Limited Roadside Visibility: Analysis & Effects

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Abstract

Run-off-road collisions are going unnoticed, obscured from the view of passersby due to factors such as steep roadside slopes, bodies of water, and dense foliage. Consequently, road-users are disappearing, perishing, and first responders are being misplaced or are unable to act. Current literature does not address the hazard of concealability of ROR collisions within limited roadside visibility areas, and the extent of its impact, by nature, cannot be fully known.

A case study of a North Saanich couple who were reported missing in August of 2019 is explored. Tragically, the couple was found deceased forty feet from the highway down a steep embankment and just out of sight from their families and the police officers who drove past them. Through analyzing the design elements and topography of a roadside's cross section, this study demonstrates which run-off-road collisions may become hidden, and where. A map of such locations can then be compiled to assist authorities, Search & Rescue operations, and families in locating victims of this hazard, as well as to quantify the scope of the associated risk.

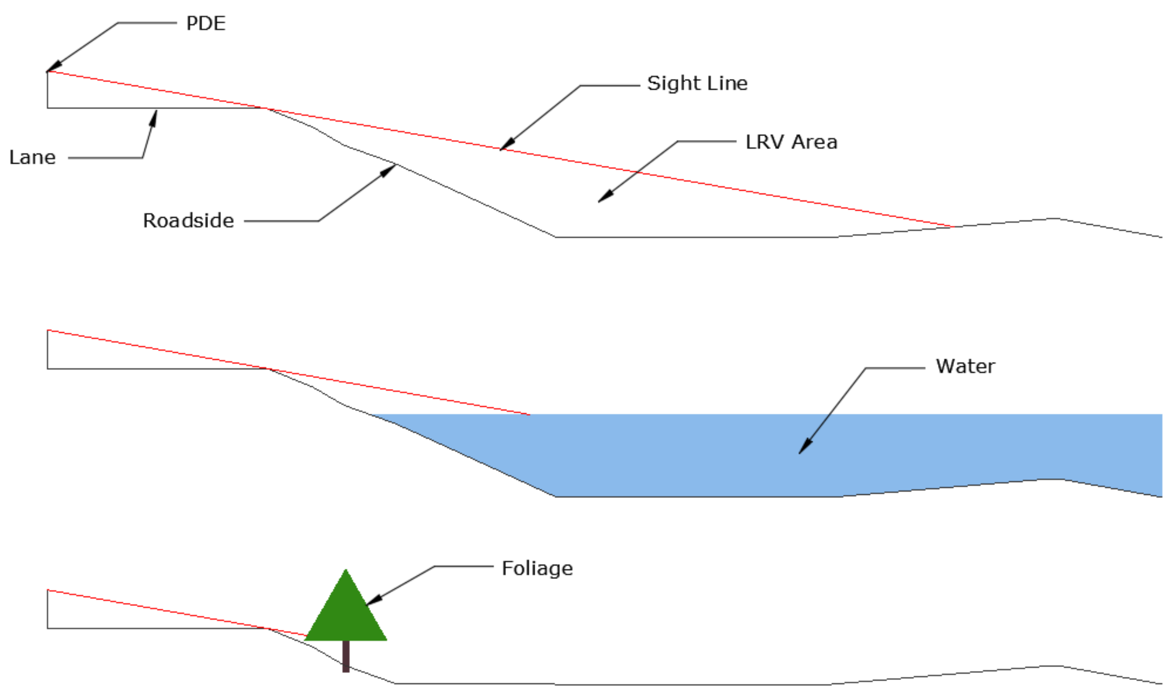
This research finds that, due to many factors, run-off-road collisions are easily concealable, and the number of these locations is significant. Not only are lives being lost unnecessarily, but the cost to communities is substantial.

When locations with limited roadside visibility are charted, search parties are provided a strategic vantage point for rescue and recovery, cost estimates of future roadside safety treatments capable of collision detection are more accurately derived, and first responders are enabled to act in a more efficient manner. This approach can help mitigate the severity of roadside collisions, save lives, protect the environment, and significantly reduce the cost of ROR collisions to communities.

Introduction

Run-off-road (ROR) collisions are being concealed from the view of passing drivers along the roadway due to factors such as steep roadside slopes, bodies of water, and dense foliage creating an area of limited roadside visibility (LRV) to a passing driver's eye (PDE) (Fig.1) .[1]

Figure 1. Cross Section of LRV Area Created by Steep Roadside Slopes, Bodies of Water, and Foliage



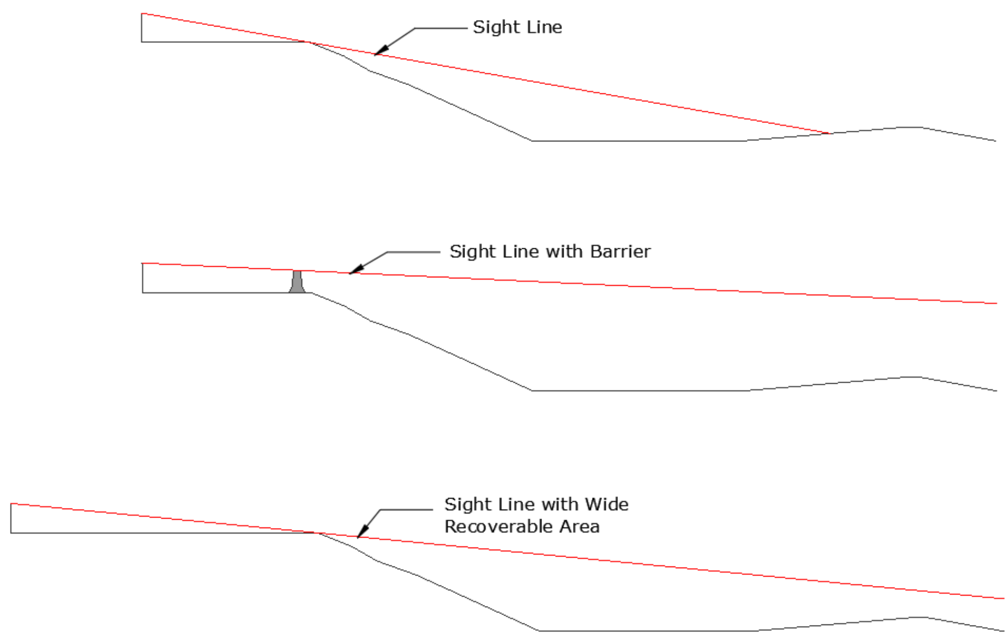
Occupants involved in concealed ROR collisions may be trapped in their vehicle, unable to reach their phones, and unable to be tracked.[2] As a result, they may be left unfound and may perish due to complications such as dehydration or hypothermia.

Roadside locations capable of concealing ROR collisions are not always immediately obvious, and therefore may be unknown or overlooked during a search. Additionally, costly search efforts may be misdirected, and unfound vehicles can be left contaminating the environment for decades.[3]

Although steep roadside embankments can warrant shielding by a roadside barrier, LRV of ROR collisions may not have been a consideration during the design and decision of the barrier's placement. As well, it may not be considered safer to occupants of impinging vehicles to extend or install barriers in certain LRV locations, nor be within designer's budgets to do so.

Some safety elements such as roadside barriers and wide recoverable areas for errant vehicles can further limit roadside visibility of where ROR collisions may occur (Fig. 2).

Figure 2. Roadside Barrier and Wide Recoverable Area Further Limiting Roadside Visibility of PDE with Height Equal to 1.05 m and Height of Fill of Roadside Equal to 3.5 m



Safety concepts such as the 'clear zone' and 'forgiving roadside' can assist errant vehicles in recovering, however, it may not always be practical or cost-effective to comply with their recommendations. Additionally, as seen in Figure 2, roadside visibility of a PDE over non-recoverable and critical slopes may decrease as the distance from the PDE to the outside edge of a recoverable slope widens.

Upon realizing I had unwittingly driven past an ROR collision which occurred in North Saanich in 2019, I wanted to see if there were any other roadside locations prone to this hazard in the district. I inspected a slope map of the area to find where roads intersected with slopes greater than 30%. From this map, I estimated that there may be three locations along the crash victim's route which may be able to conceal an ROR collision.

Indeed, the ROR collision occurred within one of these three locations, just a few metres from the edge of the Patricia Bay highway. The victim's vehicle was found weeks after the collision occurred and, tragically, both occupants had since perished.[4] Myself, along with my community, were mortified to know we had driven past them multiple times and, possibly, while they were still alive.

According to a traffic count done for this section of highway in 2021 by the BC Ministry of Transportation and Infrastructure, it was estimated to have a seasonal average annual daily traffic volume of 9,555 vehicles.[5] I was surprised that the collision remained concealed for so long, so close to the road, and in such a high-traffic location.

During a search for a potential ROR collision, no database of roadside locations capable of concealing them is available. Consequently, roadside searchers may be directed to look along routes where these locations are not present. Furthermore, nighttime searching conditions make identifying these locations extremely difficult. This can cause critical time to be lost during a search while the victims helplessly listen on to driver's passing by.

Objective

This study intends to develop a method by which we can approximate where locations with LRV capable of concealing an ROR collision (of specified dimensions) are present. For this study, I will focus on the effects of design elements and steep slopes on roadside visibility. I will analyze cross sections of a roadside location to determine whether the height and width of my 'vehicle of search' (VOS) can be concealed between the surface of the roadside and a passing driver's sight line.

These cross sections will then be aligned and converted into a three-dimensional surface model of the roadside to aid in determining whether the width and length of our VOS can also be concealed.

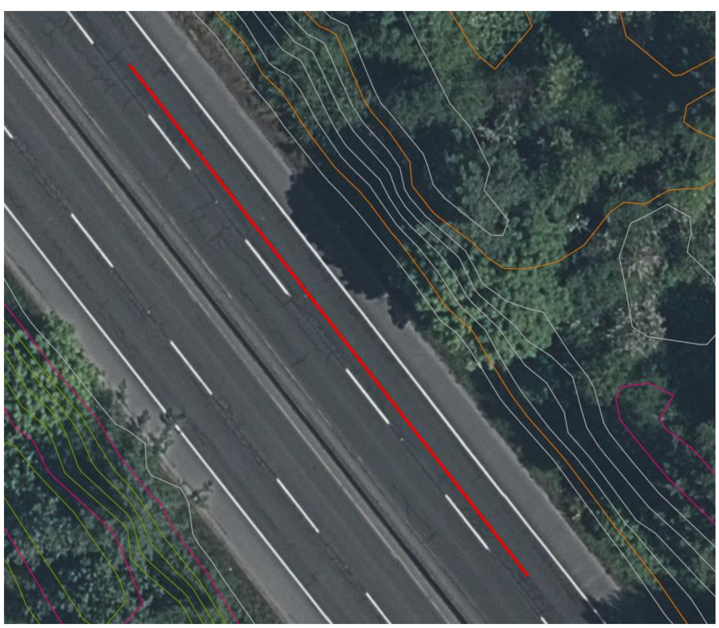
A severity rating for these locations can then be obtained to inform transportation authorities and designers when considering and prioritizing appropriate countermeasures for mitigation. Finally, roadside locations capable of concealing ROR collisions can then be compiled into a usable map for use during a search.

Method

Selecting Roadside Location for LRV Analysis

First, I select a section of roadside where I suspect LRV may be present and where my VOS of specified height, width, and length may be concealable. I then choose a path along the outer travelled lane where I expect a passing driver's eye (PDE) to be (Fig. 3).

Figure 3. Expected Path of Travel of PDE Along Outer Travelled Lane



Determining Angle of Sight of PDE for Cross Section

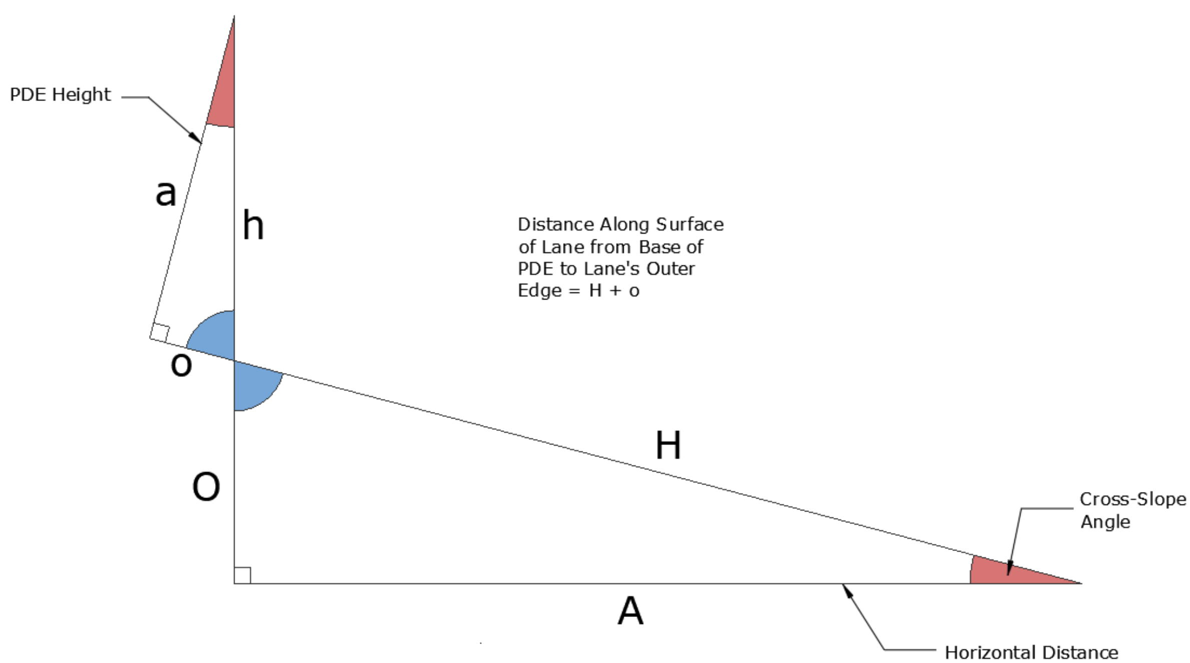
Once I've chosen an expected path of travel for my PDE, I need to determine the angle of sight (AOS) of my PDE for each cross section. For this, I measure the horizontal distance from a coordinate along my path of travel to the lane's outer edge.

From this, I need to determine the distance along the lane's surface from my PDE to the lane's outer edge while considering any cross-slope present in the lane. I must now, also, set the height (off the lane's surface and perpendicular to it) at which I expect my PDE to be.

To begin finding this distance, I calculate the hypotenuse of a right-angled triangle whose adjacent side is set equal to my horizontal distance, and whose angle between that hypotenuse and adjacent side are set equal to the lane's cross-slope.

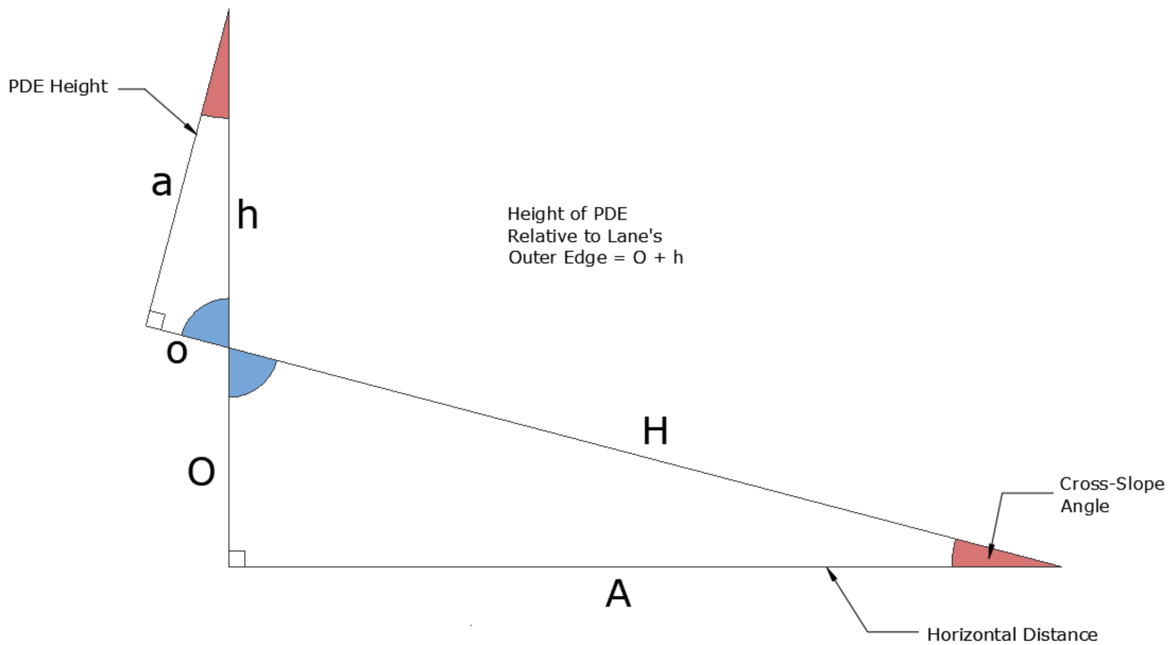
I observe that a similar right triangle can be drawn whose angles are congruent with the previous triangle. Using the Pythagorean theorem, I can determine the opposite side of this triangle and add it to the hypotenuse of my previous triangle to obtain the distance along the lane's surface between the base of my PDE and the outer edge of the lane (Fig. 4).

Figure 4. Determining Distance Along Lane's Surface from Base of PDE to Lane's Outer Edge



If I add the opposite side of my first triangle to the hypotenuse of my second triangle, this will give me the height of my PDE relative to the outer edge of the lane (Fig. 5).

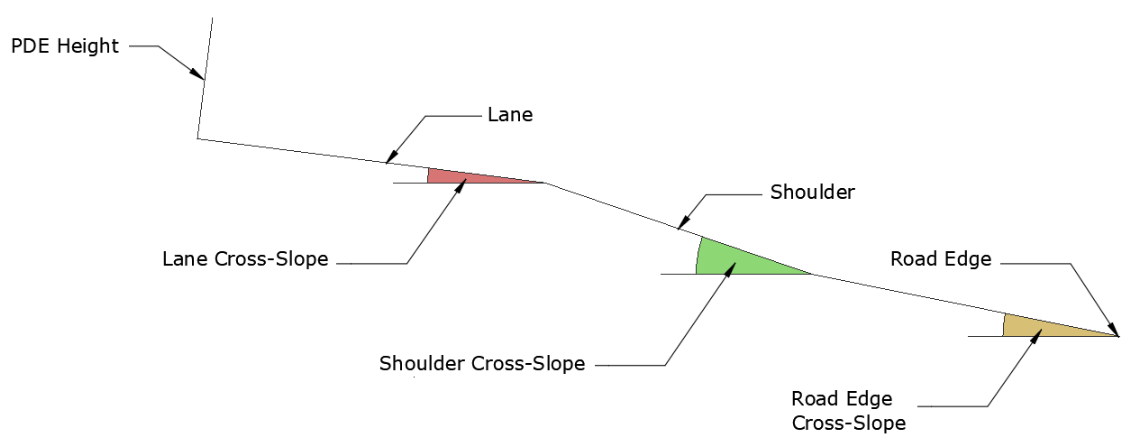
Figure 5. Height of PDE Relative to Lane's Outer Edge



Next, I measure the horizontal distance between the lane's outer edge and the outer edge of the road's shoulder. I repeat the previous procedure to determine the distance along the shoulder's surface between the lane's outer edge and the shoulder's outer edge, accounting for any cross-slope therein.

I then measure the horizontal distance between the shoulder's outer edge and the outer edge of the road and account for any cross-slope therein. I connect these three distances (with their attributed cross-slopes and set PDE height) to form a cross-sectional profile of the roadway. From this, I can determine the actual height and distance of my PDE relative to the road's outer edge (Fig. 6).

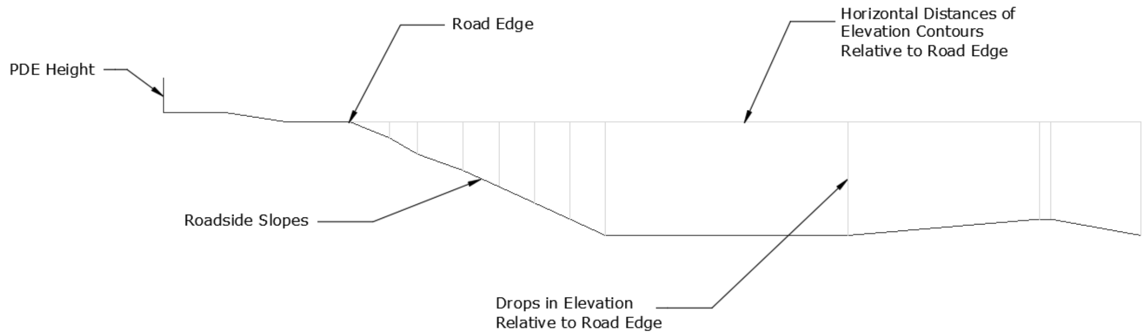
Figure 6. Cross Sectional Profile of Road with PDE Height and Distance Relative to Road Edge



If any other design elements (such as roadside barriers or curbs) are present, I add the coordinates of their vertices where they are in relation to the edge of the road into my cross section.

Next, I measure the horizontal distances from the road's edge to the adjacent contour lines and apply their drops in elevation to form a two-dimensional profile of the roadside (Fig. 7).

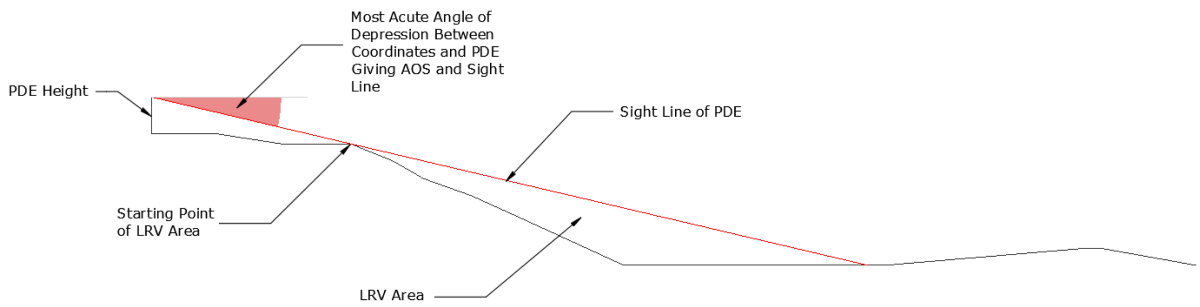
Figure 7. Roadside Profile of Horizontal Distances and Elevations of Contour Lines from Road's Edge



To find the AOS of my PDE for this cross section, as well as the coordinates at which my LRV area begins, I measure the angles of depression between the coordinates of my PDE and all adjacent coordinates down to the toe of the roadside slope.

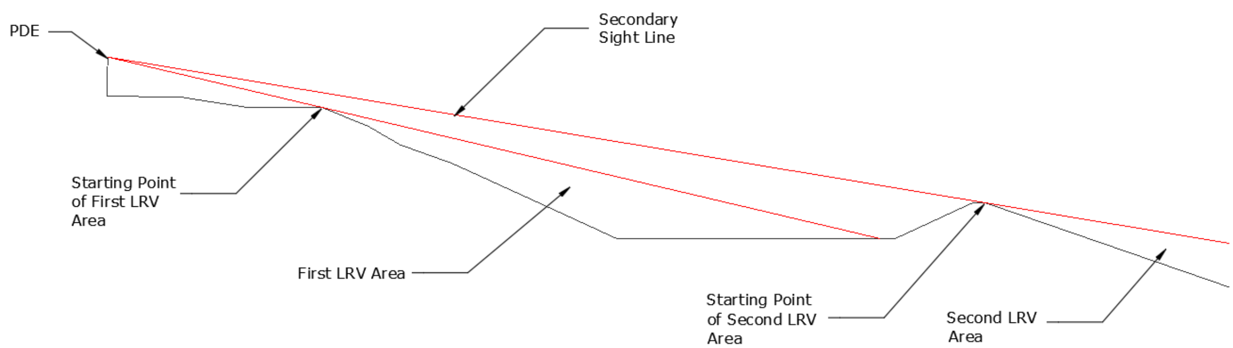
The coordinate at which the angle of depression between it and my PDE is most acute determines the starting point of my LRV area. From the angle of depression between this coordinate and my PDE, I obtain the AOS and sight line of my PDE (Fig. 8).

Figure 8. Angle of Sight and PDE Sight Line Forming LRV Area



If there are any other coordinates beyond this sight line where the subsequent coordinate's angle of depression is less acute than it, this may be the starting point of a secondary LRV area (Fig. 9).

Figure 9. Secondary Area of LRV Created by Next Coordinate's Angle of Depression Being Less Acute



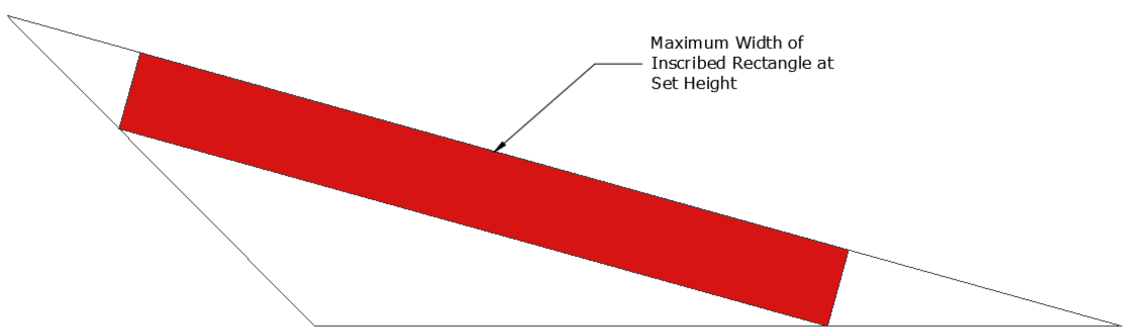
Once I have determined whether LRV areas are created underneath the sight lines in my cross section, I am ready to start calculating whether the height and width of my VOS is concealable within them.

Determining Maximum Width of Inscribed Rectangle at VOS Height

For each cross section, I want to determine whether the height and width of my VOS can be concealed within the LRV area between the sight line of my PDE and the coordinates underneath it.

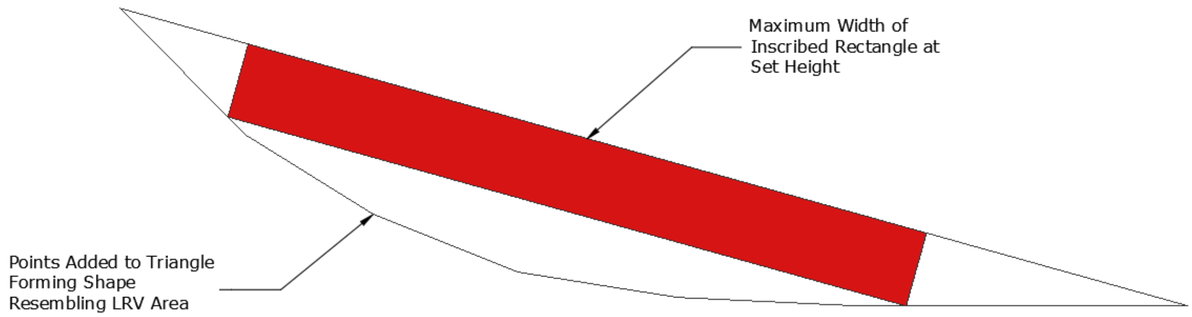
For this, I build from the assumption that the maximum width of a rectangle at a given height inscribed into an obtuse scalene triangle occurs when the rectangle's width runs parallel to the triangle's longest side (Fig. 10).

Figure 10. Maximizing Width of Rectangle at Specified Height Inscribed into Obtuse Scalene Triangle



We can see that if the rectangle grew any wider, it would no longer be inscribed, and thus, the rectangle would partially be outside the area of the triangle. If I continue adding points to my triangle, I get a shape which resembles the cross section of my LRV area, and the same logic applies; if the rectangle grew any wider, it would partially be outside my LRV area and thus within view of my PDE (Fig. 11).

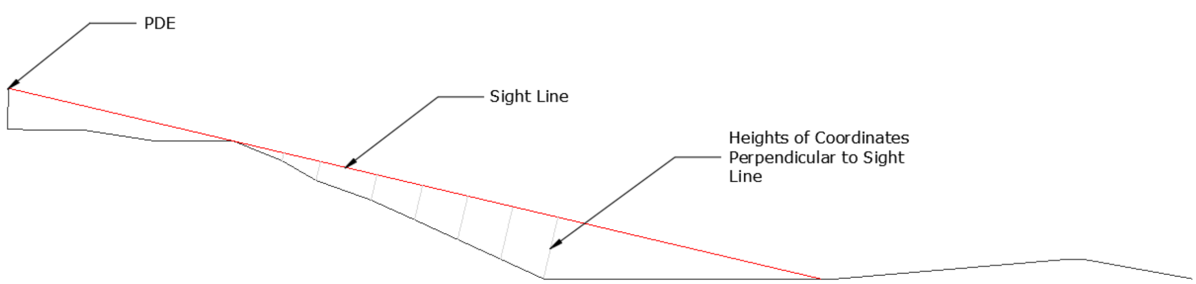
Figure 11. Points Added to Triangle Creating Shape Resembling Cross Section of LRV Area



Therefore, if I can determine the maximum width of a rectangle at my VOS height which can be inscribed into the cross section of my LRV area and it is equal to or greater than that of my VOS width, I can assume that my VOS height and width may be concealed from my PDE at that point along the path of travel.

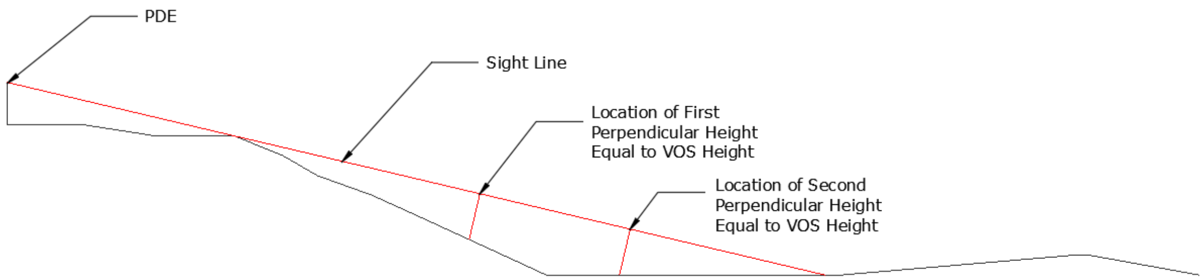
To begin finding the maximum width of an inscribed rectangle at my VOS height, I perform a rotation matrix of the coordinates underneath my sight line and subtract my AOS from them. From this calculation, I get the heights of my coordinates perpendicular to my sight line (Fig. 12).

Figure 12. Heights of Coordinates Underneath and Perpendicular to Sight Line



I can then calculate where my VOS height begins and ends being inscribable by interpolating through all the perpendicular height values between (and at) the coordinates underneath my sight line and find where they are equal to my VOS height (Fig. 13).

Figure 13. Locations Where Heights Underneath and Perpendicular to Sight line Equal VOS Height



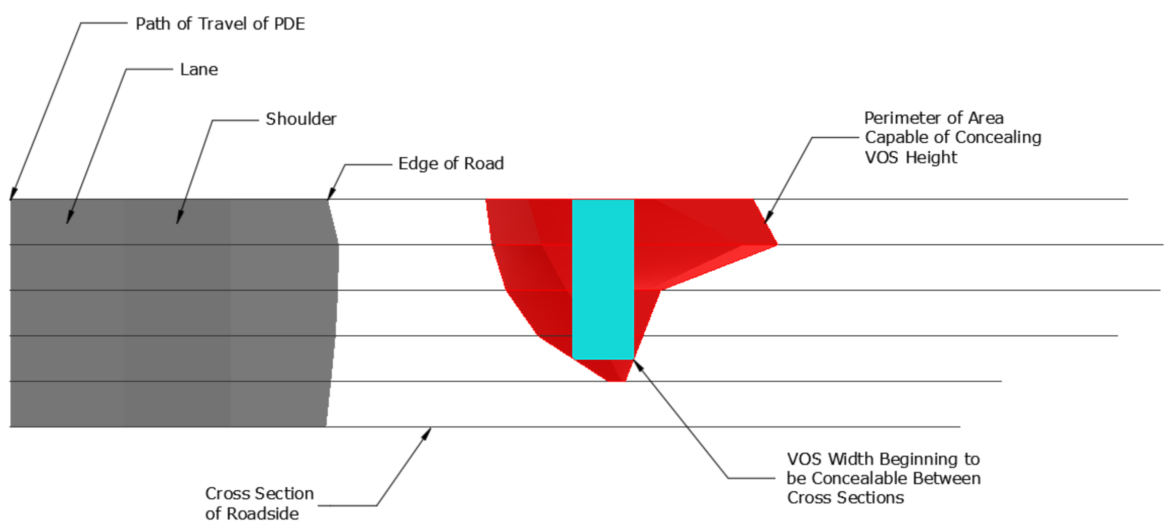
Once I have the distances along my sight line where the perpendicular heights underneath it are equal to my VOS height, I can subtract the first distance from the second distance to obtain the maximum inscribable width of a rectangle at my VOS height for this cross section.

Determining Maximum Length of Inscribed Rectangle at VOS Width

After I've analyzed each cross section, I can align them to form a three-dimensional model of the LRV area to determine whether my VOS width and length may be concealable within the perimeter capable of concealing my VOS height.

Often, there are cases (at the beginning and end of my three-dimensional LRV area) where the maximum width of my inscribed VOS height for one cross section is less than my VOS width, and the following cross section's maximum width is greater than my VOS width. This indicates that the location along the roadside at which my VOS width begins to be concealable lies somewhere between these two cross sections. For this reason, I include all cross sections capable of concealing my VOS height in order to obtain a more precise location of where my VOS width begins to be concealable (Fig. 14).

Figure 14. Overhead View of VOS Width Beginning to be Concealable Between Cross Sections



In this instance, I interpolate through the maximum width values between these two cross sections and determine where they are equal to my VOS width. From this location, I can check whether the length of my VOS also fits within the perimeter of the area capable of concealing my VOS height.

It may be the case that my VOS is not concealable when parallel to the roadway but may be concealable when rotated by some angle. For this reason, it is important to check the concealability of my VOS width and length within the perimeter of the area capable of concealing my VOS height at different angles.

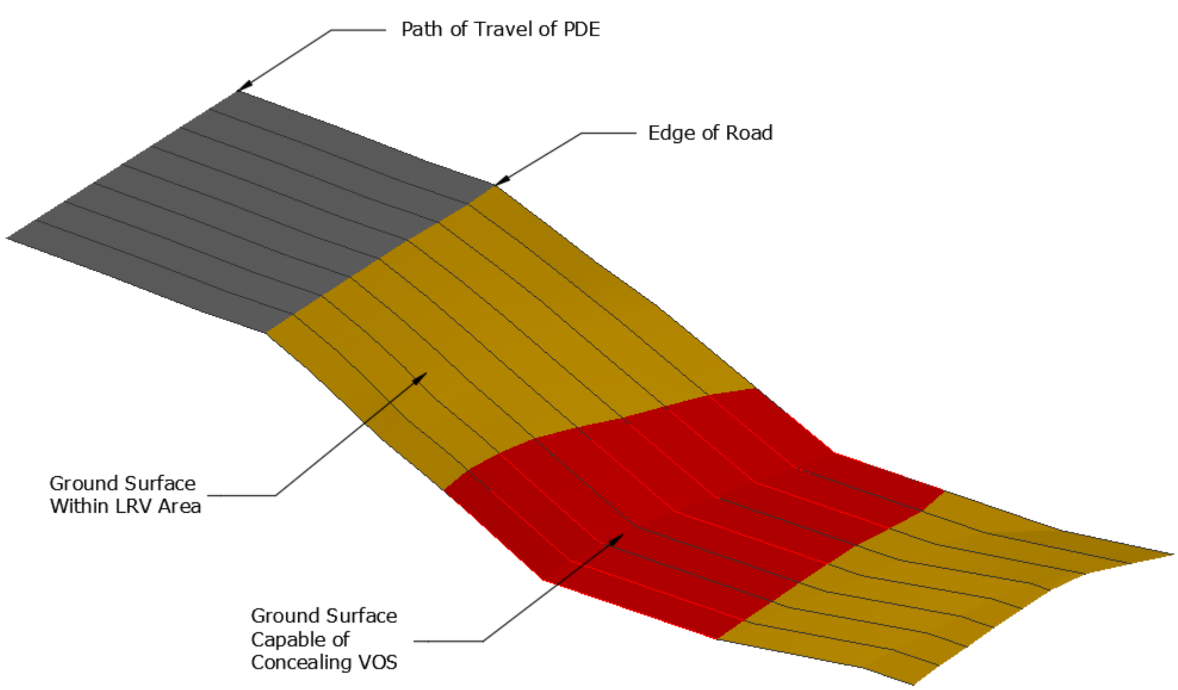
If the maximum length of a rectangle at my VOS width which can be inscribed within the perimeter of the area capable of concealing my VOS height is equal to or greater than my VOS length, I can assume that my VOS is concealable within this roadside location's LRV area from the view of my PDE.

Determining Surface Area of Ground Within LRV Area and Ground Capable of Concealing VOS

Now that I have the locations where my VOS is concealable, I can measure the surface area of the ground between these coordinates and the entire ground within the LRV area.

For this, I place the cross sections at the distance apart from which they were taken and connect them via newly drawn elevation contours. I then measure the surface area of each quadrilateral they create and sum them up to obtain the total surface area of ground within the LRV area and the total surface area of ground capable of concealing my VOS (Fig. 15).

Figure 15. Ground Surface Within LRV Area and Ground Surface Capable of Concealing VOS



The surface area of the ground capable of concealing my VOS can be divided by the total surface area of ground within the LRV area to approximate the percentage of the unseen roadside capable of concealing my VOS. This percentage, along with the total surface area capable of concealing my VOS, can be used to rate the severity of LRV for this roadside location.

Case Study

For this study, I chose to analyze a 50-metre section of roadside on the Patricia Bay highway where the concealed ROR collision occurred in North Saanich, BC. With the aid of CAD software, I imported a file of the elevation contour lines for this area and overlayed satellite imagery onto it. I then drew a line down the outer travelled lane (approximately two thirds of the lane width from the lane's outer edge) for the expected path of travel of my PDE, and a line down the inner and outer edge of the road's shoulder.

I then measured the horizontal distances from (and perpendicular to) my path of travel to the beginning of the shoulder, to the outside edge of the shoulder, to the roadside edge, and to the adjacent elevation contour lines. I assumed the lane to have cross-slope of 2%, the shoulder to have a cross-slope of 4%, and the region between the shoulder's outer edge and the edge of the roadside to have a cross slope of 0%. I added the drops in elevation for my contour lines and thus, using the previously mentioned method, I drew cross sections of the roadside for every metre and obtained the AOS of my PDE for each one.

Although research indicates that more than 90% of all driver's eye heights exceed 1.08 metres,[6] as a matter of precaution, I chose 1.05 metres (approximately one inch lower) for the height of my PDE to include driver's having a lower eye height, and to account for any shifting in driver positions. It is noteworthy that while many truck, bus, and double-decker bus drivers (having an eye height greater than 1.08m) drove past the victims in North Saanich, the victims remained undetected for weeks.

Results

I selected my VOS height (1.384m), width (1.750m), and length (4.470m) to match the approximate dimensions of the vehicle involved in the North Saanich ROR collision. I automated the process to determine the maximum width of an inscribed rectangle at my VOS height using computer code. I then drew these heights along my sight line into each cross section and highlighted the space between them in red (Fig. 17 & 18).

Figure 17. Cross Sections from Metres 0-25 Showing Maximum Width of Area Capable of Concealing VOS Height

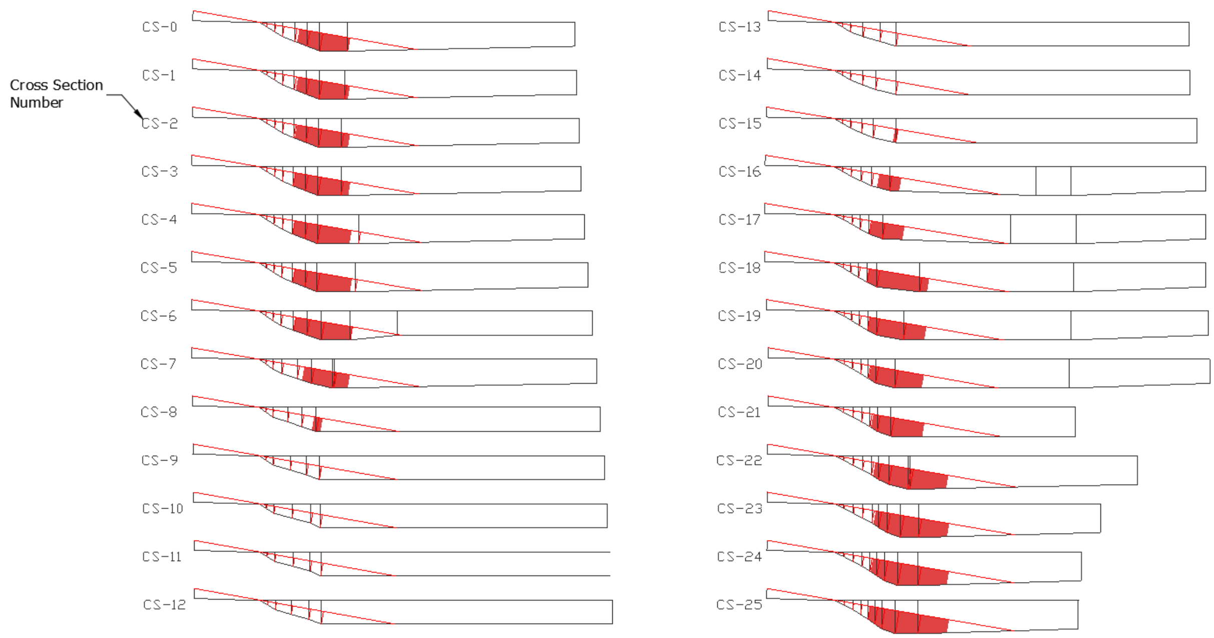
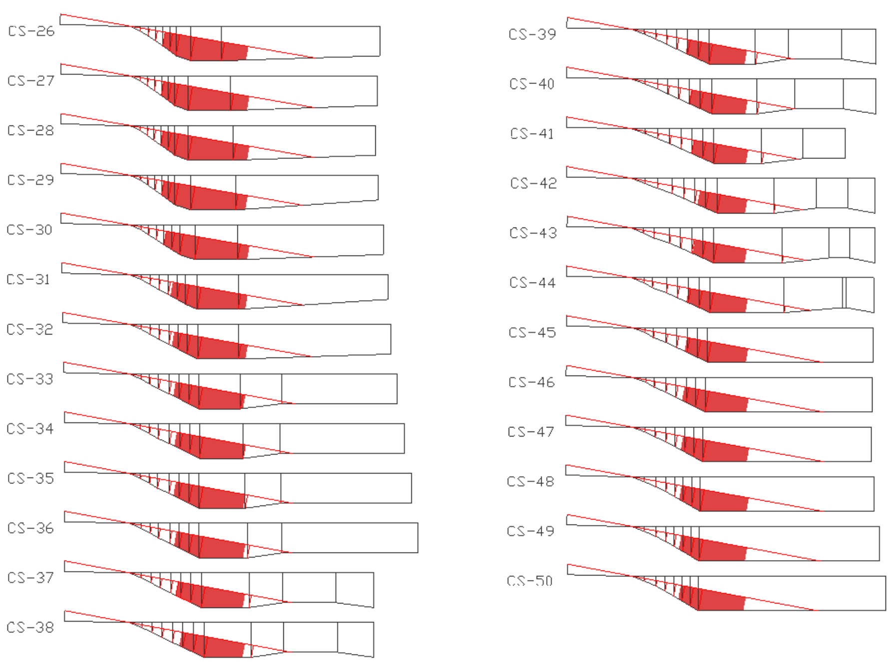


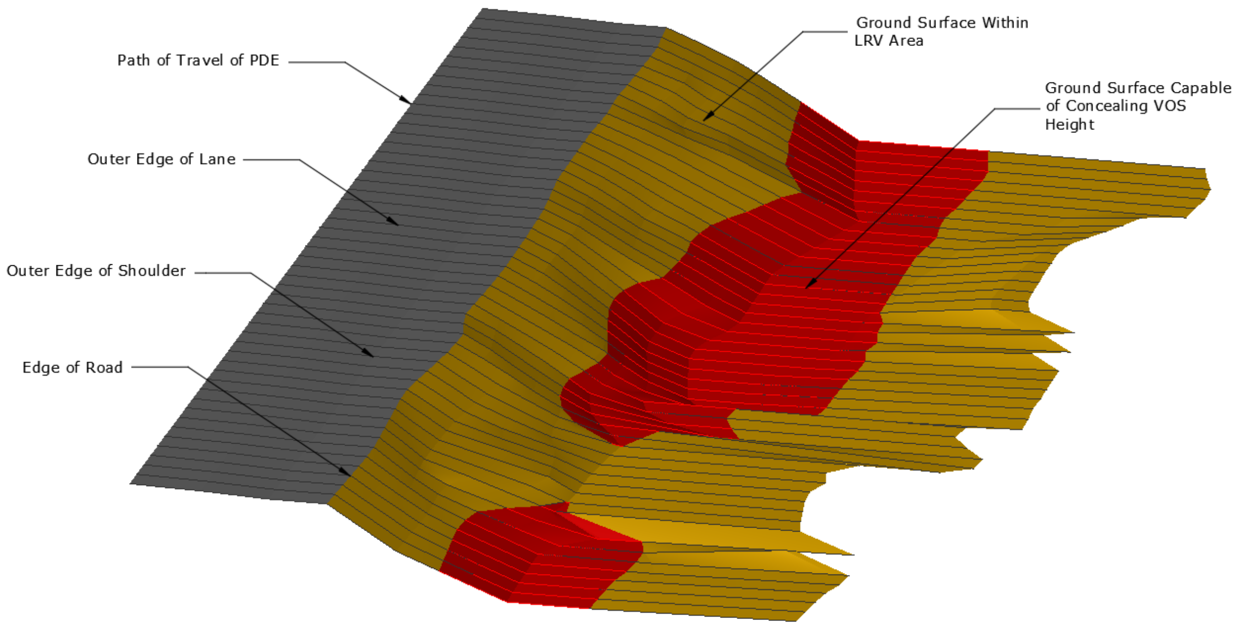
Figure 18. Cross Sections from Metres 26-50 Showing Maximum Width of Area Capable of Concealing VOS Height



After analyzing each cross section for this roadside location, I could see that the length of road the cross sections capable of concealing my VOS height and width cover exceeded the length of my VOS. From this, I was able to predetermine that my VOS was concealable.

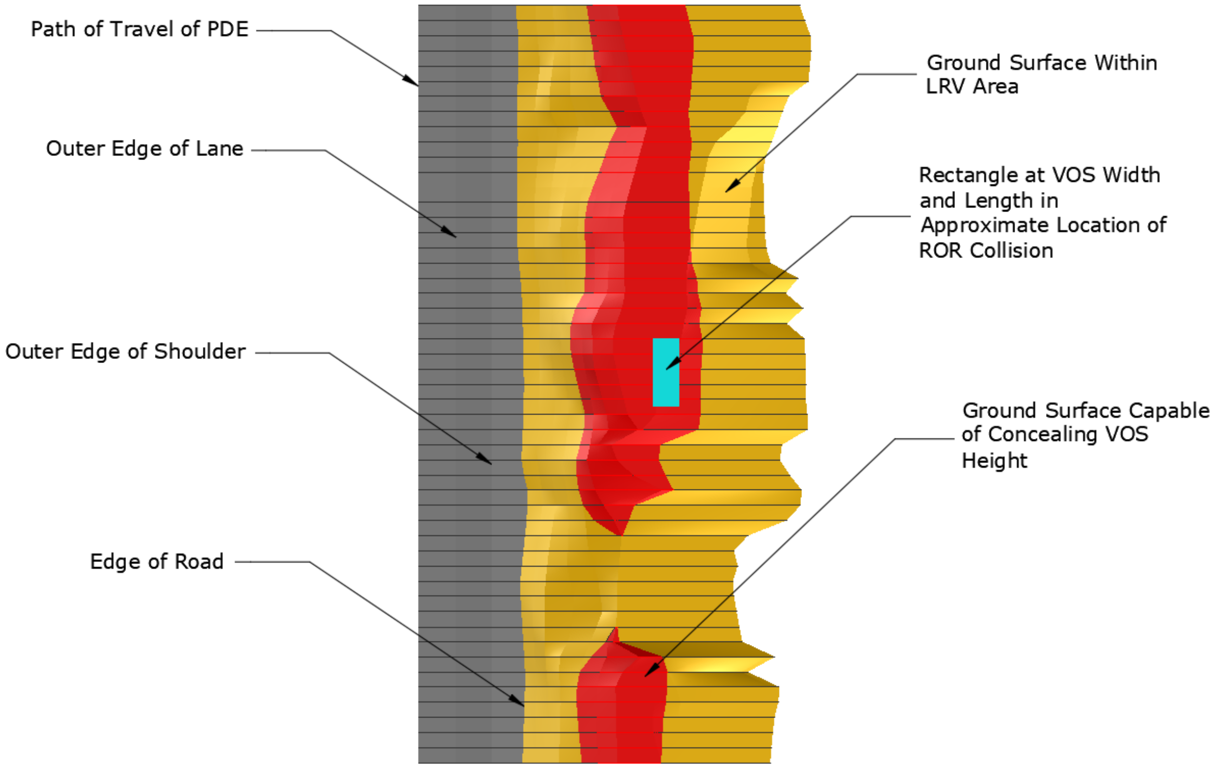
I then aligned my cross sections, spaced them one metre apart, converted them into a mesh surface, and coloured the ground surface capable of concealing my VOS height in red, and the rest of the ground surface within the LRV area in yellow (Fig. 19).

Figure 19. Ground Surface Within LRV Area and Ground Surface Capable of Concealing VOS Height



From an overhead view approximately perpendicular to my sight lines, I overlayed a rectangle having a width and length equal to my VOS to manually determine if they were concealable within the perimeter of the ground surface capable of concealing my VOS height. Though, it was apparent that the extent of the perimeter far exceeded that of my VOS (Fig. 20).

Figure 20. Rectangle at VOS Width and Length Overlayed into Surface with VOS Height Concealability



From my mesh surface, I obtained the surface area of ground capable of concealing my VOS height and found that it was equal to 282.657 m^2. I then divided this surface area by the total surface area of ground within the LRV area of 893.575 m^2 to get the percentage of ground capable of concealing my VOS height relative to the ground surface within my LRV area. This was determined to be 31.632% of the ground surface within my LRV area.

Discussion

As seen from the results of this study, my VOS was easily concealable from a PDE height of 1.05m for this roadside location. Though dense foliage in the area may have been a factor contributing to the VOS remaining concealed from passing drivers with a higher PDE height, due to the depth of the LRV area and the location at which the vehicle came to rest (between cross sections 23-28 approximately), it is likely that the VOS would have remained out of sight from most drivers.

It is also noteworthy that this was a location unexpected by the community to be able to conceal a vehicle, which may have led to this location going unsearched. The dense foliage present may also have given a false perception of the ground surface being higher than it was, thus causing passersby to dismiss it as unable to conceal an ROR collision. However, there are many roadside locations with much more severe LRV.

Had locations with LRV been documented for use by searchers, the victims may have been found alive, emergency response resources and search efforts could have been allocated where they were needed elsewhere, and the cost of such misdirected search efforts could have saved.

Other Considerations

Nighttime driving conditions cause a PDE to only be able to see what their vehicle's headlights can shine on. Therefore, if I wanted to account for nighttime visibility of the roadside, I would use the height of the passing driver's headlights for my PDE height.

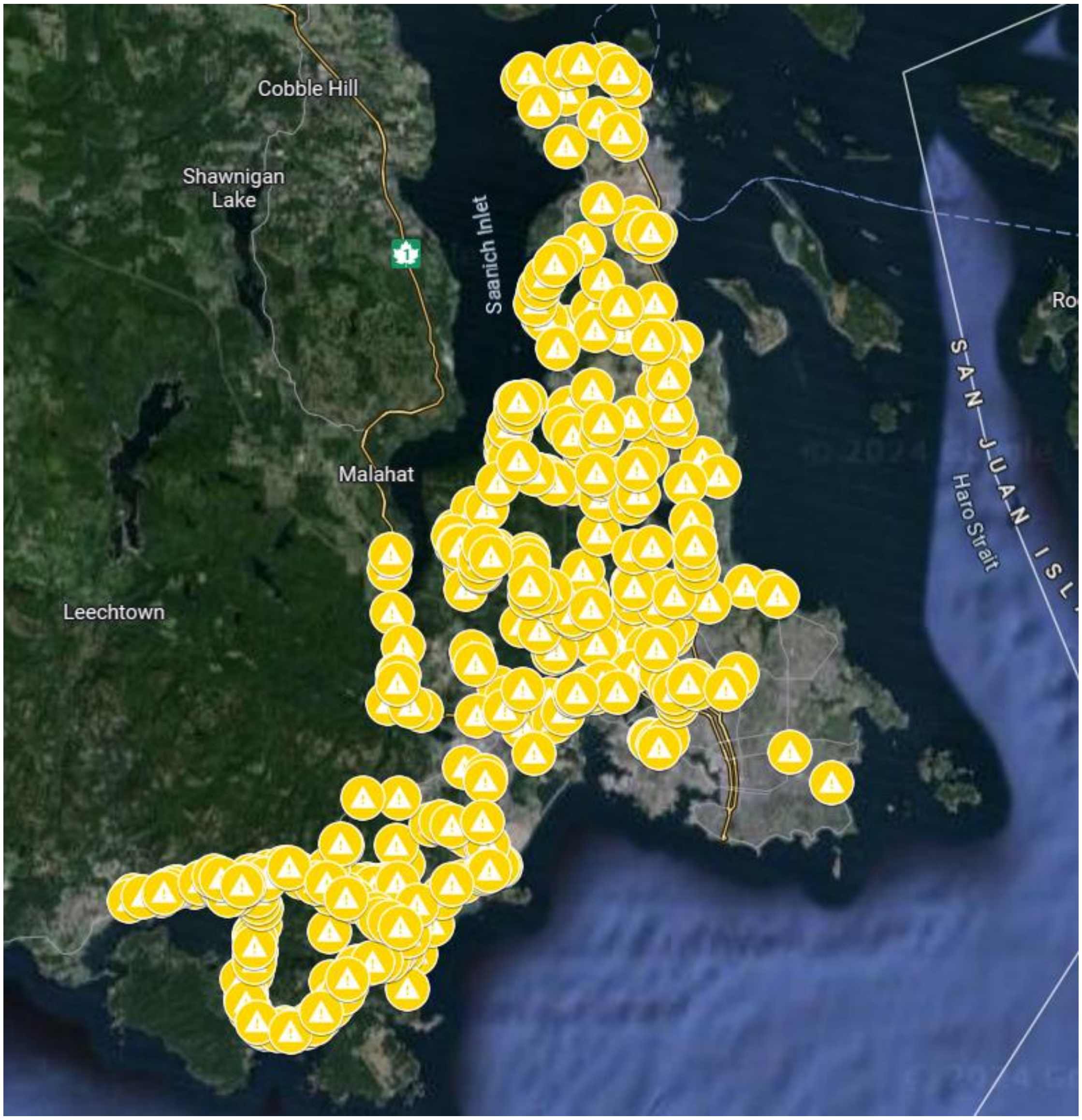
With active transportation and economic vehicles growing in popularity, the average VOS size (e-bikes, e-scooters, etc.) may decrease. In turn, this would cause the number of LRV locations capable of concealing victims to increase.

There may be instances, such as on roads with no shoulder, where the bottom of the passenger window of a vehicle becomes the point at which the LRV area begins. To account for this possibility, I would include the height of the vehicle's passenger door off the lane as well as it's distance from the PDE when determining the most acute angle of depression between my PDE and the adjacent coordinates for my cross sections.

According to chapter 7.1.1 of the 2017 edition of the Transportation Association of Canada's Geometric Design Guide for Canadian Roads, "Canadian Research shows that collisions with fixed objects account for 30% of all fatal collisions in Canada and the United States. [7] The same research also points out that an additional 10% of road fatalities are attributable to non-collision rollovers caused by loose shoulder material, a sudden change in roadside slope, or similar roadside factors. These statistics indicate that the roadside environment and its design have a vital role to play in improving road safety".

Although I was unable to obtain statistics regarding how many of these fatalities were attributable to LRV and how many may have been preventable via LRV awareness, I began compiling a map of locations in and around the Capital Regional District (CRD) of British Columbia where slopes equal to or greater than 30% intersect with the roadway or are otherwise suspected of being affected by LRV due to nearby water, etc. There is much more road to be inspected within the region, however, so far, I have found around 400 locations which I suspect may be affected by LRV (Fig. 21).[8] I anticipate thousands more to be found across Vancouver Island due to its steep terrain, abundant foliage, and proximity to water.

Figure 21. Locations Around the CRD Where Slopes Greater Than or Equal to 30% Intersect with the Road and/or are Suspected of Being Affected by LRV



Source: Google MyMaps

Future Research

Recommended future research on this topic includes determining the probability of an ROR collision occurring in LRV locations with the use of collision prediction and encroachment modules, determining the amount of an ROR collision which may be visible, and the creation of a dynamic map where a VOS size and PDE height are inputted by a searcher and the corresponding LRV locations capable of concealing them appear. Such a map could also display to a search party when LRV locations have been 'checked' during active searches.

Recommendations

It is recommended that an inventory of LRV locations be kept by transportation and emergency officials. Not only could this be used during searches, but it could also help to estimate the scope of future costs for roadside safety treatments capable of collision-detection or other mitigation strategies.

It is also recommended that encroachment and collision prediction modules be used in conjunction with LRV analysis to help determine the likelihood of a concealed ROR collision occurring within LRV areas capable of concealing them. Countermeasures taken at locations with LRV could be prioritized based on the risk determined by these assessments.

A cost-benefit analysis of different mitigation strategies could also help to determine the feasibility of such countermeasures.

As well, awareness of these locations should be raised to prevent victims of concealed ROR collisions from being overlooked during searches.

Conclusion

There are many roadside locations capable of concealing ROR collisions. However, for locations where it is not immediately obvious, it is helpful to have a method by which we can approximate their concealability. The analysis set forth in this paper can be used as the basis for the development of a tool for determining which ROR collisions can or cannot be concealed from a PDE in certain LRV locations.

A map of LRV locations could help prevent concealed ROR collision victims from being overlooked during a search. This could not only save their lives but save the expense of misplaced search efforts. Through the development of this initiative, we can mitigate the severity of ROR collisions when they occur and prevent this tragic scenario from taking place again.

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