Transportation Research Part C 86 (2018) 563–579

Contents lists available at ScienceDirect

Transportation Research Part C

journal homepage: www.elsevier.com/locate/trc

Overview Paper

3D virtual intersection sight distance analysis using lidar data

Jaehoon Jung*, Michael J. Olsen, David S. Hurwitz, Alireza G. Kashani, Kamilah Buker

School of Civil and Construction Engineering, Oregon State University, 101 Kearney Hall, Corvallis, OR 97331, USA

A R T I C L E   I N F O

Keywords:
Stopping sight distance
Intersection sight distance
Intersection safety
Lidar
3D viewshed

A B S T R A C T

Sight distance analyses require careful and detailed field measurements to facilitate proper engineering decision making regarding the removal of obstructions, establishment of regulatory and advisory speed limits, and the location of new access points, among numerous other purposes. However, conventional field measurements for these analyses present safety concerns because they require personnel to be in or adjacent to traffic lanes. They can also be time consuming, costly, and labor intensive. Furthermore, the predominantly two-dimensional (2D) methods involve simplifying assumptions such as a "standard" vehicle heights and lengths without considering the wide range of vehicles and drivers present on the road. Recently, many transportation agencies worldwide have begun to acquire mobile lidar data to map their roadway assets. These data provide a rich three-dimensional (3D) environment that enables one to virtually visit a site at any frequency and efficiently evaluate sight distances from the safety of the office. This study investigates advanced safety analysis methodologies for drivers' sight distance based on high resolution lidar data. The developed simulation method enables users to virtually evaluate available sight distances in a 3D context considering a variety of objects, vehicle types, and multi-modal forms of transportation (e.g., bicycle, pedestrian). The feasibility of this technique was analyzed with a case study at an intersection located in Corvallis, Oregon, USA. The experimental results demonstrated the ability of the proposed methodology to capture significantly more detail on visibility constraints when compared with conventional measurements as well as provide more flexibility in the analysis.

1. Introduction

Sight Distance (SD) is the length of road visible to a road user measured from any point along the traveled way. A key component in the safe design, operation, and maintenance of highways is the provision of adequate SD (AASHTO, 2011; Fambro et al., 1997). Two categories of SD are Stopping Sight Distance (SSD) and Intersection Sight Distance (ISD). SSD is defined as the sum of the distance traversed by the vehicle from the instant the driver detects an object obstructing the forward progressing of the vehicle on the current path necessitating the driver to stop to the instant the brakes are applied (brake reaction distance) and the distance needed to stop the vehicle once the brakes have been applied (braking distance). In addition to SSD, SD must also be considered at intersections (commonly termed ISD) to provide drivers of stopped vehicles an adequate view of the intersecting highway to allow them to cross or enter the intersecting highway (AASHTO, 2011).

SD analyses require careful and detailed field measurements to facilitate proper engineering decision making regarding the removal of obstructions, establishment of regulatory and advisory speed limits, and the location of new access points, among

* Corresponding author.
E-mail address: jaehoon.jung@oregonstate.edu (J. Jung).

https://doi.org/10.1016/j.trc.2017.12.004
Received 17 August 2017; Received in revised form 7 December 2017; Accepted 9 December 2017
0968-090X/

numerous other examples. Transportation facilities should be designed such that a driver has sufficient visibility to avoid collision with an object obstructing the traveled way. SD measurements and calculations are based on driver characteristics, vehicle types, road grade, horizontal and vertical curves in road, road conditions (e.g., wet surface), and the type of maneuver that the driver will perform.

Limited visibility is a principal cause of crashes in transportation corridors. Investigation of these cases showed that specific preventive safety practices could reduce the number of these fatalities. One solution is to identify obstacles and hazardous road or construction work spaces, which will allow for the selection of proper strategies such as removing obstructions, implementing safety warning signs, and optimizing blind spaces by alternating the road or construction site features and equipment locations.

Conventional field measurements of SD present safety concerns because they require personnel to be in or adjacent to active traffic lanes (e.g., McKinley, 2014). These studies are generally time consuming, costly, and labor intensive. Further, the methods that are currently used are based on 2D theoretical equations (AASHTO, 2011), which require simplifying assumptions such as a "standard" vehicle (height and length) without considering the wide range of vehicles present on the road. Another limitation in conventional SD analyses is that only static objects and vehicles are considered. This method does not enable one to model the dynamic motion of both vehicles and objects that occurs in the real world. They do not also consider multi-modal forms of transportation such as bicycles.

Lidar is a recent technology that can rapidly generate survey quality, 3D data of a scene, which can be utilized to analyze visibility within a space (e.g., Batchelor, 2016). A key benefit to lidar technology is the ability to utilize the same data source to support multiple applications including asset management, safety analyses, construction, planning, and maintenance. Lidar data provide a 3D environment that enables one to frequently visit a site virtually and obtain measurements from the safety of the office efficiently.

Recently, many transportation agencies worldwide have begun to acquire Mobile Lidar data for their highways (Olsen, 2013), which has a great potential for supporting a wide range of applications, such as condition evaluation of traffic signs and road markings (Ai and Tsai, 2016; Soilán et al., 2017), assessment of highway alignment (Marinelli et al., 2017), and simulation of vehicle dynamics (Brown and Brennan, 2015). Recently, Oregon DOT (ODOT) has completed mobile lidar surveys of all state owned and maintained highways and updates high priority areas annually (Mallela et al., submitted for publication). Among other purposes, ODOT utilized this data to manually extract measurements to perform virtual passing SD analyses of passing lanes in rural highways where speed limit increases were introduced. The efficiency of this approach resulted in $250,000 (US) savings compared to conventional technique.

This research explores the feasibility, benefits, and challenges of a 3D safety analysis for sight distances based on lidar data. Specifically, the following objectives were accomplished:

- Developed a systematic framework to utilize 3D laser scanning data to evaluate sight distances,
- Compared the framework to conventional techniques for validation,
- Evaluated visibility changes during vehicle movements such as turning,
- Considered differences in visibility based on different vehicles and multi-modal forms of transportation, and
- Provided 3D viewsheds that can help agencies manage SD obstructions.

The remainder of this paper is organized as follows. Section 2 reviews the latest developments in SD analysis using GIS, lidar and other 2.5D technologies that cannot account for the objects with the same horizontal locations but different elevations. Section 3 outlines the procedure of the proposed methodology in detail. Section 4 presents the description of the study site and point-cloud data collected for an intersection. Section 5 provides the test results of the proposed methodology with several visibility constraints. Finally, Section 6 identifies the potential utility of the proposed methodology and upcoming work.

2. Related works

Initial efforts of using geospatial data for SD analysis were related to the design phase of roads (Hassan et al., 1996; Ismail and Sayed, 2007; Jha et al., 2011; Jha and Karri, 2009). These methods used design alignments and terrain topographic information to simulate the road geometry and conduct SD calculations. However, a major limitation arises since they only consider the road geometry and ignore the influence of other effective objects such as trees, buildings, signs, etc. Moreover, these methods simplify the road geometry (e.g. constant road grade and cross slope) with assumptions.

Recent developments in Geographic Information Systems (GIS) and Digital Elevation Modeling (DEM) provided efficient tools that can be used for SD analysis of existing roads. GIS enables one to conduct line of sight analysis that is in accordance with the available GIS terrain and surface model and combine the result of such analysis with other sources of information such as crash statistics and speed limits for further evaluations. Table 1 summarizes studies that have performed geospatial visibility analysis for roads and highways.

The ArcGIS Line of Sight (LOS) and viewshed analysis tools have been used in some studies in Table 1 to determine Available Sight Distance (ASD) on roads (Castro et al., 2014, 2017; Khattak and Shamayleh, 2005) and intersections (Khattak et al., 2003; Tsai et al., 2011). Two main methods were reported. In the first method, which is often used for intersection SD analysis, a viewshed for a driver is first determined based on assumptions such as vision range, angle, and obstacle locations. Then, the intersection area included in the viewshed polygon is determined and the length of ASD is extracted. In the second method, which is typically used for road SD analysis, path points with equal distances are generated on a road trajectory polyline. Then, the GIS LOS tool is used to determine the farthest seeable point for each of the path points to generate the viewshed.