Automated sight distance evaluation based on airborne topographical data for risk management along a linear infrastructure

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ABSTRACT
The sight distance from a given point of view can be evaluated using a digital elevation model (DEM) with most geographic information system (GIS) software. The Rockfall Hazard Rating System's decision sight distance evaluation could be carried out meter-by-meter along a transportation corridor using these programs. However, doing this over hundreds of kilometers would not be practical as it is very time consuming. We developed an algorithm and program to obtain sight distance values along a linear infrastructure efficiently. The geographical input data required are a DEM and a shape file of points located along the studied infrastructure. We applied our algorithm to a 260 km long section of the railroad linking Port-Cartier to Fermont to evaluate the sight distance every two meters and for both driving directions. From these, we extracted the sight distances along rock cuts and other sections where rockfalls could potentially reach the railroad. The results are compared to field measurements of the sight distance.

RÉSUMÉ
La distance de visibilité à partir d'un point de vue peut être évaluée à partir des modèles numériques de terrain (MNT) en utilisant des outils disponibles dans les programmes de type SIG. L'un des paramètres du *Rock Fall Hazard Rating System* est la distance de visibilité-décision. Il pourrait être évalué mètre par mètre en utilisant les outils disponibles, mais l'opération serait longue et fastidieuse. Nous avons développé un algorithme et un programme qui permet d'évaluer la distance de visibilité le long d'une infrastructure efficacement. Les données d'entrée nécessaires sont un MNT et un fichier vectoriel de points espacés régulièrement le long de l'infrastructure. Le programme a été appliqué à un tronçon de voie ferrée de 260 km dans les deux directions du trafic. À partir des valeurs retournées à chaque points le long du tronçon, les distances de visibilité moyennes, maximales, minimales et l'écart-type ont été extraites pour chacune des coupes de roc bordant la voie ferrée. Les résultats sont comparés à des mesures terrain, qui montrent que le programme fonctionne bien.

1 INTRODUCTION

Natural hazards impacting on transportation corridors can affect the users by direct impact on vehicles or by impact of the moving vehicle with deposited material (Fell et al. 2005, Nicolet et al. 2016). This second type of impact is dependent on the capacity of the user to see the danger in time to stop before impact or to avoid the danger. For this reason, the visibility distance or stopping distance is a parameter used in the *Rockfall Hazard Rating System* (Pierson et al. 2012). The logic is that if two rock slopes are similar in term of rock fall susceptibility, traffic density and speed limit, the probability for a rock fall to lead to a serious accident is higher for the slope with the shortest visibility distance.

The sight distance can be defined in different ways. For example, the stopping sight distance is the sum of the travelled distance during the perception and reaction time with the breaking distance (Association des Transports du Canada, 2011). This definition implies that the initial vehicle speed and deceleration capacity must be taken in account. In this paper, the sight distance is defined simply as the maximum distance at which a driver can see an object located on the infrastructure. This distance is measure along the infrastructure. It is not a straight line linking the observer and the obstacle. Moreover, no distance is added to account for the reaction of the vehicle operator.

This paper presents a numerical tool develop to estimate the sight distance along a linear infrastructure and its application to a 260-km long railroad. This evaluation was part of the Para*Chute* reasearch project (Cloutier et al. 2017a and b, and 2015; Noël et al. 2015). The aim of the Para*Chute* research project was to integrate a variety of technologies into a common approach to manage work prioritization and data related to slope stability over large areas. Thus, this numerical tool could be useful to every agency applying a systematic system to characterize rockfall hazard along a transportation corridor.

Some tools to measure sight distance from a specific view point are imbedded in GIS software (e.g. ArcGIS). However, they do not allow for their use along a linear infrastructure easily, which is why we developed this tool. The paper starts with the description of the algorithm used for the computation of the sight distance along a

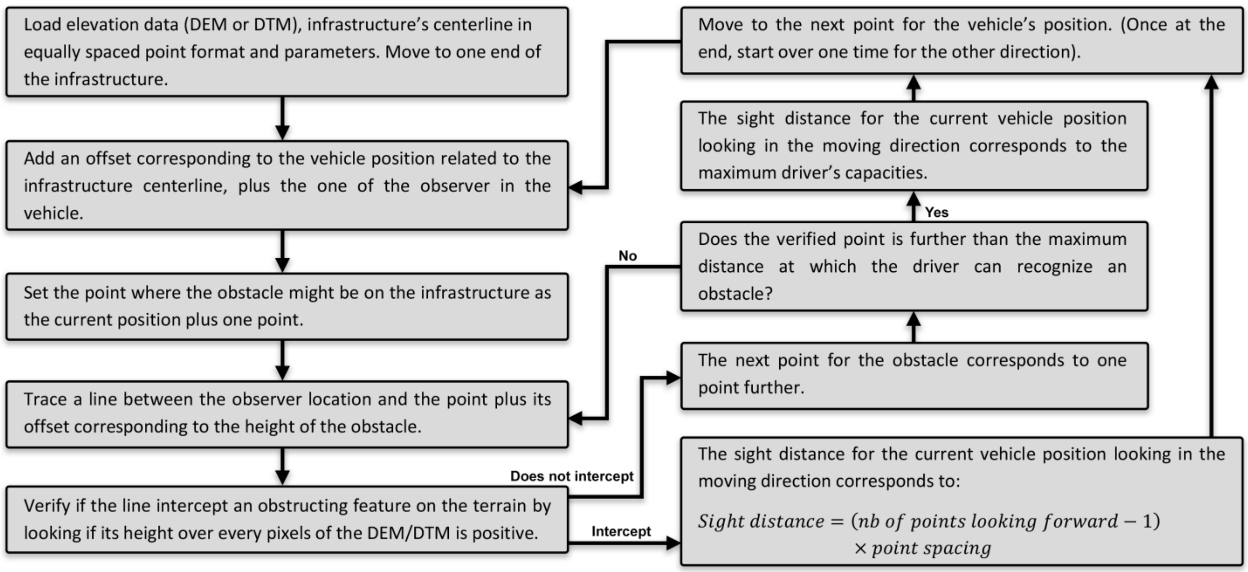

Figure 1. Flowchart presenting the steps followed by the algorithm to evaluate the sight distance along a transportation corridor.

transportation corridor and then, explains how it was applied to evaluate and assign a sight distance to specific rock cuts. Field validation was conducted and is presented. This methodology is suited to compare rock cuts relatively, but might need more validation before it is adequate to obtain absolute sight distances.

2 METHODOLOGY

2.1 Algorithm

The numerical tool, which has been developed in MatLab, is illustrated in the flow chart of Figure 1. The inputs are:

- a DEM (we used a 1 m² pixels derived from an airborne lidar survey);
- a point shape file, representing the transportation corridor (we transformed the centerline of the railway to points spaced every two meters);
- the height of the observer;
- the height of the obstacle;
- horizontal and vertical angles of the field of vision (we used 150° and 65° (45° upward and 20° downward);
- a threshold, in meters, representing the maximum tested distance.

As the infrastructure is represented by an ordered list of points, the algorithm starts by locating the observer at one end. From this point, it creates a vector to the next point and test to see if it intercepts the DEM. If it does not, it tests by tracing a vector to next point, and so on, until the vector intercepts the DEM. Then, the previous point is considered to be the furthest the observer can see. The distance is computed not as a straight line, but as the sum of the points times their spacing. Thus, the distance that is saved for the point representing the observer is the distance along the infrastructure. This distance represents the distance available for breaking. A threshold is set for the maximum distance tested by the algorithm. In our study we used one kilometre.

Once the algorithm computed the maximum sight distance for all points representing the infrastructure, it starts over again, but starting at the other end. The output is a table (.csv) with the coordinates of each point and the computed sight distances in both directions.

Tunnels are a special case, as they do not exist in the DEM. The sight distance in a tunnel will be of zero meter. This algorithm is not suited to evaluate the sight distance near tunnels.

2.2 Evaluation of sight distance along rock cuts

The objective of our study was to evaluate the sight distance associated with particular rock slopes. In order to obtain these values, we switched the observer and the obstacle. In the inputs of the software, the "rock blocking the railway" becomes the observer. When doing so, the output sight distance associated to a particular point represents the maximum distance from which this point is seen (Figure 2). The height of the observer inputted in the software to compute the sight distances was 0.5 m, to represent a rock of 0.5 m in diameter and the height of the obstacle was 4 m, to represent the height of the train operator.

All natural rock slopes and rock cuts located along the railroad were inventoried in this study, so the location (and mileage) of their extremities are known. With this information in hand, statistics are computed for points located along rock slopes. Average, standard deviation, maximum and minimum sight distances are computed for each portion of the railroad located along a rock cut or a natural rock slopes. These values are then incorporated in the rock slope data base.

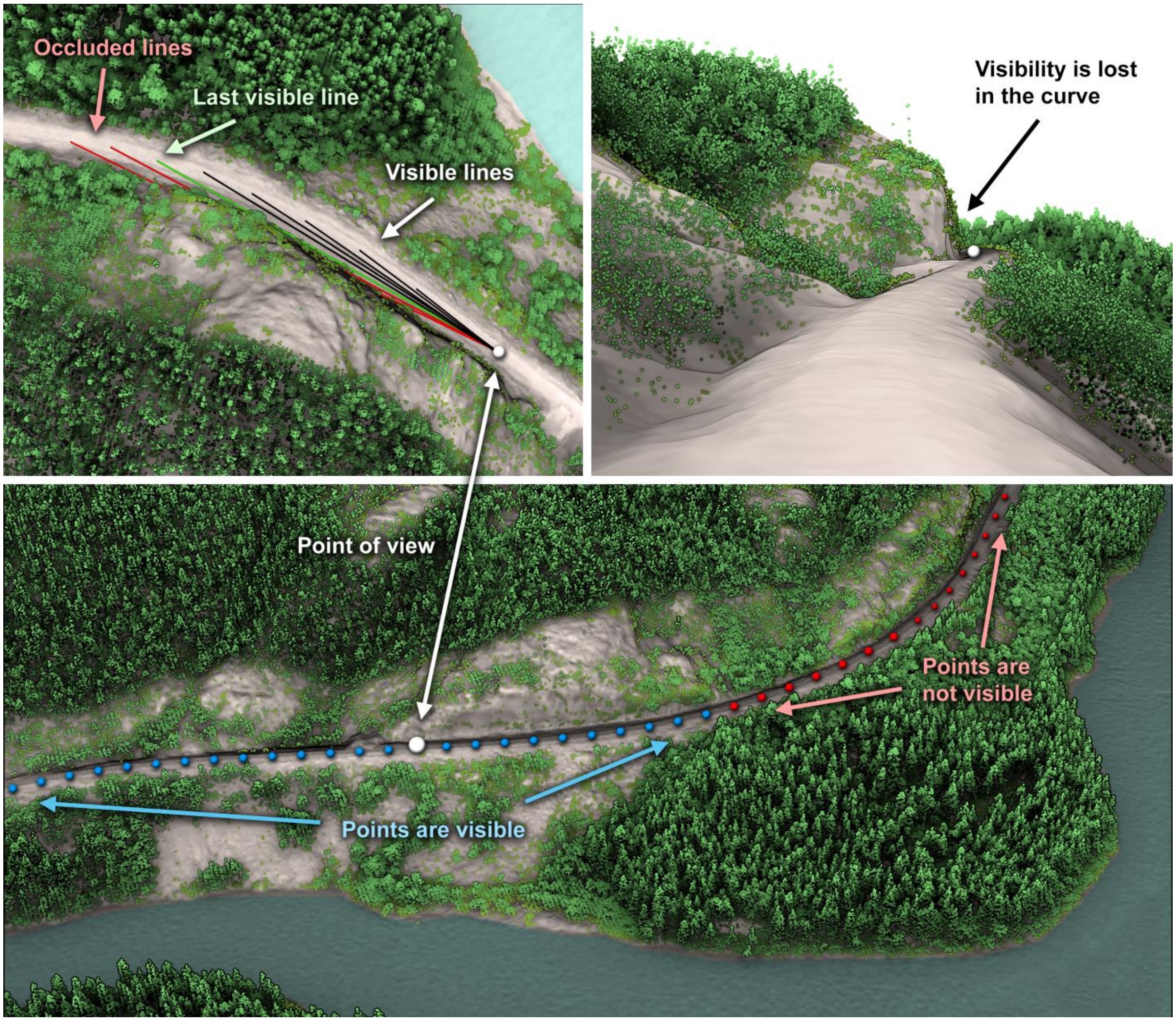

Figure 2. Illustration of the algorithm seen on a DEM. To evaluate the sight distance at locations where rock falls can occur, the rock is supposed to be the observer.

2.3 Field evaluation of the sight distance

For some rock slopes, the sight distance was evaluated in the field. One person, representing the “rock”, would stay in place in a squat position. Another person, in a vehicle on rail, would travel away from the “rock” until the furthest distance at which the “rock” can see the flashing light located 3.5 m high on the vehicle is reached. Both person saved their position using a handheld GPS and the distance in a straight line between them is measured with a laser device. It was noted if the sight was blocked by vegetation, by vegetation growing on a rock slope, or by the rock slope itself. This operation is repeated at different points along a rock slope. The number of measurements per rock slope varied according to the available time and other characterization work going on. The sight distances along the infrastructure were computed from the GPS locations and the centerline of the railroad in GIS.

3 RESULTS

The computed sight distance obtained numerically for a train travelling south and for a train travelling north along a short part of the railroad are illustrated in Figures 3a and b, respectively. The computed average sight distance along the rock slopes in this sector and their standard deviation are also shown. An histogram of the average sight distances computed for 396 rock slopes located along this railroad are presented in Figure 4. The minimum average sight distance compute is 85 m, the maximum is 1000 m, which was the maximum threshold imposed. The impact of the railroad curves on the sight distance are highlighted from this type of representation (Figure 3). The analysis of this map show that the results obtained with the program are adequate.

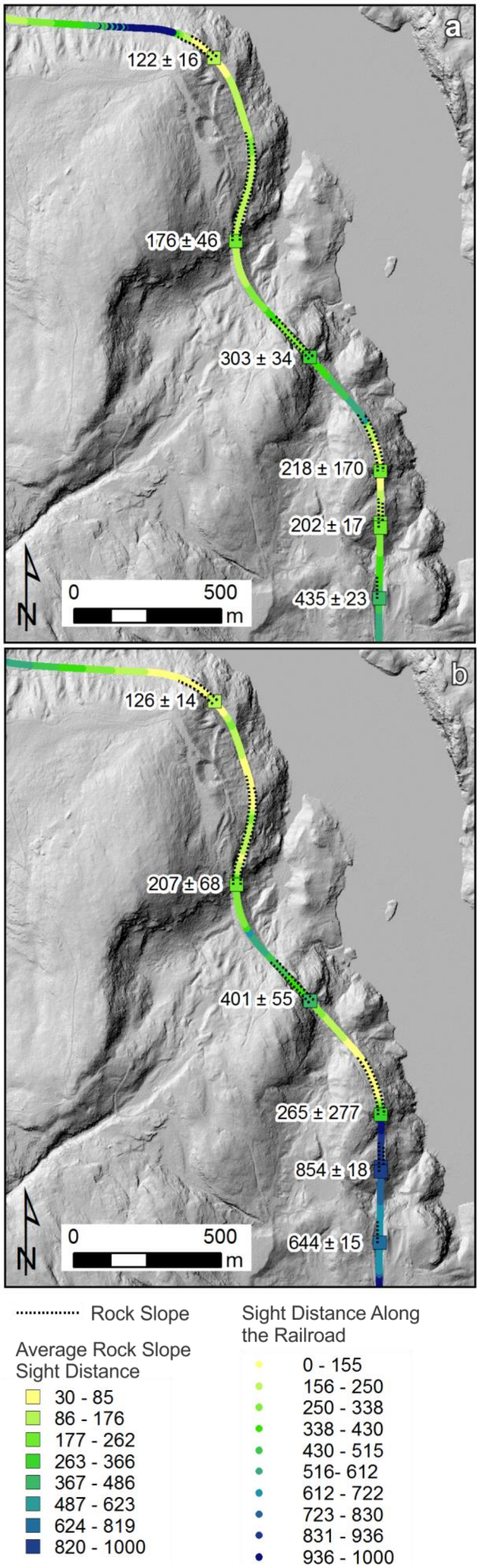

Figure 3. (Left column) Computed sight distances for a train travelling southward b) and northward. Average sight distances associated with particular rock slopes are also shown.

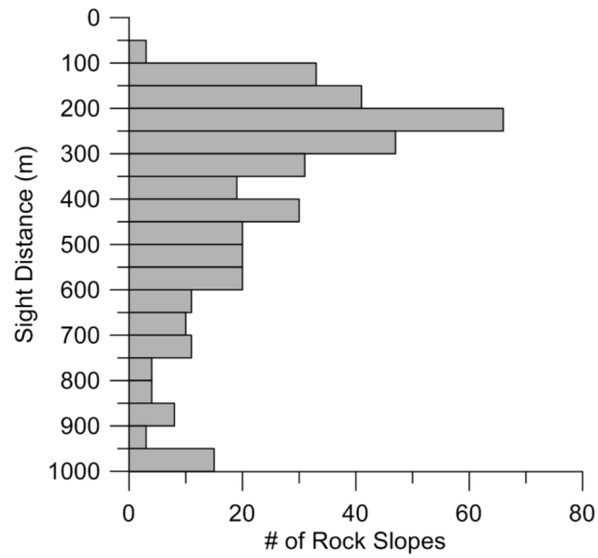

Figure 4. Histogram of the average sight distance for a train travelling north associated to the 396 rock slopes along the railroad.

Sight distances were evaluated in the field at 160 positions, located along 15 different rock slopes. The difference between the sight distance measured in the field and the one obtained numerically are shown in the histogram of Figure 5. Table 1 presents the average differences, based on the type of material blocking the view.

The average difference, for all points, is 62 m. If we remove the 7 values that are over 400 m, the average difference reduces to 36 m, which we consider an adequate accuracy. All of these 7 points are related to shorter measured values in the field caused by trees. As we used the DEM, so a surface from which the trees were removed, the numerical evaluation does not account for trees blocking the view. The sight distance measured in the field is larger for 57 measurements.

For the 64 points where the view is blocked by the rock slope, 42 differences are equal or less than 10 m, which is considered being inside the uncertainty margin. The GPS precisions leads to imprecision in the evaluation of the sight distance along the infrastructure in the order of 5 m. In general, the script gives values in accordance with field measurements.

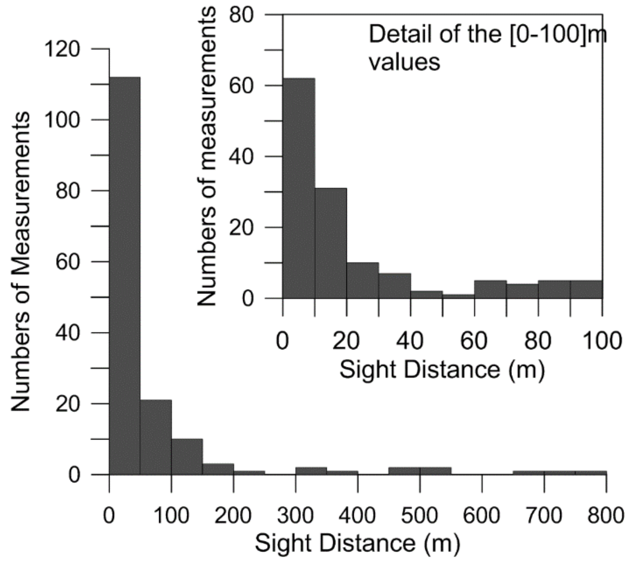

Figure 5. Histogram of the difference between the sight distance measured in the field and the one obtained numerically.

Table 1. Absolute differences between field and numerical sight distances. A: Vegetation; B: Vegetation growing on the rock slope; C: Rock slope

Type of view obstruction	Number of measurement points	Difference in field and numerical sight distances	
		Average	S.D.
	[#]	[m]	[m]
A	64	126,06	186,60
B	31	16,39	21,63
C	65	19,54	36,37

4 DISCUSSION

The results obtained numerically are suited to use in such a classification as the one develop in the Para*Chute* project, because the aim is to compare slopes in between them. Because this sight distance evaluation is systematic, it is adequate for relative comparison. However, we believe that more validation is needed before the sight distances, as computed with this algorithm, can be used as absolute values. The validation should test the influence of DEM resolutions on the sight distances.

The use of the surface model, including the vegetation, could be suited to evaluate the sight distance. The large differences observed between field and numerical evaluations are mainly due to the presence of trees. However, meshing of noisy point clouds (such as the one with vegetation) can create artefacts that could contribute to underestimate the sight distance. Another possible usage of this script could be to compute the differences in sight distance for the cases with and without vegetation. Such an analysis could help managers to pin point locations where vegetation cuts would increase significantly the sight distance.

The computed sight distances could be used in conjunction with the speed limit and inclination of the track to compute stopping distances and compute impact probabilities.

During a fairly nice, but cloudy summer afternoon, we evaluated the maximum distance at which we could see a 0.5 m high box located next to the railroad. We tested this in a straight part of the railroad and concluded that at distances over 500 m, it was not possible to distinguish the box. The maximum distance threshold, which is one of the input parameters, could be used to represent this maximum detection capacity, which depends on the visibility of the debris. This visibility is function of the volume and colours of the debris. We used a threshold of 1000 m, which is not totally consistent with the 0,5m diameter considered for the size of the block.

The sight distances could be classified in not adequate, moderately adequate and adequate sight distances. In this case, the value of the threshold would not be problematic as they would be classified as “very good sight distances”. Such a classification has not been done in the project, but some tests were carried on. The sight distances were finally not used as a parameter to classify the slopes according to their rock fall hazard. However, the data is available for the managing team that can use it when prioritizing slope mitigations or tree cuts.

5 CONCLUSION

In conclusion, we developed this algorithm and computer program in order to evaluate efficiently the sight distances along a linear infrastructure. This tool was develop during the Para*Chute* research project. One of its objectives was to optimize the use of DEM in the characterization of rock slope in terms of their rockfall hazard.

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