Roadside Safety Study: Inventory and Condition and Risk Assessment

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ABSTRACT

Road authorities are often concerned with roadside safety and their understanding of the condition of their existing roadside safety systems and the identification of potentially hazardous roadside elements or objects. These roadside elements or objects fall under two generic categories: existing but deficient roadside safety systems and/or unprotected roadside hazards including, but not limited to, embankments, watercourses, box-culverts, and bridge rails or walls. According to the Ministry of Transportation's *Ontario Road Safety, Annual Report 2012* [1], in 2012 there were a total of 41 collisions between a motor vehicle and a fixed object resulting in a fatality and another 2,021 resulting in a non-fatal injury.

In 2014, Associated Engineering (Ont.) Ltd., in partnership with Cole Engineering Group Ltd., was awarded an assignment to conduct a roadside safety study of approximately 940 kilometres or predominantly two-lane, rural roadways within a municipality situated in southwestern Ontario. The roadside safety study consisted of taking inventory and conducting a condition and risk assessment of the existing roadside safety systems, identifying unprotected roadside hazards, and developing a prioritized plan for addressing the noted deficiencies thereby assisting the municipality in regards to capital planning and annual maintenance of roadside safety systems.

For the assignment, the existing roadside safety systems were inventoried and assessed in terms of condition in addition to identifying any unprotected roadside hazards using a tablet computer and a global positioning system (GPS) unit. The roadside safety systems and roadside hazards were assessed in terms of their conformance to the existing standards set forth in the Ministry of Transportation's *Roadside Safety Manual* [2]. Remediation measures to correct any noted deficiencies and non-conformances were provided and include: installation of a new system, extension of an existing system, replacement of an existing system, and removal of an unnecessary system. In addition, a risk score was developed to allow for the accurate prioritization of the remediation measures based upon exposure (to traffic), probability (of collision), and consequence (severity of collision). The municipality will be able to utilize the risk scores in conjunction with the remediation measures to aid in capital planning and annual maintenance of roadside safety systems.

On the basis of the review, a total of 469 roadside safety systems, consisting of 304 standalone systems and 165 compound systems were inventoried. The following deficiencies were highlighted: inadequate delineation (94 percent), incorrect mounting height (28 percent), inadequate cable-tension (92 percent), design consistency issues (15 percent), poor rail condition rating (36 percent), poor post condition rating (26 percent), and poor block-out condition rating (12 percent). Approximately 52 percent of the roadside safety systems had an inadequate approach or departure length required to prevent motorists from outflanking the system resulting in the potential for a collision with the roadside hazard.

A total of 372 roadside hazards were identified; a majority were situated behind some form of roadside protection while a lesser number (128) remained completely unprotected.

The risk score was effective at highlighting the roadside protection systems and/or unprotected roadside hazards that should be first addressed in regards to the municipality's capital plans moving forward.

1.0 BACKGROUND

Road authorities are often concerned with roadside safety and their understanding of the condition of their existing roadside safety systems and the identification of potentially hazardous roadside elements or objects. These roadside elements or objects fall under two generic categories: existing but deficient roadside safety systems and/or unprotected roadside hazards including, but not limited to, embankments, watercourses, box-culverts, and bridge rails or walls. According to the Ministry of Transportation's *Ontario Road Safety, Annual Report 2012* [1], in 2012 there were a total of 41 collisions between a motor vehicle and a fixed object resulting in a fatality and another 2,021 resulting in a non-fatal injury.

In 2014, Associated Engineering (Ont.) Ltd., in partnership with Cole Engineering Group Ltd., was awarded an assignment to conduct a roadside safety study of approximately 940 kilometres of predominantly two-lane, rural roadways within a municipality situated in southwestern Ontario. The roadside safety study consisted of taking inventory and conducting a condition and risk assessment of the existing roadside safety systems, identifying unprotected roadside hazards, and developing a prioritized plan for addressing the noted deficiencies thereby assisting the municipality in regards to capital planning and annual maintenance of roadside safety systems.

2.0 GOALS AND OBJECTIVES

The goals and objectives of this paper are to:

- Present a defendable methodology for taking inventory and conducting a condition and risk assessment or existing roadside safety systems and identifying unprotected roadside hazards;
- Bring to light common issues experienced by road authorities regarding roadside safety based upon the data collected and the analyses completed; and
- Relate perceived risk and associated remediation strategies to the capital planning and annual maintenance of roadside safety systems for road authorities.

3.0 METHODS

At the outset of the assignment, the municipality provided its single line road network layer including roadway attribute information and traffic volume data from their geographic information system (GIS). Based upon the data provided, a detailed data dictionary was developed to define key attributes required to adequately identify and assess existing roadside safety systems and unprotected hazards in terms of classification, condition, and risk. This detailed data dictionary further expanded on the purpose of the attributes as well as the attributes' data source, data type, allowable values, and optionality. Furthermore, the attribute information had been divided into six attribute categories with key attributes as follows:

- **General Information:** adjacent roadway information, direction, position, date entered, date updated, photograph identifier, and general notes;
- **Feature Characterization Information:** classification, type, end treatment classification, end treatment type, entrance or intersecting roadway conflicts, post material, block-out material, and geographic coordinates;
- **Hazard Characterization Information:** classification, type, and geographic coordinates;
- **Condition Assessment Information:** delineation, mounting height, plumb angle, cable-tension, shoulder stability, design consistency, rail condition rating, post condition rating, and block-out condition rating;
- **Risk Assessment Information:** exposure based upon average annual daily traffic volume (AADT) and roadside safety system and/or roadside hazard length, probability based upon roadside safety system and/or roadside hazard lateral offset and roadside clear zone requirements, and consequence based upon roadside safety system and/or roadside hazard type and collision severity; and
- **Remediation Information:** remediation measures, and remediation costs.

The roadside clear zone is defined as an area in close proximity to the edge of the travelled lanes that should be kept free and clear of any roadside elements or objects; otherwise, a roadside safety system may be required to guide errant motorists away from a collision with the respective element or object. Roadside clear zone requirements are based upon the adjacent roadway's traffic volume and design speed as presented in the Ministry of Transportation's *Roadside Safety Manual* [2].

In order to improve the data collection efficiency, reduce the potential for error, and minimize the post-processing time, a tablet computer had been utilized for data collection with a graphical user interface developed for the purpose of conducting roadside safety studies including direct integration with single line road network layer in GIS. With the implementation of the data collection interface, real-time validation of the data collected provide feedback to the user as well as allowed for pre-determination of certain attributes where applicable. As a result, a detailed inventory and condition and risk assessment of the existing roadside safety systems and unprotected roadside hazards within the study area was geo-spatially documented. The resulting dataset formed the basis for a new roadside objects layer within the municipality's GIS to be further expanded upon and maintained.

While the inventory and condition assessment provided detailed information regarding the current state of the roadside safety system network, it was necessary to develop an index to allow for accurate comparisons to be drawn regarding the relative risk of each roadside safety system and/or roadside hazard. These relative risks would then be used to assist in developing a prioritized plan for remediation to be accounted for during the capital planning and annual maintenance of the roadside safety system network. Since every roadside safety system and roadside hazard are unique due to varying adjacent roadway characteristics and/or roadside environments, the key contributing factors to risk were categorized based upon exposure, probability, and consequence.

3.1 Exposure

In order to quantify the risk of a roadside safety system or an unprotected roadside hazard, the exposure was determined through three key factors: frequency of roadside encroachment, traffic volume, and the length of the roadside safety system or unprotected roadside hazard. Exposure is a measure of the number of vehicles expected to encroach onto the roadside over a given length. It is a function of the roadway's traffic volume and the length of a roadside safety system or unprotected roadside hazard. As the traffic volume or the length of system or hazard increases, the exposure to the system or hazard also increases resulting in a higher number of expected roadway departures within the conflict area. As indicated in the American Association of State Highway and Transportation Officials' *Roadside Design Guide* [3], roadside encroachments occur at a rate of 0.0003 encroachments per kilometre per year per vehicle per day for a single direction of travel. The AADT attributed to each of the roads under investigation was used to determine the number of vehicles travelling past the system or hazard. The length of the system or hazard (in metres) was determined through calculation using the GPS coordinates for the approach and departure points for the respective element. The exposure component to the risk score calculation is presented below:

$$\begin{aligned} Risk\ Score_{Exposure} &= 0.0003\ encroachments/kilometre/year/vehicle/day \\ &\times (x_{AADT}\ vehicles/day \div 2) \times \left(x_{length} metres \div 1000\ metres/kilometre\right) \end{aligned}$$

3.2 Probability

In addition to the exposure component of the risk model, it is important to describe the likelihood of a collision with a roadside safety system or unprotected roadside hazard in the event of a roadway departure. Based on the American Association of State Highway and Transportation Officials' *Roadside Design Guide* [3], the probability of colliding with a roadside safety system or unprotected roadside hazard is a function of the design speed and the extent of lateral encroachment or horizontal offset. The design speed was calculated as 10 kilometres per hour above the posted speed limit as noted during the field assessment. The horizontal offset is based on two scenarios: adjacent lane roadway departure, and opposing lane roadway departure. Since the adjacent lane will always be in closer proximity to the guide rail or unprotected hazard, the probability of a collision will always be higher should the vehicle leave the roadway from the adjacent lane. The horizontal offset of the adjacent lane was estimated in 0.5 metre increments from the edge of the travelled lane to the roadside safety system or the unprotected roadside hazard. To determine the horizontal offset of the opposing lane, a standard lane width was assumed to be 3.50 metres. This lane width was added to the estimated offset of the system or hazard on the opposite side of the roadway.

Given the horizontal offsets as described above, the probability of collision with a system or hazard would be negligible if it were located outside of the roadway's clear zone defined by the Ministry of Transportation Ontario in the *Roadside Safety Manual* [2]. The clear zone was determined based on the roadway's AADT and design speed.

Should the roadside safety system or the unprotected roadside hazard be located within the clear zone, the probability of colliding with it would increase as the design speed increases or the horizontal offset decreases. In essence, the higher the vehicle speed or the closer the roadside object, the likelier it is to be struck in the event of roadway departure. To determine the probability of collision, the adjacent and opposing lanes were reviewed independently due to their different horizontal offsets. The probability of collision was determined based on the design speed and the horizontal offset in 0.5 metre increments for both the adjacent and opposing lanes using encroachment rates. The probability component to the risk score calculation is presented below:

$$Risk\ Score_{Probability} = x_{adjacent\ lane\ probability} + x_{opposing\ lane\ probability}$$

The above noted probabilities are determined through empirical data presented by the American Association of State Highway and Transportation Officials in the *Roadside Design Guide* [3] relating the design speed and the horizontal offset from the edge of the travelled lane to the roadside safety system or the unprotected roadside hazard.

3.3 Consequence

After understanding the exposure and the probability of collision with a roadside safety system or an unprotected roadside hazard, the consequence of colliding with the roadside object is best determined by the severity of the collision. The severity of a collision is based on several factors such as the design speed, type of system or hazard, and the general conformance to standards to provide a certain degree of safety. These severity indices have been adapted from the *Roadside Design Guide* [3] and are provided in **Table 1** and **Table 2**. While the severity indices present within this study range between 2 and 7, theoretical values may exceed this range and go between 0 and 10.

Associated with each severity index are the probabilities pertaining to the severity of collision: property damage only, non-fatal injury, and fatality. As the severity index increases, the probability of a more severe collision resulting in a fatality is increased. For instance, a severity index of 0.5 may be assigned a probability of 100% for a property damage only collision while a severity index of 10 may be assigned a probability of 100% for a fatality collision as discussed in the *Roadside Design Guide* [3]. Adapted severity indices, indicating collision severity on a scale of 0 to 10, were assigned to various types of scenarios (i.e. conforming guide rails versus non-conforming guide rails and unprotected hazards at different design speeds). These values, based on similar values provided in the *Roadside Design Guide* [3], are shown in **Table 3** and were used for the purposes of this roadside safety study as approved by the municipality.

For the purposes of this study, it has been assumed that:

- Guide-posts act in the same manner as three-cable guide rails;
- Box-beam guide rails act in the same manner as steel-beam guide rails; and

- Entrance or intersecting roadway guide rails, thrie-beam guide rails, and concrete barriers act in the same manner as steel-beam with channel guide rails.

When assessing the consequence within the risk score, the relative weighting of each collision severity level needs to be assessed to emphasize the higher societal cost associated with fatality collisions over non-fatal injury collisions and property damage only collisions. The relative costs are a factor of '1' for property damage only collisions, a factor of '10' for non-fatal injury collisions, and a factor of '1,967' for fatality collisions as derived from the most recent societal cost values applicable in Ontario [4]. The consequence component to the risk score calculation is presented below:

$$Risk\ Score_{Consequence} = \left(1 \times prob^{property\ damage\ only}\right) + \left(10 \times prob^{non-fatal\ injury}\right) + \left(1{,}967 \times prob^{fatality}\right)$$

To determine the consequence component of the risk score, the severity index of the roadside safety system or the roadside hazard must first be derived from **Table 1** or **Table 2**. With this severity index, the collision severity is determined as presented in **Table 3**. The probabilities for each collision type are them multiplied by their social costs as determined in Ontario [4] and summed together to provide the resulting consequence component of the risk score.

3.4 Combined Risk Score

After assessing risk in terms of exposure, probability, and consequence, a total combined risk score for each roadside safety system and/or roadside hazard was calculated as follows:

$$Risk\ Score_{Combined} = Risk\ Score_{Exposure} \times Risk\ Score_{Probability} \times Risk\ Score_{Consequence}$$

Each roadside safety system and/or roadside hazard will have a resulting risk score in the form defined above. Based on the results of the condition assessment and the length of need calculations, the roadside safety system may not necessarily be fully protecting motorists from the corresponding roadside hazard. As a result, the risk associated with the roadside hazard may be prorated and added to the risk associated with the roadside safety system based on one of the two following scenarios:

- The roadside safety system is in inadequate condition to properly function as it was intended resulting in the full risk of the corresponding roadside hazard being added to the roadside safety system's associated risk; or
- The roadside safety system is of inadequate length resulting in a portion of the risk of the corresponding roadside hazard being added to the roadside safety system's associated risk prorated based upon the extension needed to meet the length of need requirements.

It is noted that if the roadside safety system was in good condition and was long enough to fully protect against the roadside hazard, then the roadside hazard risk score would be negligible as the system is considered to provide the necessary protection from the hazard.

4.0 RESULTS

On the basis of the review, a total of 469 roadside safety systems, consisting of 304 standalone systems and 165 compound systems were inventoried.

4.1 Roadside Safety System Inventory

The various types and corresponding instances of the roadside safety systems inventoried are presented in **Figure 1**. As illustrated, a majority of the systems inventoried along the municipal roadways were steel-beam guide rails (195) accounting for approximately 42 percent of the network.

4.2 Roadside Hazard Inventory

A total of 372 roadside hazards were identified; a majority were situated behind some form of roadside protection while a lesser number (128) remained completely unprotected as illustrated in **Figure 2**. Of these 372 hazards, the most frequently observed type of hazard were box-culverts, of which 150 were identified, followed by watercourses and embankments at 103 and 99 instances, respectively.

4.3 Condition Assessment

Based upon the condition assessment attributes discussed briefly in **Section 3**, the existing roadside safety systems were assessed concerning their conformance to the respective design standards and their ability to safely guide errant motorists away from a collision with the corresponding roadside hazard. Should one or more of the attributes fail to adhere to the applicable design standards or the condition of the rail, posts, or block-outs fall below acceptable levels, then the system was deemed to be of inadequate condition. The rail, post, and block-out condition ratings were based on a scale of 1 to 5; 1 representing a condition of 0 to 20 percent and 5 representing a condition of 80 to 100 percent.

Table 4 presents summary statistics of the condition assessment information attributes of the existing roadside safety systems inventoried; specific attention was given to delineation, mounting height, cable tension, and design consistency. The following deficiencies were highlighted: inadequate delineation (94 percent) concerning hazard markers, snow plow markers and delineation strips, incorrect mounting height (28 percent), inadequate cable tension (92 percent), and design consistency issues (15 percent) such as a fixed object situated within the deflection zone behind the guide rail or incorrect offset between a barrier curb and the guide rail. In regards to the condition, the following was noted: poor rail condition rating (36 percent), poor post condition rating (26 percent), and poor block-out condition rating (12 percent).

In comparison with the Ministry of Transportation Ontario's *Roadside Safety Manual* [2], the approach and departure lengths were reviewed for their conformance to the required lengths of need. Length of need refers to the minimum length requirements for a roadside safety system in order to adequately protect motorists from a roadside hazard. Approximately 52 percent of the roadside safety systems had an inadequate approach or departure length required to prevent motorists from outflanking the system resulting in the potential for a collision with the roadside hazard.

4.4 Remediation Measures

For any unprotected roadside hazard determined to warrant protection by means of a roadside safety system, the length of system required was determined based on the length of need. **Figure 3** presents a histogram of the length of the system recommended to be installed at all unprotected roadside hazards based on the length of need recommended in the *Roadside Safety Manual* [2]. Typically, a system ranging from 76 to 100 metres was recommended for installation.

Where a system is already installed but is of insufficient length, the length of extension was determined based on the length of need as well. **Figure 4** presents a histogram of the length of the system extension recommended where the length of need was determined to be inadequate based on the length of need recommended in the *Roadside Safety Manual* [2]. Typically, a system extension ranging from 76 to 100 metres was recommended.

Figure 5 presents the most common remediation measures recommended as a result of the inventory and condition and risk assessment. By far, the most common remediation measure recommended was the installation of delineation (441 cases). Installing an appropriate approach and departure end treatment was recommended in 274 and 254 cases, respectively. Less common remediation measures included installing a new roadside safety system, extending a roadside safety system, and replacing or removing a roadside system.

Figure 6 presents the average cost associated with the common remediation measures recommended. The most costly remediation measure recommended was the installation of a new roadside safety system, averaging in excess of $20,000 per installation. The second most costly remediation measure recommended was the extension of an existing roadside safety system, averaging approximately $11,000 per installation.

4.5 Risk Assessment

Based on the methodology discussed in **Section 3**, the roadside safety systems and unprotected roadside hazards inventoried were assigned a risk score. **Table 5** and **Table 6** present the top ten roadside safety systems and unprotected roadside hazards with the highest ranked risk scores; these risk scores may be attributed to a number of factors including the roadway's AADT, the length of the system or hazard, and specifically in the case of a roadside safety system, the condition of the system and its ability to provide protection from the corresponding roadside hazard. It is noted that the top system or hazard is relatively higher than the others and is due a combination of high traffic volumes, poor condition or lack of a functional system, and a close proximity of the hazard to the adjacent roadway. The risk score may be used as a means of prioritizing remediation amongst the different roadside safety systems and/or unprotected roadside hazards. From the analysis, the risk scores range between 0.0 and 160.9 with a distribution presented in **Figure 7** whereby 0.0 represents a situation with a very low risk due to the presence of an adequate system fully protecting from the hazard in a location with low traffic volumes situated near the edge of the clear zone.

4.6 Common Issues

The following section of the paper outlines common roadside safety issues identified over the course of the inventory and condition and risk assessment in addition to the review of potential unprotected hazards. These issues have been documented in other municipalities within Ontario in which similar studies have been conducted and similar strategies employed.

4.6.1 Fully Unprotected Roadside Hazards

Unprotected roadside hazards located within the minimum roadside clear zone were inventoried and assessed based upon their linear (along the roadway) and lateral (at right-angles to the roadway) extent, to determine the length of need for roadside protection to adequately shield road users from the hazard. Where elimination, relocation or making the hazard traversable/crashworthy was not practical, and the extent of the hazard was amenable to shielding throughout its length, a roadside safety system rail installation was recommended.

Steel-beam guide rail, with or without channel, was the treatment of choice due to the effectiveness and life-cycle economics of this system. One example of an unprotected roadside hazard is shown in **Figure 8**. The length of need requirement was determined based on the *Roadside Safety Manual* [2], with the approaching and leaving end treatments extending beyond.

Since both the approaching and leaving ends of this new system would be in the minimum roadside clear zone for their respective directions of travel, a suitable end treatment was recommended for both the approaching and leaving ends. The end treatment of choice in conjunction with steel-beam guide rail was the extruder end terminal, based upon its effectiveness at design speeds up to 100 kilometres per hour, its ability to be retrofitted without grading modifications to the roadway shoulder or ditch/drainage design in most applications, and in consideration of the advantages of roadside safety system standardization.

4.6.2 Partially Protected Roadside Hazards

Many locations were identified where: a roadside hazard was present within the minimum roadside clear zone and roadside protection in the form of guide rail was provided, but the system proved to be obsolescent, in poor condition, and/or of insufficient length to adequately shield the hazard from both directions of travel. One example of a system that is inadequate to protect a hazard is shown in **Figure 9**. In this instance, obsolescent three-cable guide rail, in poor condition, and of insufficient length, is present.

To upgrade the roadside protection to current standards, and to adequately shield the hazard, simply extending the three-cable guide rail is impractical. In this instance, the recommendations are to: remove the three-cable guide rail; replace it with the required length of steel-beam guide rail; provide guide rail extruder end treatments on the approaching and leaving ends of the system; and provide object markers visible to approaching traffic from both directions of travel.

Over time, this upgraded form of roadside protection will adequately shield road users from the hazard without introducing other risks into the roadside, while being less-costly and longer-lived to maintain.

4.6.3 Design Conformance Issues

Adequacy issues identified were not limited to three-cable guide rail. Length of need issues, protection of approaching and leaving ends, and clear zone issues involving fixed object hazards located within the run-out area behind gating-type end treatments such as eccentric loaders, were also identified with steel-beam guide rails. Common design conformance issues identified were:

- Incorrect mounting height of the roadside safety system.
- Fixed objects in the run-out area behind an end treatment;
- Improper transition between semi-rigid and rigid roadside safety systems; and
- Barrier curb in front of steel-beam guide rail.

4.6.4 Unnecessary Roadside Safety System

Despite their crashworthy design, roadside safety systems represent a potential roadside hazard. They are only justified where their presence is likely to result in less-severe crash outcomes relative to interactions with the hazard being shielded. In all instances, the justification for existing roadside safety system installations was revisited, to ensure that the presence of a continuing hazard merited the continued presence of roadside protection.

In some instances, despite careful evaluation, an original or continuing justification for the presence of some systems could not be found. Since these installations do not serve a bona fide purpose, pose a potential hazard, and would consume precious resources to bring them up to current standards presently, and to maintain them into the future, their removal was recommended.

Removal is a low-cost resolution to issues of non-conformance, and eliminates the need for future maintenance. Provided removal does not expose road users to a hazard that would otherwise justify shielding, elimination of an unnecessary system results in a relatively safer roadside. From a liability perspective, elimination removes a potentially non-compliant system which, unaddressed, could be cited as a source of increased harm in a collision, and therefore attract allegations of neglect.

An applicable axiom is, "provide roadside safety systems where necessary (i.e. a compliant system in the presence of a justifying hazard), but no unnecessary roadside safety systems (a clear roadside, free of fixed object hazards which includes roadside safety systems is always the safest design solution)."

In the example shown in **Figure 10**, no justifying hazard for the obsolescent three-cable guide rail was found, and as a result, its removal was recommended.

4.6.5 Entrance or Intersecting Roadway Conflicts

Intersecting roadways, driveways, and field accesses may preclude the provision of a run of guide rail sufficient to meet length of need requirements and to prevent an errant vehicle from outflanking the system and reaching the hazard. In such instances, a special form of end treatment, known as a driveway return, is employed. The driveway return provides protection around a small radius and runs perpendicular to the roadway. Its approach end may either employ an extruder (generally reserved for public roadway approaches), or it may be flared and buried or may be left upright (driveways and field entrances).

The radius and the perpendicular portion of the system preclude outflanking, and transition seamlessly to the steel-beam guide rail running parallel to the roadway. Posts in the radius are drilled to weaken them, allowing them to break away in a head-on impact. The steel-beam then acts like a crash cushion, going into tension and restraining the errant vehicle.

In the example shown in **Figure 11**, the eccentric loader is recommended for removal, and a driveway return with an object marker is recommended to replace it.

4.6.6 Drainage Ditches

Large, water-filled agricultural irrigation ditches, some extending for several kilometres, were present within the roadside clear zone, adjacent to several rural roads. An example of one such drainage ditch is presented in **Figure 12**. These watercourses pose a submergence hazard throughout their length. However, the provision of roadside protection throughout is difficult to justify given that the roadways are generally straight and flat, and the traffic volumes upon them are relatively low; the cost to employ a steel-beam guide rail would be far too extensive for many municipalities to install for many kilometres.

Applying best-practices gathered from various municipalities within the area whom have completed similar studies, options include: shielding road users from the hazard by means of a low-cost roadside safety system (e.g. three-cable guide rail); road edge delineation to assist road users in selecting an appropriate speed and path so as to remain on the roadway; or a reduction in the posted speed limit to reduce the likelihood of roadway departures.

Collision histories suggest that roadway departures involving these features are infrequent, and rarely if ever result in vehicle submergence. Shielding road users from such extensive hazards would be expensive. Three-cable guide rail, which deflects up to three metres on impact, may not prevent vehicles from reaching the hazard. A reduced speed limit would likely achieve poor compliance and prove ineffective, as most road users would fail to perceive the connection between it and roadside threat.

Delineation, to help keep road users on the road, is both effective, and cost-efficient. Options include one or more of the following: painted edge lines; partially-paved shoulders; edge line rumble strips; permanent retro-reflective pavement markers; and post-mounted delineation. Any or all of these treatments could be considered in order to clearly define the extent of the roadway, and the hazard area beyond, allowing road users to make decisions in support of their own safety. On this basis, a delineation treatment is recommended.

5.0 OUTCOMES

The municipality wished to be pro-active in incorporating life-cycle replacement costs into its capital budget on a yearly basis in keeping with asset management best-practices. The replacement cost of the existing inventory was determined to be approximately $3.6 million. Using a 30-year useful asset-life, this suggests an annual maintenance requirement of approximately $120,000 to maintain the status-quo for the 940 kilometres of roadways reviewed. When remedial measures to address deficiencies associated with existing systems were priced and summed with the remedial measures required to address unshielded hazards, the combined backlog of deficiencies was found to total approximately $6.7 million.

While initially appearing counter-intuitive, as the remedial cost exceeds the replacement cost of the entire network, this finding is consistent with the following observations:

- Many elements of the existing inventory are either approaching or at the limit of their expected service life, and thus in need of complete replacement;
- Many existing system elements are fundamentally deficient in terms of existing standards applicable to delineation, approaching and/or leaving end treatments, transitions, and length of need; and
- Where replacement is identified as a required remedial measure, often less-expensive (considering capital cost only) three-cable guide rails are recommended for replacement by more-expensive (again, considering capital costs only) steel-beam guide rails.

Thus, while the cost of eliminating the deficiency backlog may appear excessive, relative to the estimated value of the inventory as a whole, backlog elimination accomplishes numerous objectives, including:

- Replacement of all deficient systems with compliant systems offering comprehensive shielding, superior crash performance, enhanced maintainability, and lower overall life-cycle costs (albeit with higher initial capital costs). This accomplishment will add significantly to the overall size (in terms of linear metres of guide rail, and numbers of end treatments) of the inventory; and
- Elimination of numerous unshielded hazards through the provision of shielding, further adding to the overall size of the inventory.

Once the deficiency backlog is fully eliminated, the value of the overall inventory will be effectively increased to $8.5 million representing the summation of the value of the retained elements of the existing inventory, plus the value of the additional elements introduced to eliminate deficiencies. The end result should be a fully-compliant, safer, and more maintainable (at lower overall cost) inventory.

6.0 DISCUSSION AND CONCLUSIONS

Overall, this paper has provided a high-level overview of a comprehensive roadside safety study of a selected group of roadside safety systems and roadside hazards situated alongside approximately 940 kilometres or two-lane, rural roadways within the municipality.

The purpose of the inventory and assessment was to confirm the location, type, and condition of the existing roadside safety systems (type of system, end treatments, condition, geometry, etc.) as well as document the existing unprotected roadside hazards. For each roadside safety system and unprotected roadside hazard, a set of remediation measures was recommended to address any noted deficiency or non-conformance to the applicable standards. In addition, a risk score was developed for each asset and is suitable for use in comparing systems and hazards in terms of risk and prioritization for remediation and capital planning purposes.

As a result, the municipality has received a detailed inventory of their existing roadside safety systems and unprotected roadside hazards including the results of the condition and risk assessment associated with each. The detailed remediation measures and costing will assist in the municipal capital planning and annual maintenance requirements regarding roadside safety.

References

[1] Ministry of Transportation Ontario, *Ontario Road Safety, Annual Report 2012*, 2013.

[2] Ministry of Transportation Ontario, *Roadside Safety Manual*, 1993.

[3] American Association of State Highway and Transportation Officials, *Roadside Design Guide*, 2011.

[4] Transport Canada, *Analysis and Estimation of the Social Costs of Motor Vehicle Collisions in Ontario*, 2007.

TABLES

Table 1
Severity Indices by Roadside Safety System/Roadside Hazard - Part 1

Design Speed (km/hr)	Severity Index									
	Guide-Post		Three-Cable		Steel-Beam		Steel-Beam with Channel		Thrie-Beam	
	Conf.	Non Conf.	Conf.	Non Conf.	Conf.	Non Conf.	Conf.	Non Conf.	Conf.	Non Conf.
50	3	4	3	4	2	3	2	4	2	4
60	3	4	3	4	2	3	2	4	2	4
70	3	5	3	5	2	3	2	4	2	4
80	4	5	4	5	2	4	2	5	2	5
90	4	6	4	6	3	5	3	5	3	5
100	4	6	4	6	3	5	3	6	3	6

Notes: Conf. - Conforming, Non-Conf. - Non-Conforming

Table 2
Severity Indices by Roadside Safety System/Roadside Hazard - Part 2

Design Speed (km/hr)	Severity Index							
	Box-Beam		Entrance or Intersecting Roadway		Concrete		Embank -ment	Fixed Object
	Conf.	Non Conf.	Conf.	Non Conf.	Conf.	Non Conf.		
50	2	3	2	4	2	4	4	4
60	2	3	2	4	2	4	4	4
70	2	3	2	4	2	4	4	4
80	2	4	2	5	2	5	5	5
90	3	5	3	5	3	5	6	6
100	3	5	3	6	3	6	7	7

Notes: Conf. - Conforming, Non-Conf. - Non-Conforming

Table 3
Collision Severity by Severity Index

Collision Type	Collision Severity											
	Severity Index											
	0.0	**0.5**	**1.0**	**2.0**	**3.0**	**4.0**	**5.0**	**6.0**	**7.0**	**8.0**	**9.0**	**10**
Property Damage Only	0	100	90	71	43	30	15	7	2	0	0	0
Non-Fatal Injury	0	0	10	29	56	67	77	75	68	50	25	0
Fatality	0	0	0	0	1	3	8	18	30	50	75	100
Total	0	100	100	100	100	100	100	100	100	100	100	100

Table 4
Condition Assessment Summary Statistics

Condition Attribute	Percent Adequate	Percent Inadequate
Delineation	6	94
Mounting Height	72	28
Cable Tension	8	92
Design Consistency	85	15

Table 5
Highest Risk Roadside Safety Systems

Rank	Rationale	Risk Score
1	Poor Condition	160.933
2	Poor Condition	90.391
3	Non-Functional, Unnecessary	46.384
4	Incorrect Mounting Height	45.310
5	Poor Condition	42,610
6	Poor Condition	42.398
7	Unnecessary	39.284
8	Poor Condition	33.352
9	Poor Condition, Unnecessary	31.730
10	Poor Condition	30.526

Table 6
Highest Risk Unprotected Roadside Hazards

Rank	Rationale	Risk Score
1	Watercourse	33.856
2	Embankment	8.575
3	Bridge Rail Or Wall	8.040
4	Bridge Rail Or Wall	8.016
5	Watercourse	7.903
6	Embankment	6.343
7	Watercourse	5.698
8	Other	5.064
9	Embankment	4.661
10	Embankment	4.658

FIGURES

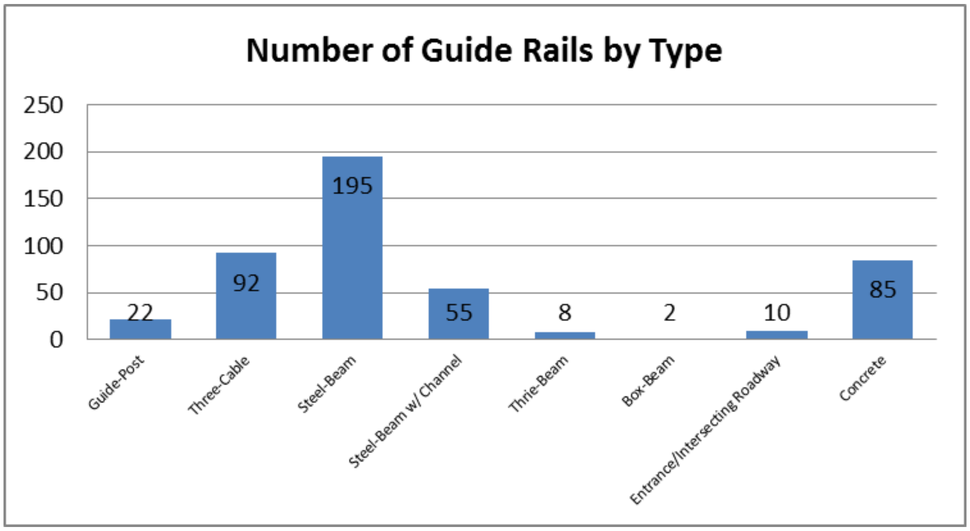

Figure 1
Number of Guide Rails by Type

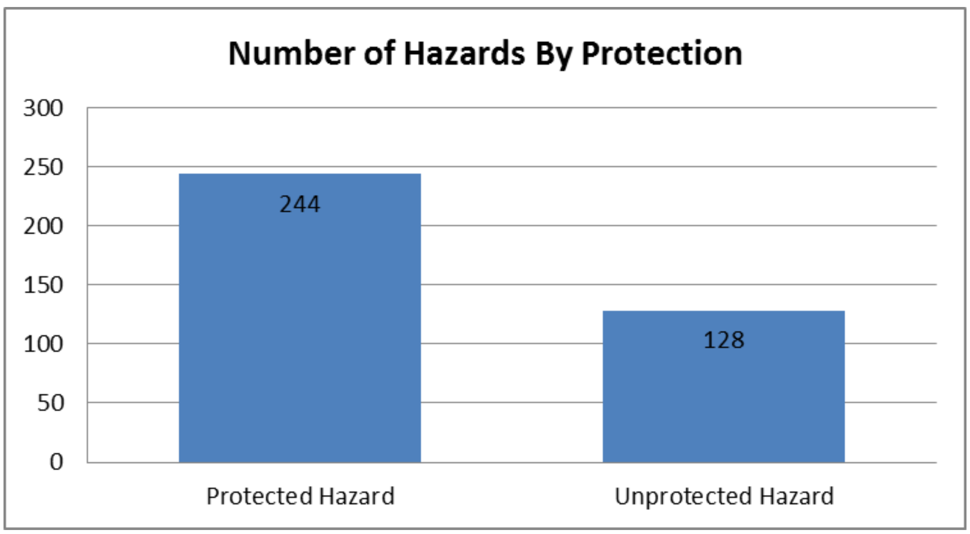

Figure 2
Number of Hazards by Protection

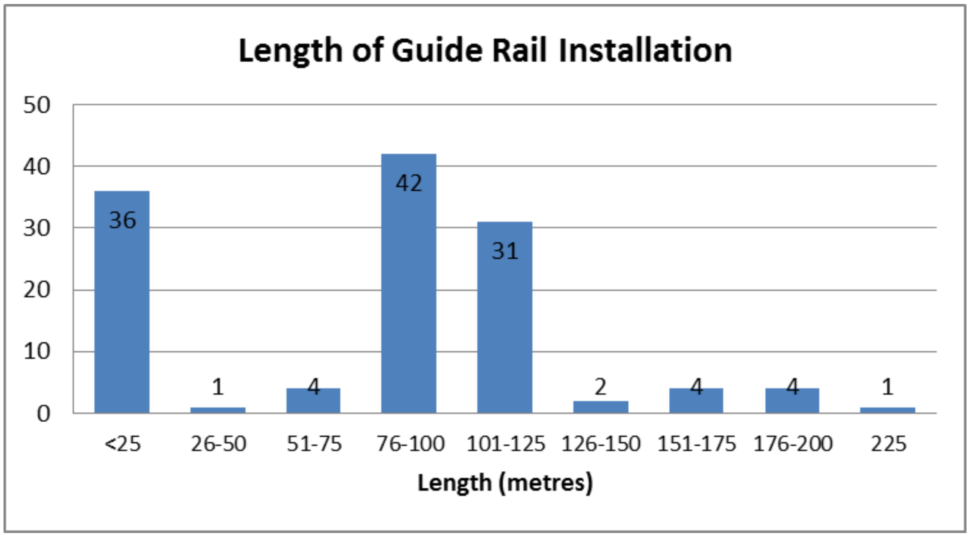

Figure 3
Length of Guide Rail Installation

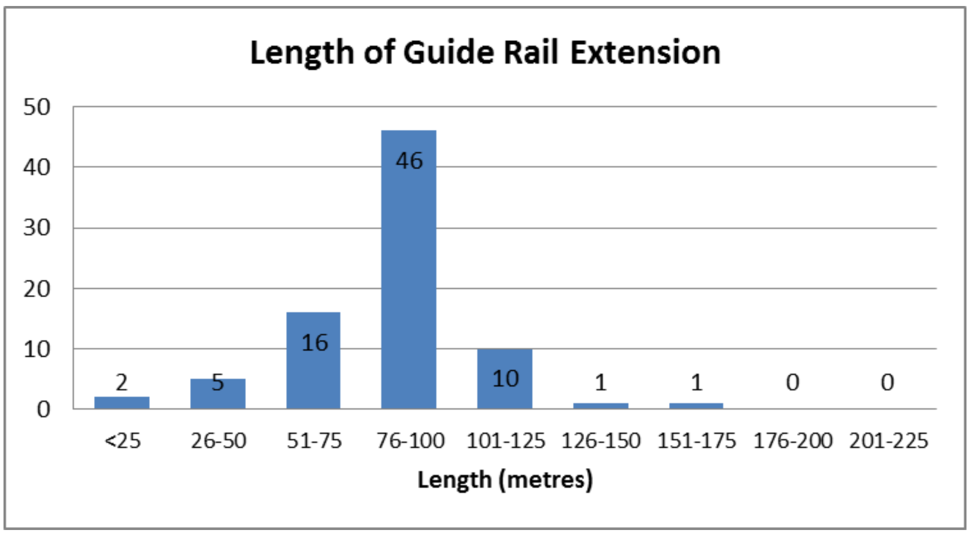

Figure 4
Length of Guide Rail Extension

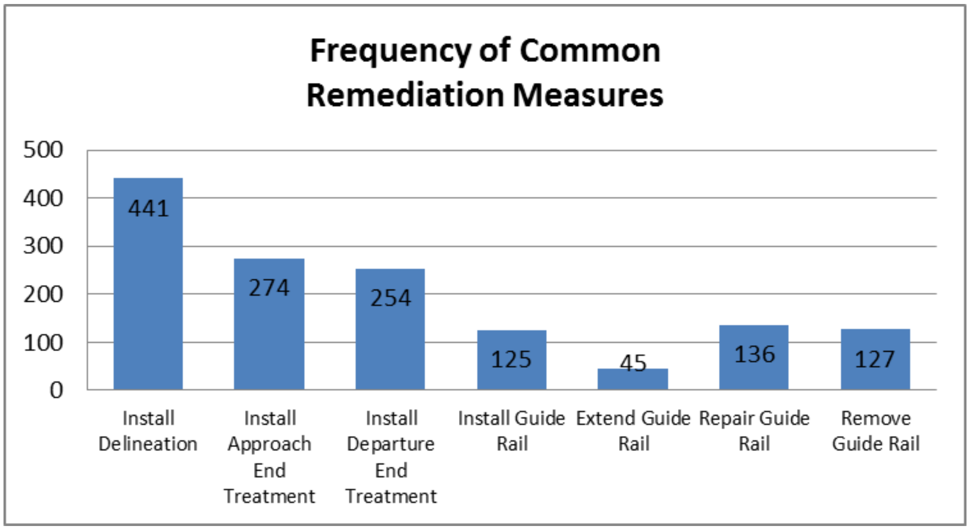

Figure 5
Frequency of Common Remediation Measures

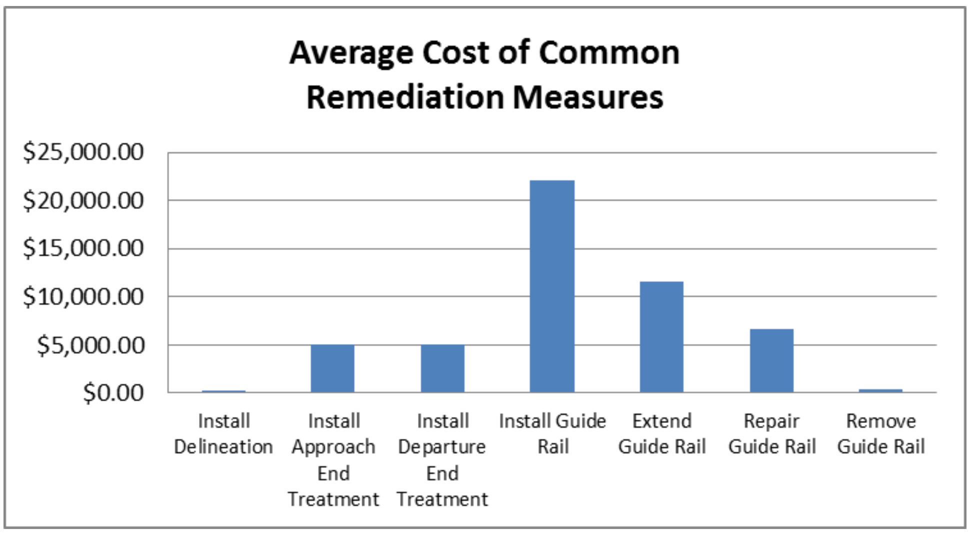

Figure 6
Average Cost of Common Remediation Measures

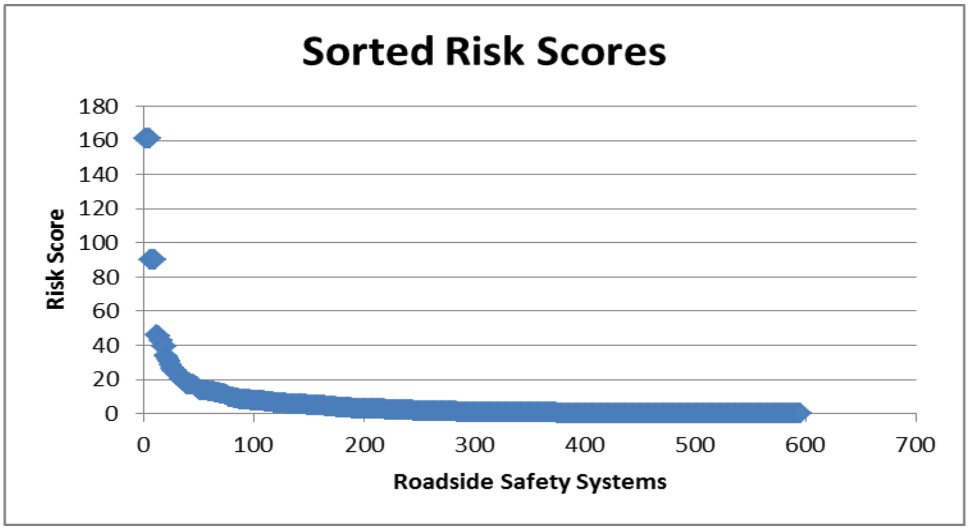

Figure 7
Sorted Risk Scores

Figure 8
Fully Unprotected Roadside Hazard

Figure 9
Partially Protected Roadside Hazard

Figure 10
Unnecessary Roadside Safety System

Figure 11
Entrance Conflict at Roadside Safety System Departure

Figure 12
Roadside Drainage Ditch