problem, the secondary issue of railway impacts serves to exacerbate an undesirable situation.

2.2.2 Slope Debris

The east side (inside) of the Marshall Mountain curve is dominated by a large steep slope of loose rock material. A rock catch retaining wall protects the highway and the railway from loose debris. This slope is in a constant state of erosion, and requires a significant investment in maintenance to preserve its stability. Even with the wall and associated maintenance it is not uncommon for loose rocks to pass over the wall and land on either the highway or the railway tracks. This results in an additional risk to both highway and railway users.

Loose Gravel Slope on East Side of Highway

2.3 Causal Factors

While excessive speed for the conditions is likely to be the primary cause of most truck rollovers at this location, other factors, which cannot necessarily be addressed within the scope of a typical highway improvement project, may be contributing to the situation and are often significant contributors to other similar issues at other locations. These issues include:

- Driver Inexperience
- Non-Compliance with Advisory Conditions
- Driver Impairment (Fatigue, Alcohol, and Drug use)
- Environmental Effects (Wind, Blinding Sunlight)
- High Centre of Gravity Loads
- Poor Cargo Distribution and Load Shift
- Poor Brake Performance
- Collapsed Suspension
- Under-Inflated Tires

With the limited availability of details relating to the truck operating conditions at all of the incidents, it was not possible to quantify the impact of these factors.

3.0 IMPROVEMENT PROJECT DEVELOPMENT

This section outlines how improvement project packages aimed at addressing the primary issue identified were developed and analyzed. To ensure consistency with the scope and order of magnitude of the problem, a guiding principle was been established.

3.1 Guiding Principle

The guiding principle for the development of improvement options at this location, as developed by the Ministry of Transportation, can be summarized as follows:

- *Reduce the frequency and severity of truck related incidents at the Marshall Mountain (Thompson Siding) location*

An improvement project at this location must consider the context within which this location exists and the fact that an over-riding intent to upgrade or invest in the entire Fraser Canyon segment of Hwy 1 does not exist at this point in time. As such, the project location will always be located immediately adjacent to an area of topographically challenging highway alignment, with sections of steep vertical grade and advisory design speed horizontal curvature. A clear recognition and understanding of this fact is paramount, as improvement project candidates that aim to '4 lane' or significantly enhance the design speed of this short segment of Hwy 1, are wholly out of context with the theme and intent of the remainder of this segment of the corridor, and were not considered.

Due to the number of related issues and causal factors that may be contributing to the risk of truck rollover events and are outside of the scope of what such a highway geometry improvement project could possibly achieve, it is unrealistic to assume that all incidents could positively be eliminated.

3.2 'Online' Improvements

Consistent with the guiding principles defined, the 'Online' package was developed to address the truck rollover concerns at this location making use of the existing highway alignment to the extent possible. This package attempts to address the primary issue of truck rollovers through the use of a 'toolbox' of enhanced warning and guidance techniques, resulting in a relatively low cost package of preventative measures.

3.2.1 Warning Signs

Given the high percentage of truck traffic and the history of truck rollovers at this location, the placement of advisory and warning signs could be modified to more effectively convey the critical message (that a truck rollover hazard exists) to southbound traffic. The suggested total number of warning signs has been reduced from six to four, further enhancing the conspicuity of the truck rollover warning message. The modified advisory and warning sign placement could be as follows:

1. '7% Downhill Grade' sign (W-29) with 'For 1 km' tab (W-24) in the same location as the existing downhill grade sign

2. ‘Right Curve’ sign (W-1R)
3. Overhead truck rollover warning message sign (**described in Section 3.2.2**)
4. ‘Left Curve’ sign (W-2L) with a ‘60 km/h’ tab (W-22 60 km/h)

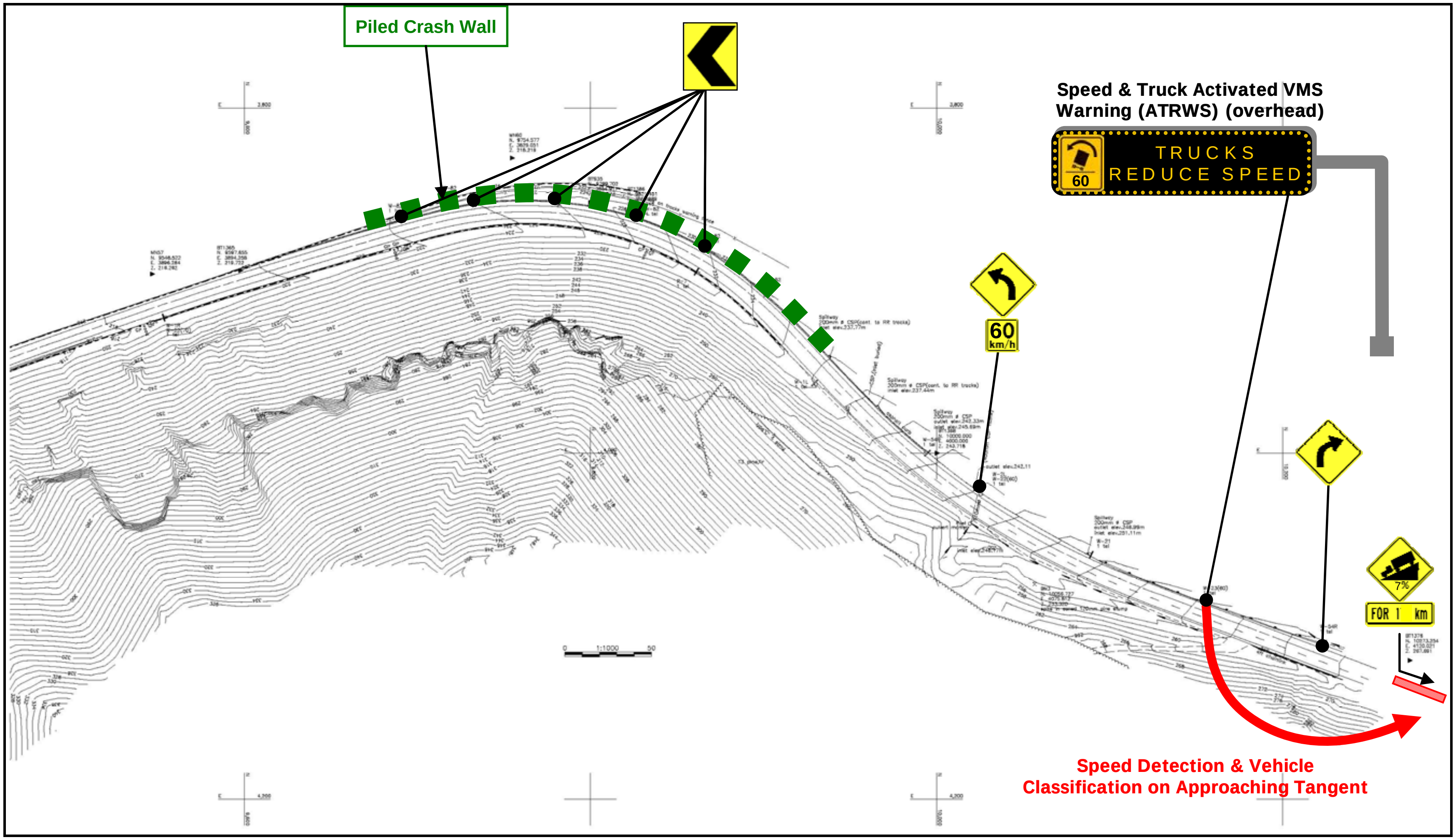
The proposed static sign placement is illustrated in **Figure 3.1**.

3.2.2 Automatic Truck Rollover Warning System

Static warning signs convey the same message to all users regardless of actual risk. Generally, highway users become desensitized to the message, leading to reduced compliance. In order to convey the specific rollover warning message to southbound trucks, the use of an Automatic Truck Rollover Warning System (ATRWS) could be considered, as illustrated in **Figure 3.1**. These systems use Intelligent Transportation System (ITS) technologies to provide an automatic assessment of rollover risk to approaching vehicles. By considering the various factors which contribute to rollover conditions (i.e. vehicle type, speed, weight, and height) ATRWS systems can determine if an approaching vehicle is exceeding the estimated rollover threshold. When an unsafe condition is detected, a warning message is displayed on an overhead or roadside Variable Message Sign (VMS). By only displaying a warning when required, the message is more relevant to individual highway users. Due to their size, illumination, and dynamic message VMS displays are also more conspicuous than static signs.

The potential placement of the overhead VMS sign was determined in order to ensure that sufficient time is provided for truck operators to reduce their speed in advance of the critical curve. As stated in the 2001 ICBC report, the Rollover Threshold Speed (according to *Estimating Truck’s Critical Cornering Speed and Factor of Safety – Navin, 1992*) for this location is estimated to be 118 km/hr. Therefore, it was assumed that trucks traveling at approximately 120 km/hr would constitute an unsafe condition. Using a conservative and comfortable deceleration rate of 2.1 m/s^2, it can be determined that approximately 8 seconds or 200 m would be required to decelerate from 120 km/hr to 60 km/hr in advance of the critical curve. The placement of the overhead VMS sign is shown to be approximately 250 m before the beginning of the curve. This location also has the advantage of providing increased time and space for truck operators to react given that the VMS warning would be visible from the approaching tangent.

Figure 3.1: ‘Online’ Improvement Package



Various technologies can be used to detect vehicle configuration, speed, weight, and height of approaching vehicles. These variables are used to assess the rollover risk of an approaching vehicle. While more complex systems provide the most accurate determination of rollover risk, they are more costly in terms of both installation and maintenance. For the purposes of this assignment, two detection systems were considered.

Simplified ATRWS

This system included a basic set of detectors focusing on the classification and speed of approaching vehicles. Due to its simplicity and the minimal intrusion on the roadway itself (in-pavement sensors) this system has a relatively low cost. The key components of the 'Simple ATRWS' are described as follows:

- Vehicle classification detection to identify approaching trucks:
  - Using limited in-pavement piezo-electric sensors or,
  - Using '*SmartSonic'* acoustic sensing and processing technology.
- Speed detection using piezo-electric, acoustic, or radar devices.
- Overhead Variable Message Sign displaying both a static truck rollover warning sign (W-324) with a 60 km/h advisory and flashing a set warning message such as 'TRUCKS REDUCE SPEED'. This display would be activated only when an unsafe condition is detected and would be displayed to trucks only.
- Estimated costs are approximately $234,000 for supply and installation. Factors to be considered include the availability of electrical power (although solar power can be used in some cases), and communication to a monitoring facility.

Advanced ATRWS

The second system considered includes a more advanced set of detection technologies and may provide a more accurate assessment of rollover risk. This system is able to measure an increased number of critical variables used to determine the rollover threshold speed. While a more advanced system may provide a better determination of rollover risk, the increased complexity results in higher installation and maintenance costs. The key components of the 'Advanced ATRWS' are as follows:

- In-pavement Weigh-In-Motion (WIM) detectors used to determine vehicle classification and weight.
- Speed detection using in-pavement piezo-electric or radar devices.
- Radar based height detection (to distinguish various truck configurations).
- Overhead Variable Message Sign displaying both a static truck rollover warning sign (W-324) with a 60 km/h advisory and flashing a set warning message such as 'TRUCKS REDUCE SPEED'. This display would be activated only when an unsafe condition is detected and would be displayed to trucks only.
- Estimated costs are approximately $599,625 for supply and installation. Factors to be considered include the availability of electrical power (although solar power can be used in some cases), and communication to a monitoring facility.

3.2.3 Railway Protection Wall

The final component which could be considered is a 'soldier pile' protection wall. Keeping in mind the related issue of truck rollover impacts to the CPR railway, this heavily reinforced wall could provide an element of protection to the railway and would be able to withstand and redirect the majority of potential collisions. A wall of 2.5m in height is estimated to be required in order to contain most loose cargo during an event and would provide some 're-directive' properties to a rollover in progress. The key elements of the protection wall can be summarized as follows:

- 2.5m minimum height
- Approximately 300m in length along the outside edge of the critical curve
- Estimated cost = $1,425,000

Special consideration will need to be applied to how this wall end is introduced adjacent to southbound traffic to avoid creating a significant new hazard. A tapered approach is recommended.

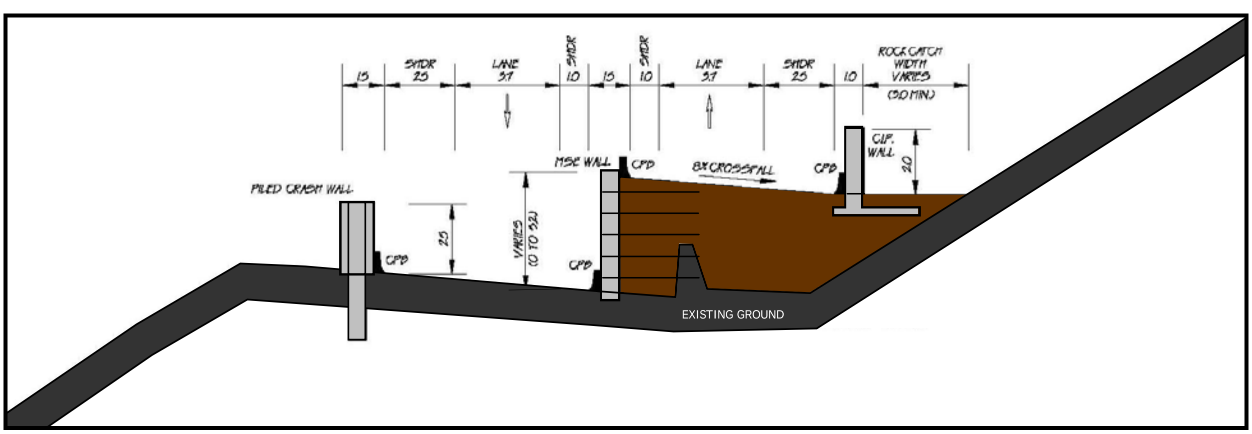
3.3 'Realignment' Improvements

To capture the other end of the potential spectrum of project scope which could be considered here, alternate 'Realignment' options were developed. This package considered potential improvements to the geometry of the critical curve, in addition to various preventative and protective measures to address the issues at this location.

3.3.1 Split Highway Grade

Due to the nature of the loose gravel slope on the east side of the highway, horizontal realignment possibilities are restricted in this location. For this reason a split-grade configuration was developed in order to make better use of the limited horizontal space. This concept was originally introduced and developed by the Ministry of Transportation. The principle motivator for the consideration of a split-grade configuration is its ability to enhance the horizontal width provision without affecting the angle of repose of the loose debris side slope. A typical cross-section of the proposed configuration is illustrated in **Figure 3.2**.

Figure 3.2: Typical Cross-Section for Split Grade Configuration



The key elements of this configuration, are as follows:

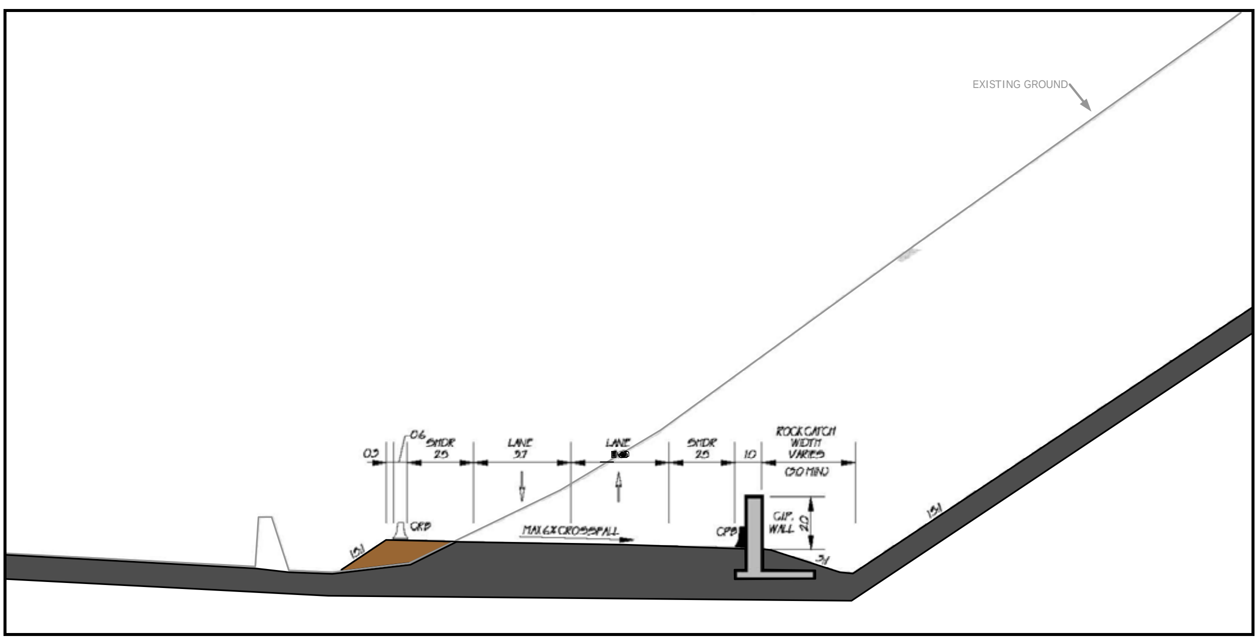
- Subtle improvement of horizontal geometry (curve radius = 230m)
- Increased lane and shoulder width (3.7m + 2.5m)
- New rock catch wall along east side
- Mechanically Stabilized Earth (MSE) retaining wall (up to 5.2m high) and median barrier
- Protection Wall (at least 2.5m high)
- **Total Project Construction Cost Estimate = $6,392,880**

This configuration would provide a subtle improvement to horizontal geometry. As with the 'Online' improvements the inclusion of the protection wall would introduce an element of protection to the railway and some re-directive properties. The separation of northbound and southbound traffic would significantly reduce the possibility of severe head-on collisions, however the addition of median and roadside walls typically increase the frequency of more minor collisions. This package could also include a similar warning and signing strategy as the 'Online' Improvement Package.

3.3.2 Curve Flattening

While the loose gravel slope on the east side of the highway make the circumstances for this type of an improvement challenging, a considerable improvement in horizontal geometry, to accommodate higher travel speed trucks, would likely generate a reduction in truck rollover events. Substantial materials excavation and rock fall protection measures would be required in order to accomplish this configuration. In addition, significant challenges would be anticipated to manage a project of this nature during construction. For the purposes of comparison, a typical cross section of the proposed 'Curve Flattening' configuration is illustrated in **Figure 3.3**.

Figure 3.3: Typical Cross-Section for Curve Flattening Configuration



The key elements of this option, are as follows:

- Significant improvement in horizontal geometry (curve radius = 390 m & 100km/hr design speed)
- Increased lane and shoulder width (3.7m + 2.5m)
- New rock catch wall along east side
- **Total Project Construction Cost Estimate = $15,950,098**

This configuration would provide a significant improvement in horizontal geometry and by eliminating the reduced speed curve, the likelihood of off-road events would be significantly diminished. Without the reduced speed curve roadside protection measures, such as the protection wall would not be required. However, a rock catch wall would remain necessary to contain the loose debris slope. Due to the extensive excavation required and the need for rockfall protection/maintenance measures the estimated construction cost of this option is substantially higher than any other proposed options.

4.0 PROJECT CANDIDATE EVALUATION

A simplified benefit-cost assessment was used in order to evaluate the relative merits of the various approaches. This evaluation was based upon the British Columbia Ministry of Transportation guidelines and methodology, with an intent to direct attention toward a likely improvement scope, and not to represent an exhaustive or detailed business case analysis. The basic principle of the benefit cost calculation is to compare the user benefits of each improvement (accrued over 25 years) to the capital cost and maintenance of the project.

4.1 Safety Benefits

While a typical benefit cost evaluation would consider several accounts of user benefits (improved mobility, reduced vehicle operating costs, and improved safety), , mobility and operating cost benefits would not have a significant impact upon the results and were not considered further in this assessment (this is a 'safety' driven project).

An estimate of rollover frequency was made based on the evidence provided by Ministry of Transportation and the RCMP. Since 10 truck rollover incidents can positively be identified between 1996 and 2006, it was assumed that at least one event occurs each year for the purposes of this comparative analysis. This estimate was further refined to consider one event involving a fatality and 4 rollovers involving injuries every 5 years (0.20 and 0.80 per year respectively). This is a conservative estimate based upon the available information. Using standard rates used by British Columbia Ministry of Transportation (*2003 BC MoT MicroBenCost Guidebook*) the cost to society of each collision type is as follows:

- Fatal Crash = $5,693,934
- Injury Crash = $99,999
- Property Damage Crash = $7,342

By accruing these costs at the assumed rate over 25 years at a 6% discount rate, the total impact to society of truck rollover collisions (before improvements) at this location is estimated to be **$16,515,040**. This does not consider the cost of delays and closures on the Canadian Pacific Railway. While these costs are significant they are normally not considered to be 'public costs' and therefore are not typically included in a benefit cost evaluation undertaken from the perspective of the Province of British Columbia.

Based on the case studies cited the ATRWS effectiveness in reducing truck rollovers has been observed to be very high (100% in many cases). It is possible that the effectiveness of such a system may be reduced over time, but given the positive case history that was found it was considered relatively conservative to assume an overall reduction in truck rollover incidents of 50%. This represents a total safety benefit of **$8,257,520** to society over a 25 year period.

The subtle improvement of horizontal geometry identified in the split grade highway realignment package typically results in overall collision reductions of approximately 25%, while the installation of median barriers significantly reduce the likelihood of severe collisions (90%), but some types of minor collisions become more likely. Given the relatively minor improvement to horizontal geometry, a 25% reduction on truck rollover incidents was assumed for the 'Split

Grade' option. The total safety benefit to society over a 25 year period was determined to be **$4,128,760** in this case.

For the 'Curve Flattening' option, a reduction in truck rollover incidents of 75% was assumed, given the significant improvement to horizontal geometry. This would represent a total benefit to society of $**12, 760, 078** over 25 years.

4.2 Benefit-Cost Comparison

Based on the estimated safety benefits and financial accounts, the strategic benefit cost comparison was conducted, the results of the analysis are summarized in **Table 4.1** below.

Table 4.1: Benefit Cost Evaluation

ACCOUNTS	ONLINE PACKAGE			HIGHWAY RE-ALIGNMENT	
	SIMPLE ATRWS SYSTEM	ADVANCED ATRWS SYSTEM	ADVANCED ATRWS & PROTECTION WALL	SPLIT GRADE	CURVE FLATTENING
CUSTOMER SERVICE					
Base Accident Costs	$16,515,040	$16,515,040	$16,515,040	$16,515,040	$16,515,040
Improved Accident Costs	$8,257,520	$8,257,520	$8,257,520	$12,386,280	$4,128,760
Total Safety Benefit	**$8,257,520**	**$8,257,520**	**$8,257,520**	**$4,128,760**	**$12,386,280**
FINANCIAL ACCOUNT					
Construction Costs	$234,000	$599,625	$2,024,625	$6,392,880	$15,950,098
Maintenance (25 yrs)	$67,751	$135,503	$135,503	-	-
Salvage Value (20%)	$46,800	$119,925	$404,925	$1,278,576	$3,190,019
Total Costs	**$254,952**	**$615,204**	**$1,755,204**	**$5,114,304**	**$12,760,078**
ECONOMIC INDICATORS					
Benefit-Cost Ratio	**32.39**	**13.42**	**4.70**	**0.81**	**0.97**
Net Present Value	$8,002,568	$7,642,316	$6,502,317	$(985,544)	$(373,798)
NPV / Cost Ratio	31.39	12.42	3.70	-0.19	-0.03

All options, with the exception of the 'Curve Flattening' option, resulted in positive economic return indicators, the three variations of the 'Online' Improvement Package demonstrate what would typically be considered very attractive and positive results, and potentially a logical starting point for project scope consideration.

No sensitivity analysis regarding the potential safety benefits was applied to this evaluation. Based on the available data, the assumption of accident reduction rates would be considered conservative in the case of the three variations of the 'Online' Improvement Packages. The intent of this comparison was to highlight the very positive benefit-cost results in the 'Online' improvements against the relatively modest results for the 'Realignment' improvements. The purpose of this evaluation is to identify the relative range in economic return between the packages, and to support the case for incremental or phased problem solving at this location.

4.3 Recommendations

The evaluation suggests consideration of a phased implementation strategy. In this case it would be advantageous to first implement the lowest cost / lowest impact elements (Simplified ATRWS and warning signage) in the short term. If further measures are implemented over the longer term, the scenarios have been developed to minimize 'throw away' construction as new elements of the improvement packages are added. For example major components of the 'Simplified ATRWS' such as the VMS structure could be used if the system was upgraded to the 'Advanced ATRWS'. Additionally, if the protection wall is constructed initially as part of an 'Online' improvement, it could be possible to use the same wall in the 'Split Grade' option in the future.

The advantage of a phased improvement strategy is that any decision made now does not eliminate the possibility of implementing other options. Many major components of the proposed improvement packages complement each other and can be used in isolation or in combination. In addition, since some proposed improvements are of relatively low cost, it could be possible to implement these in the short-term and evaluate their effectiveness prior to moving forward on more costly items.

Based on the results of this exercise the following improvements are recommended:

1. Modified advisory and warning sign placement, as described in **Section 3.2.1**
2. Installation of a 'Simplified ATRWS', as described in **Section 3.2.2**

The effectiveness of these improvements should be monitored over a period of several years. If necessary, additional measures could be undertaken if the results of the above improvements are deemed to be unsatisfactory.

5.0 CONCLUSIONS

This study found that the 'Marshall Mountain' location of Highway 1 in British Columbia presented a unique safety problem that required a unique improvement strategy. Several key points were found to be of particular relevance:

1. Historic collision records were found to under-represent the actual observed truck roll-over problem.
2. While many potential causal factors could be identified, excessive speed was found to be the primary contributing factor to truck roll-over risk.
3. In the context of the entire corridor, expensive geometric re-alignment or widening improvements were not consistent with the scope of the problem or the guiding principle.

Taking into account the context of the location, a phased improvement strategy was developed with the goal of reducing the frequency and severity of truck rollover incidents at this location. This strategy used a phased approach with a progressive suite of safety enhancements, each building upon the last. The intention was to use a series of both operational and geometric enhancements, each complementing each other, which could be implemented over time based on a continuing assessment of their effectiveness.

A significant component of the recommended strategy was the use of an Automatic Truck Rollover Warning System (ATRWS). This type of Intelligent Transportation System (ITS) is specifically designed to complete a real-time assessment of rollover risk and to provide relevant information to approaching truck operators. In this way, investments into safety improvements at this location are directed specifically to the users who need them (i.e. truck drivers). This type of system was determined to be particularly useful for the unique circumstances of this location.

REFERENCES????