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Available sight distance on existing highways: Meeting stopping sight distance requirements of an aging population

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ABSTRACT

An important element of highway design is ensuring that the available sight distance (ASD) on a highway meets driver needs. For instance, if the ASD at any point on a highway is less than the distance required to come to a complete stop after seeing a hazard (i.e. Stopping Sight Distance (SSD)), the driver will not be able to stop in time to avoid a collision. SSD is function of a number of variables which vary depending on the driver, the vehicle driven and surface conditions; examples of such variables include a driver's perception reaction time or PRT (i.e. the time required by the driver to perceive and react to a hazard) and the deceleration rate of the vehicle. Most design guides recommend deterministic values for PRT and deceleration rates. Although these values may serve the needs of the average driver, they may not satisfy the needs of drivers with limited abilities. In other words, even if the ASD exceeds required SSD defined in the design guide, it might not always satisfy the needs of all drivers. While it is impossible to design roads that satisfy the needs of all drivers, the fact that most developed countries suffer from an aging population, means that the number of old drivers on our roads is expected to increase. Since a large proportion of old drivers often have limited abilities, it is expected that the general population of drivers with limited abilities on our roads will increase with time. Accordingly, more efforts are required to ensure that existing road infrastructure is prepared to handle such a change. This paper aims to explore the extent to which ASD on highways satisfies the needs of drivers with limited abilities. The paper first develops MATLAB and Python codes to automatically estimate the ASD on highway point cloud data collected using Light Detection and Ranging (LiDAR) remote sensing technology. The developed algorithms are then used to estimate ASD on seven different crash prone segments in the Province of Alberta, Canada and the ASD is compared to the required SSD on each highway. Three different levels of SSD are defined (SSD for drivers with limited ability, AASHTOs SSD requirements and SSD for drivers with high skill). The results show that, when compared to SSD requirements which integrate limitations in cognitive abilities, a substantial portion of the analyzed segments do not meet the requirements (up to 20%). Similarly, when compared to AASHTO's SSD requirements, up to 6% of the analyzed segments do not meet the requirements. In an attempt to explore the effects of such design limitations on safety, the paper also explores crash rates in noncompliant regions (i.e. regions that do not provide sufficient SSD) and compares them to crash rates in compliant regions. On average, it was found that noncompliant regions experience crash rates that are 2.15 and 1.25 times higher than compliant regions for AASHTO's SSD requirements and those integrating driver limitations, respectively. Furthermore, the study found that a significantly higher proportion of drivers involved in collisions in the noncompliant regions were old drivers.

1. Introduction

Minimum Stopping Sight Distance (SSD) is the distance required by a driver to come to a complete stop when a hazard or obstruction presents itself on a roadway. In order to ensure safe and efficient operation of a roadway, design guidelines require that available sight distance (ASD) exceeds the minimum SSD at all points along a roadway. Minimum SSD requirements are calculated using equations derived in design guidelines and are typically a function of speed, the road's grade, the driver's perception reaction time (i.e. the time required for the driver to perceive and respond to the hazard that creates the stopping requirement), and the vehicle's deceleration rate.

Variables like perception reaction time (PRT) and deceleration rate vary depending on driver capabilities, vehicular performance and the situation on hand, however, most highway design guides use deterministic values for those variables. For instance, AASHTO's highway

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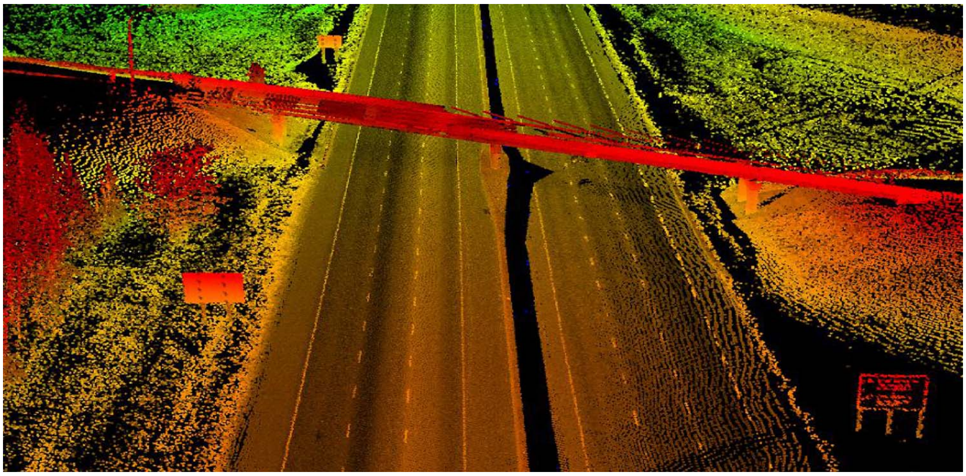

Fig. 1. LiDAR Point Cloud.

design guide recommends using 2.5 s for a driver's perception reaction time (PRT) and a deceleration value of $3.4\,m/s^2$ (AASHTO, 2011). Those deterministic values are typically percentile values which were empirically derived based on the performance of a sample of drivers. Therefore, although designing highways to meet SSD requirements defined in design codes might ensure that sufficient sight distance is available for most drivers, a significant portion of drivers, who have longer PRT or lower deceleration rates, might not find the available sight distance adequate. Although the proportion of drivers with limited abilities might currently be low, the fact that population demographics are changing (aging population) means that this will no longer be the case.

Statistics in Canada show that the average age of the driving population is on the rise with projections predicting that by 2030 around 20% of all drivers will be over the age of 65 (Road Safety Canada Consulting, 2011). A large portion of old drivers are typically slower in both their perception of risk and the manner in which they react to hazards on the road. This is due to many factors including reduced visual acuity, reduced flexibility and motion range, narrower field of vision, greater sensitivity to glare and reduced muscle strength. All these factors result in drivers having longer perception reaction time, hence, requiring longer sight distances.

Deceleration rate, is another factor that affects sight distance requirements on highways and one which may vary among drivers of different ages. Old drivers with limited abilities are less likely to apply similar pressure to brake pedals as young drivers, hence, occasional differences in deceleration rates may appear. Moreover, vehicle kinematics also differ among different vehicles. Furthermore, in places of adverse weather conditions surface traction might not always be best and result in reduction in deceleration rates. Similarly, deceleration rates might also be affected by pavement conditions or even tyre conditions.

Safety performance of old drivers has been researched in many studies (Marottoli et al., 1994; Foley et al., 1995; McGwin and Brown, 1999; Janke, 2001; Lyman et al., 2001; Jurewicz et al., 2017). In general, research has found that, despite their cautious driving habits, drivers aged 70 and older have the highest collision rates per kilometer driven when compared to other age groups except young male drivers (Li et al., 2003). Moreover, research has also shown that old drivers are at a higher risk to be killed when involved in a collision (Turcotte, 2015). The growing population of old drivers along with the fact that a large proportion of those drivers have limited abilities means that the overall population of drivers with limited abilities on our roads is expected to increase. As a result, it is extremely important that such a change is taken into account when assessing the safety of existing highways and when designing new highways, which is the motivation of research in this paper.

Whether it is human factors, deceleration rates or environmental conditions, all these factors affect how much sight distance is required by drivers on a highway segment. Although integrating all factors into design might not be economically feasible, changes in driver demographics might require slight changes to existing standards. Before that is done though, it is essential to understand whether or not existing highways are able to accommodate the anticipated changes.

This paper aims to investigate the extent to which sight distance on existing highways can accommodate variation in human factors, environmental conditions, and vehicle kinematics. Specifically, the paper aims to understand how changing those factors can impact the percentage of noncompliance in stopping sight distance on a road segment (i.e. the portion of the segment where sight distance requirements are not met).

First the paper adopts an algorithm which could be used to automatically compute the available stopping sight distance along a Light Detection and Ranging (LiDAR) point cloud model of the highway. LiDAR data is collected through laser scanners reflecting light beams off objects. The scanners are combined with Global Navigation Satellite System (GNSS) receivers and inertial measurement unit (IMU) which provide information about the exact position of the scanner. Constant scanning of objects around the sensor creates a 3D point cloud of known positional attributes illustrated in Fig. 1. LiDAR data on highways is often collected through Mobile Laser Scanning (MLS). In such practice scanning equipment is mounted on vehicles, which travel along the highway of interest capturing 360° imageries of the roadway.

Among many other applications in transportation and highway engineering (Holgado-Barco et al., 2014; Ai and Tsai, 2016; Gargoum et al., 2017b; Holgado-Barco et al., 2017; Gargoum et al., 2018a; Gargoum et al., 2018b; Gargoum et al., 2018c), the availability of LiDAR data makes it possible to assess sight distance on a road segment in a timely manner. The methodology applied in this paper is similar to that proposed in (Castro et al., 2013; Gargoum et al., 2018). The method creates a digital surface model of the highway with observer and target points defined along the road. Line of sight assessment is performed and the outputs are processed to calculate the available sight distance on the segment. This study fully automates the sight distance assessment procedure on LiDAR highways by writing a python code which can perform the analysis from multiple LiDAR highways without using the user interface in ArcGIS.

After computing the available sight distance along the highways of interest, the ASD is compared to the theoretical sight distance required while changing different variables in the sight distance equation. The percentage of noncompliance along a highway segment is then calculated for a range of perception reaction times and deceleration rates. In order to further explore the impacts of different levels of noncompliance on the safety of a road segment, collision records in the