Application of Light Detection and Ranging Technology to Assess Safe Passage of Low Ground Clearance Vehicles at Highway-Rail Grade Crossings

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A Report on Research Sponsored by

University Transportation Center for Railway Safety (UTCRS)

University of Nebraska-Lincoln

December 2015

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Technical Report Documentation Page

<table>
<tr><td colspan="2">1. Report No.
26-1121-0018-002</td><td colspan="2">2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="4" rowspan="2">4. Title and Subtitle
Application of Light Detection and Ranging Technology to Assess Safe Passage of Low Ground Clearance Vehicles at Highway-Rail Grade Crossings</td><td colspan="2">5. Report Date
December 2015</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td colspan="4">7. Author(s)
Aemal J. Khattak, Zhenghong Tang and Myungwoo Lee</td><td colspan="2">8. Performing Organization Report No.
26-1121-0018-002</td></tr>
<tr><td colspan="4" rowspan="2">9. Performing Organization Name and Address
Nebraska Transportation Center
2200 Vine St.
PO Box 830851
Lincoln, NE 68583-0851</td><td colspan="2">10. Work Unit No. (TRAIS)</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
DTRT13-G-UTC59</td></tr>
<tr><td colspan="4" rowspan="2">12. Sponsoring Agency Name and Address
University Transportation Center for Railway Safety (UTCRS)
University of Texas Rio Grande Valley (UTRGV)
1201 W. University Dr.
Edinburg, TX 78539</td><td colspan="2">13. Type of Report and Period Covered
November 2013 – December 2015</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code
USDOT UTC Program</td></tr>
<tr><td colspan="6">15. Supplementary Notes</td></tr>
<tr><td colspan="6">16. Abstract
The focus of this research was to test and validate the feasibility of assessing humped highway-rail grade crossings for safe passage of vehicles with low ground clearance using Light Detection and Ranging (LiDAR) data. Collected using an airborne platform, LiDAR data provide geo-referenced spatial information about the shape and surface characteristics of Earth. The suitability of humped highway-rail grade crossings for use by vehicles with low ground clearance is a concern because of the possibility of vehicles getting lodged on rail tracks. The situation is more critical for vehicles with low ground clearance and a long wheelbase. While such vehicles usually travel on designated routes, emergencies or highway closures may result in these vehicles travelling on highways with humped grade crossings that may be unsafe for their passage.
Using LiDAR data and line-of-sight analysis in a geographic information system (GIS), potentially problematic grade crossings for certain types of low ground clearance vehicles with a long wheelbase were identified. Results of the GIS analysis were validated in the field at actual grade crossings using survey equipment. The main conclusion was that LiDAR data could be successfully used to identify vehicle hang-up issues at rail grade crossings.</td></tr>
<tr><td colspan="3">17. Key Words
Highway-rail grade crossings, HRGC, approach surface, LiDAR, crossing geometry, GIS, terrain model</td><td colspan="3">18. Distribution Statement</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td colspan="3">20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
35</td><td>22. Price</td></tr>
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List of Abbreviations

American Association of State Highway and Transportation Officials (AASHTO)
American Railway Engineering and Maintenance-of-Way Association (AREMA)
Digital Elevation Model (DEM)
Environmental Systems Research Institute (ESRI).
Federal Highway Administration (FHWA)
Federal Railroad Administration (FRA)
Geographic Information System (GIS)
Global Positioning System (GPS)
Ground Sample Distance (GSD)
Highway-Rail Grade Crossings (HRGCs)
Light Detection and Ranging (LiDAR)
Nebraska Department of Natural Resources (DNR)
Root-Mean-Square Error (RMSE)
Universal Transverse Mercator (UTM)

Disclaimer

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Executive Summary

The focus of this research was to test and validate the feasibility of assessing humped highway-rail grade crossings for safe passage of vehicles with low ground clearance using Light Detection and Ranging (LiDAR) data. Collected using an airborne platform, LiDAR data provide geo-referenced spatial information about the shape and surface characteristics of Earth. The suitability of humped highway-rail grade crossings for use by vehicles with low ground clearance is a concern because of the possibility of vehicles getting lodged on rail tracks. The situation is more critical for vehicles with low ground clearance and a long wheelbase. While such vehicles usually travel on designated routes, emergencies or highway closures may result in these vehicles travelling on highways with humped grade crossings that may be unsafe for their passage.

Using LiDAR data and line-of-sight analysis in a geographic information system (GIS), potentially problematic grade crossings for certain types of low ground clearance vehicles with a long wheelbase were identified. Results of the GIS analysis were validated in the field at actual grade crossings using survey equipment. The main conclusion was that LiDAR data could be successfully used to identify vehicle hang-up issues at rail grade crossings.

Chapter 1 Introduction

1.1 Problem Statement

According to the Federal Railroad Administration (FRA), rail safety in the U.S. is at an all-time high, but we owe it to the public and rail workers to do better [1]. Continuous safety improvement requires a comprehensive strategy designed to eliminate risks on railroads [1]. In this respect an issue requiring attention is the safe passage of vehicles with low ground clearance and a long wheelbase across humped highway-rail grade crossings. A vehicle may become lodged (i.e., hung-up) on a crossing if the lowest part of the vehicle body comes in contact with the top of the crossing surface due to elevation difference between the crossing surface top and surrounding roadway surface. Figure 1.1 shows a situation when a truck is lodged on the rail tracks. It also shows damage to pavement (scratching) at another rail crossing location due to low-clearance vehicles.

Figure 1.1 Truck lodged on a highway-rail grade crossing (left) and scratched pavement due to passing low-clearance vehicles at one of the study sites in this research (right)
(Left image source: http://www.inkfreenews.com/2013/05/07/semi-fails-to-clear-railroad-crossing/)

A hang-up issue may even be encountered at a previously “safe” crossing due to the addition of track ballast under rails, re-grading or repaving of a crossing road, or due to erosion of an unpaved approach road surface. Such vehicle hang-up issues at a rail crossing may result in a severe train-involved crash in case oncoming trains are not warned well in advance. The vehicle hang-up issue has been around for some time and is often encountered when vehicles with low ground clearance make deviations from prescribed routes [2-4]. The issue may also be encountered during emergency situations when commonly used routes are not available for use, necessitating the use of routes (with rail crossings) not previously used for large vehicles. Thus, an in-office quick and accurate assessment of the hang-up issue at rail grade crossings would be valuable.

1.2 Research Objectives

The objectives of this project were to assess the vertical accuracy of obtained LiDAR elevation data at selected highway-rail grade crossings (HRGCs) in Nebraska, and to test and validate the crossing suitability of low ground clearance and/or long-wheel base vehicles at humped HRGCs for safe passage using LiDAR elevation data. Elevation data were collected using a geo-positioning system along with other surveying tools such as a theodolite at selected HRGCs, and the collected data were compared with the LiDAR elevation data statistically to show how accurately LiDAR data represent the actual field elevation data at given HRGCs. Design vehicles with different dimensions were then used for assessment of crossing suitability, and the results of the crossing suitability assessment were field-validated.

1.3 Report Organization

The current chapter is followed by a description of the published literature in chapter 2, which focuses on design criteria for vertical alignment of rail grade crossings, techniques for identifying problematic rail crossings, various design vehicles, and highway safety-related LiDAR applications. Data characteristics and data collection are described in chapter 3. The data analysis and field validation of the results are presented in chapter 4. Conclusions, including a brief discussion, and limitations of the research were documented in chapter 5, and a cited reference list completes this report.

Chapter 2 Literature Review

This literature review covers current design criteria for vertical alignment of HRGCs, previously utilized identification techniques for vehicle ground clearance issues, established design vehicles for humped HRGCs, and highway safety-related LiDAR applications. The vertical design criteria of HRGCs in different guideline books are referred in order to check whether the current vertical designs regard safe passage on the low ground clearance vehicle and that the different design books accord closely with each other with respect to vertical design criteria. Previously used identification techniques and design vehicles for problematic rail grade crossings for low ground clearance vehicles were investigated to recognize the weaknesses and to develop improved methods. Finally, the applications of LiDAR data to highway safety issues were reviewed to include the identification and articulation of relationships between the literature and the research objectives in this report. A summary of the literature review appears at the end of this chapter.

2.1 Design Criteria for Vertical Alignment of HRGCs

The American Association of State Highway and Transportation Officials (AASHTO)'s Policy on Geometric Design of Highways and Streets (commonly called the Green Book, [5]) recommends that the railroads be constructed as level as possible, focusing on motor vehicle driver's sight distance, vehicle braking, and acceleration distances. It also recommends that the crossing surface should be leveled at the top of the rails for a distance of 2-ft outside of the rails to avoid low ground clearance vehicles from being lodged on the track. The surface of the highway after the leveled area should not be more than 3 inches higher or lower than the leveled area by a point 30-ft from the rail unless track superelevation makes a different level appropriate. The vertical grade crossing geometric design is shown in Figure 2.1.1.

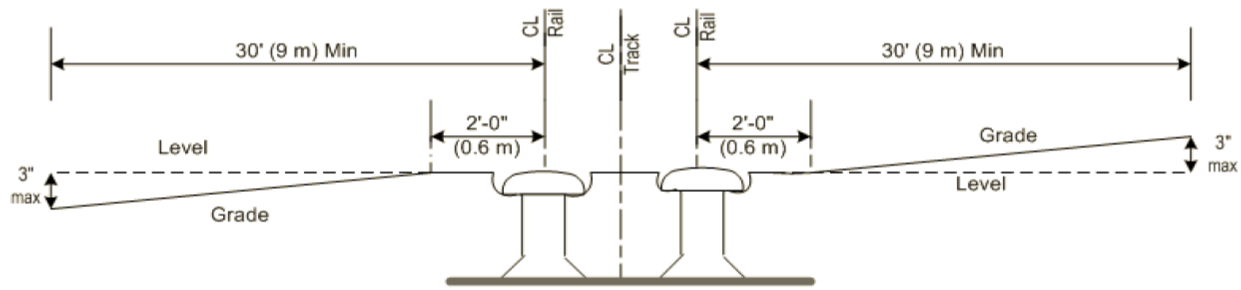

Figure 2.1 Vertical grade crossing geometric design [Source: Green Book]

The American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering [6] also states that advisable highway surface at rail grade crossings should not be more than 3 inches higher or lower than the top of the rail track by a 30-ft distance point from the track line unless the track superelevation dictates otherwise. The manual cites particular concerns for low ground clearance vehicular traffic to avoid hang-up issues at HRGCs. If the given design criteria is impractical, the manual recommends that the relevant authority restrict the movement of low ground clearance vehicles or install necessary traffic signs near the crossing.

The Federal Highway Administration (FHWA)'s Railroad-Highway Grade Crossing Handbook [7] also includes the vertical alignment section for rail grade crossing elevation design. The handbook states that the highway intersection and the railroad should be as level as possible, but water drainage and track maintenance often make the intersection area "humped." It recognizes that this elevated area may cause an adverse effect on the safe operation of rail grade crossings.

Even though all the guideline books cited possible hang-up issues on low ground clearance vehicular traffic, it was noted that half of the government agencies and railroad companies across the U.S. did not recognize the possible vehicle hang-up problems on rail grade crossings [8]. It was also noted that 87% of all agencies did not have detailed formal guidelines in terms of low ground clearance vehicles at HRGCs [8].

2.2 Identification Techniques for Vehicle Ground Clearance Issue

Bauer [9] studied the low ground clearance issue for vehicles at driveway entrances where varying vertical profiles exist. Due to the limited computing power at that time (1958), the author created a cardboard model vehicle and positioned it at sites to identify problematic design spots. Eck and Kang [10] conducted a vehicle classification count in West Virginia to identify the proportion of low ground clearance vehicles and found that about 5.7 percent of all trucks in the traffic stream had low clearance. They pointed that the percentage is significant to cause potentially serious low-clearance hang-up problems on rail grade crossings. Eck and Kang [11] developed a computer software program (HANGUP) to simulate trajectories of trucks passing on HRGCs. Figure 2.2 shows the output of a hang-up issue for a vehicle having a 30 ft wheelbase and 5 inch ground clearance. The vertical arrows on the terrain profile represent the problematic segments.

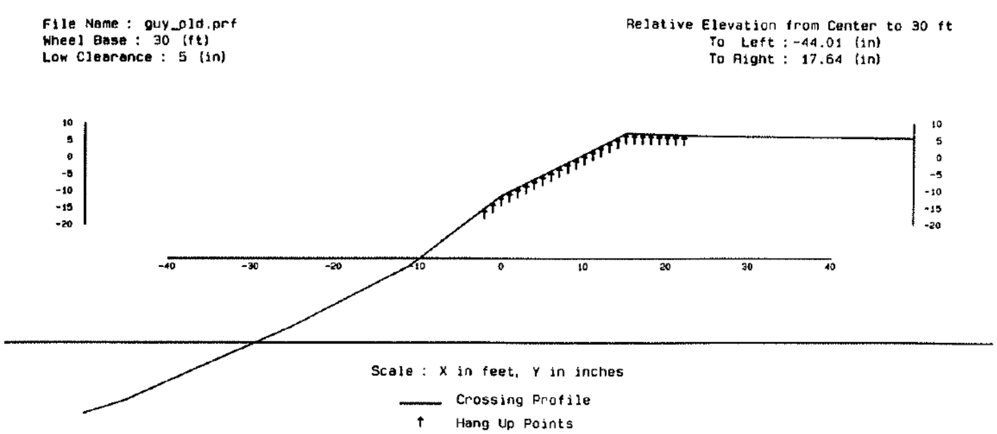

Figure 2.2 Manual mode output of HANGUP program [Source: Eck and Kang, (1991)]

Table 2.1 shows the output of the software in an automatic mode where the program provides a hang-up issue with combinations of different wheelbase and ground clearance values. For example, a vehicle having a 28 ft wheelbase will not lodge in this site until the ground clearance is below 10 in. This program required a field data input of the roadway vertical profile to calculate truck movement and produced a plot with problematic locations for low ground clearance or long wheelbase characteristics.

Table 2.1 Automatic mode output of HANGUP program [Source: Eck and Kang (1991)]

Wheelbase (ft)	Ground Clearance (in)									
	1	2	3	4	5	6	7	8	9	10
20	1	1	1	1	1	1	0	0	0	0
21	1	1	1	1	1	1	0	0	0	0
22	1	1	1	1	1	1	1	0	0	0
23	1	1	1	1	1	1	1	0	0	0
24	1	1	1	1	1	1	1	0	0	0
25	1	1	1	1	1	1	1	1	0	0
26	1	1	1	1	1	1	1	1	0	0
27	1	1	1	1	1	1	1	1	0	0
28	1	1	1	1	1	1	1	1	1	0
29	1	1	1	1	1	1	1	1	1	0
30	1	1	1	1	1	1	1	1	1	1
31	1	1	1	1	1	1	1	1	1	1
32	1	1	1	1	1	1	1	1	1	1
33	1	1	1	1	1	1	1	1	1	1
34	1	1	1	1	1	1	1	1	1	1

1: Hang up   0: No hang up

In developing a methodology for identifying and ranking crossings for possible hang-up issues using the HANGUP software, Mutabazi and Russell [12] developed a physical model to simulate trajectories of low ground clearance vehicles on humped rail grade crossings, as shown in Figure 2.3. The model was created with four rubber wheels and a steel/wooden frame to represent the body of a vehicle. This model vehicle was then pushed across a rail grade crossing to check contact points with the crossing surface to evaluate HANGUP software results.

Figure 2.3 Physical model vehicle to simulate low ground clearance vehicle trajectories [Mutabazi and Russell (2003)]

Sobanjo [8] conducted 3D profile data collection using a laser profilometer for rail grade crossing areas in Florida to reveal the elevation information useful for identifying hang-up issues. However, the profilometer data would not provide detailed ground surface elevation information without proper configuration, so the author proposed several alternative methods to collect ground elevation data including a 3D laser scanner, Global Positioning System (GPS), as-built construction drawings, aerial surveys, GIS and contour maps, and 3-D digital photography.

2.3 Design Vehicle for Humped HRGCs

To avoid low ground clearance vehicle issues at HRGCs, establishment of design vehicles were required for HRGC vertical design criteria. After their vehicle classification counts in West Virginia [10], Eck and Kang proposed a low-clearance design vehicle with a 36-ft wheelbase and a 5 inch ground clearance based on the 85^{th} percentile values of collected field data in West Virginia [11]. Using the selected design vehicle, they established maximum safe grades and curve lengths for elevated highway-rail grade crossings.

Wooldridge et al. [13] reviewed the associated literature and recommended design vehicles to be vehicle type-specific for rail grade crossings where a potential hang-up problem may occur for low ground clearance vehicles. They maintained that analysis be conducted with the type of design vehicle with high expectation of using the crossing being designed rather than using a prescribed design vehicle, such as a vehicle with a 36-ft wheelbase and a 5 inch ground clearance. In other words, analysis on hang-up issues should be conducted with specific design vehicles which are highly expected to use the target crossing. The authors argued that the determination of a specific design vehicle relies totally upon local traffic composition.

French et al. [14] determined more specified design vehicle types and dimensions, considering three options: (1) worst-case dimensions, (2) statistical analysis, and (3) HANGUP software with sample profiles. The worst-case dimensions method was used to find design values that covered the entire vehicle population–the most conservative way. The second method involved statistical measures using the mean, median, and 85^{th} (or 15^{th}) percentile of vehicle count data. The last method used HANGUP software with sample vertical profiles by testing different vehicle dimension combinations. Using these methods, French et al. [14] determined 17 types of design vehicles based on critical design values including ground clearance, wheelbase, and overhang lengths for the front and rear parts of the vehicles. However, the dimensions of those design vehicles were determined without consideration of possible effects of vehicles in motion, such as vehicle bounce, implying that maximum design values may be smaller [15].

2.4 Application of LiDAR to Highway Safety

Advances in LiDAR technology have made terrestrial data collection easier, more economical, and relatively accurate [16, 17]. Collection of LiDAR data involves shooting thousands of laser beams per second at a target surface and measuring the return time of reflected beams to estimate the distance between the LiDAR instrument and the target surface. The LiDAR instrument consists of a laser, a scanner, and a GPS receiver. To obtain the vertical profile of the Earth's surface, an airplane or helicopter with a LiDAR instrument flies on the target area, measuring the distance to calculate vertical elevation data.

Early applications of LiDAR elevation data to the issue of highway intersection sight distance obstruction was reported by Khattak et al. [18] and Khattak and Gopalakrishna [19]. The authors focused on a driver's sight line distance using the LiDAR elevation data manipulated in GIS to identify potential obstructions. Results showed that about 90 percent of the identified obstructions were accurately confirmed, concluding that the LiDAR technology could be successfully applied for identifying sight-distance obstructions at highway intersections.

Khattak and Shamayleh [20] further developed the preceding research by utilizing LiDAR data to visualize obstructions for two-lane highway passing and stopping sight distances. After creating the 3D visual model of their study area, proper passing and stopping sight distances were calculated with line-of-sight analysis in GIS for 10 different locations based on AASHTO's Green Book. Potential stopping sight and passing sight distance blockages were validated in the field; their results showed that line-of-sight analysis for highway stopping and passing sight distances could be accomplished in GIS using the LiDAR data.

LiDAR technology applications for management of highway inventory data have been reported because conventional inventory data collection techniques are costly and laborious [20-23]. Souleyrette et al. [21] found that roadway grade crossings can be efficiently measured from LiDAR elevation data by using regression to validate the accuracy. To establish an accurate and more feasible way to manage roadway inventories, Cai and Rasdorf [22] used LiDAR point cloud data to measure roadway centerline distance in a 3D vector model. After validation of their results, the authors concluded that LiDAR data-based 3D modeling successfully represented the roadway centerline at a satisfactory level. More recently, Wang et al. [24] used LiDAR data to create a 3D surface for building a vehicle dynamic model to quantify highway-rail grade crossing roughness and introduced an accurate and cost-effective procedure to test the rail grade crossing surface quality by using 3D sensing and imaging technology. Compared to the conventional rating that was used to identify ground roughness, the applied quantitative method provided a more objective way to view the actual condition of the surface.

2.5 Summary of Literature Review

In summary, the review of literature showed associated publications regarding the hang-up issue at HRGCs. In order to identify the problem, diverse methods were used including model cars, HANGUP software, or profilometer. However, to evaluate the crossing suitability, the proposed methods require a field survey which may be in danger or laborious for surveyors. A review on application of LiDAR elevation data revealed that the appropriateness of the data for highway safety issues showed applicability on identifying hang-up problems at HRGCs using the developed design vehicles. The next chapter provides details of data collection and characteristics for this research project.

Chapter 3 Research Methodology and Data Characteristics

3.1 Research Methodology

Figure presents the methodology adopted for this research. Relevant data were obtained from several sources and integrated in a GIS. The acquired data included study area orthophotos, LiDAR elevation data, and geo-referenced ranges of target rail grade crossings. Those data were integrated using ArcGIS 10.2 software (Environmental Systems Research Institute, ESRI). Using the software, the integrated data were manipulated to measure accuracy of LiDAR elevation data for ranges of target rail grade crossings and to assess crossing suitability of certain vehicles having a low ground clearance and a long wheelbase. Subsequently, the crossing suitability results were field-validated.

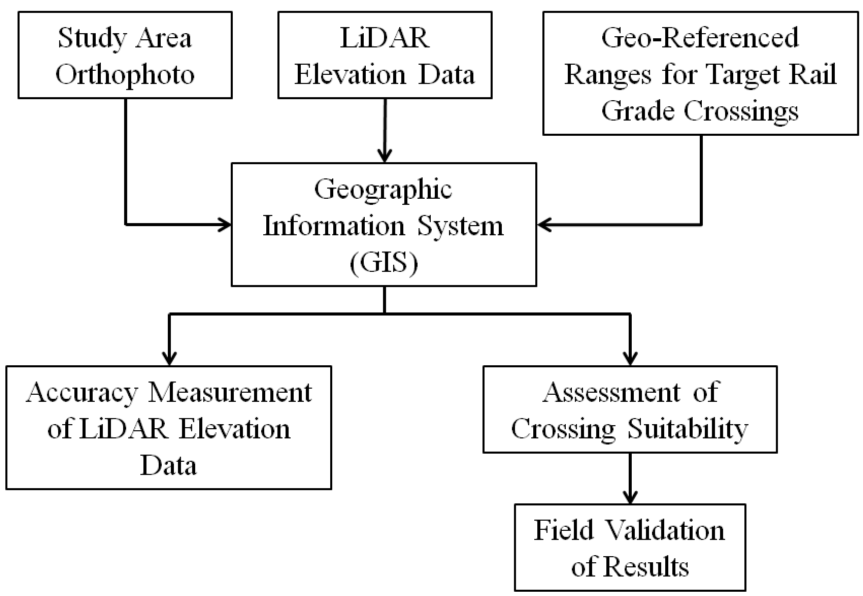

Figure 3.1 Research methodology

3.2 Data Collection and Characteristics

3.2.1 Geo-Referenced Ranges of Target Rail Grade Crossings

Three rail grade crossings located in Lincoln (Lancaster County), Nebraska were chosen for this research; Site 1 was located on N 22nd Street, site 2 was located near the intersection of N 17th Street and Y Street, while site 3 was situated on N 33rd Street (see Figure).

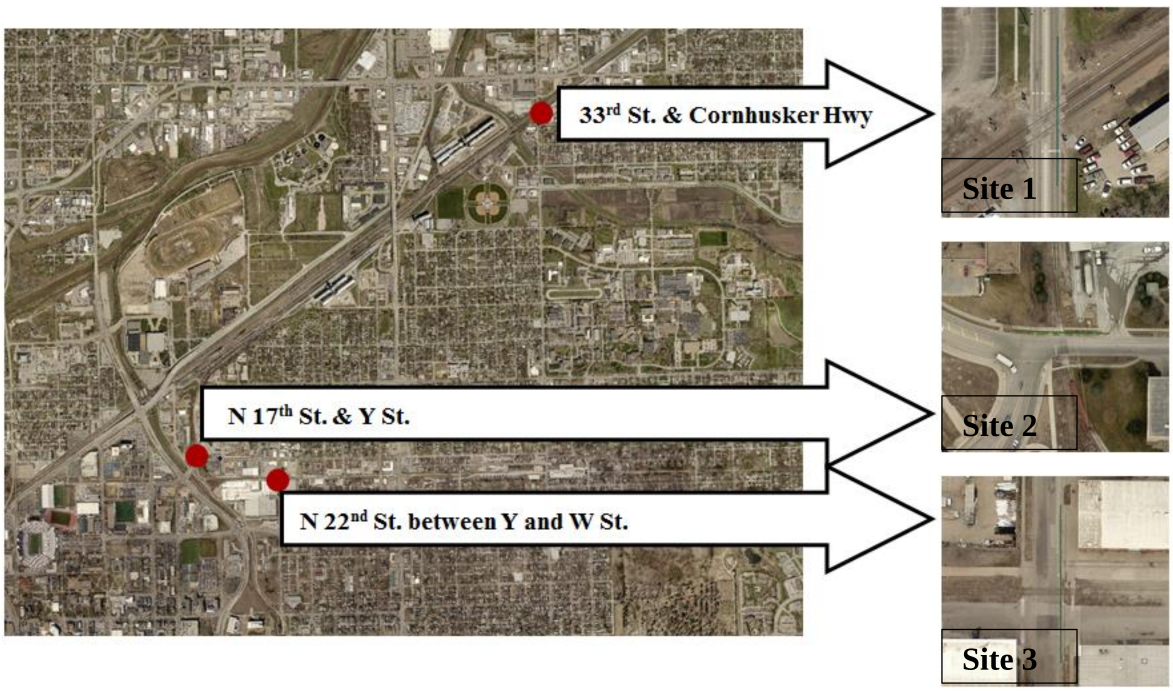

Figure 3.2 Selected rail grade crossings in Lincoln, Nebraska

To obtain geo-referenced points along the crossing roads, coordinates (x and y) at every 2-ft in a range of 160-ft (80-ft each from the centerline of the rail tracks) were measured using a geopositioning system (TOPCON HiPer II) along with other surveying tools such as a theodolite. The specified dataset derived from TOPCON HiPer II appears in Appendix A. Figure represents the illustration of the geo-referencing method at a rail grade crossing. Those points provide the exact coordinates and relative elevation differences for the crossing roadway sidelines. The acquired coordinates and relative elevation data of crossing road sidelines were used for accuracy measurement of LiDAR elevation data, the assessment of crossing suitability, and field validation of the crossing suitability results in GIS.

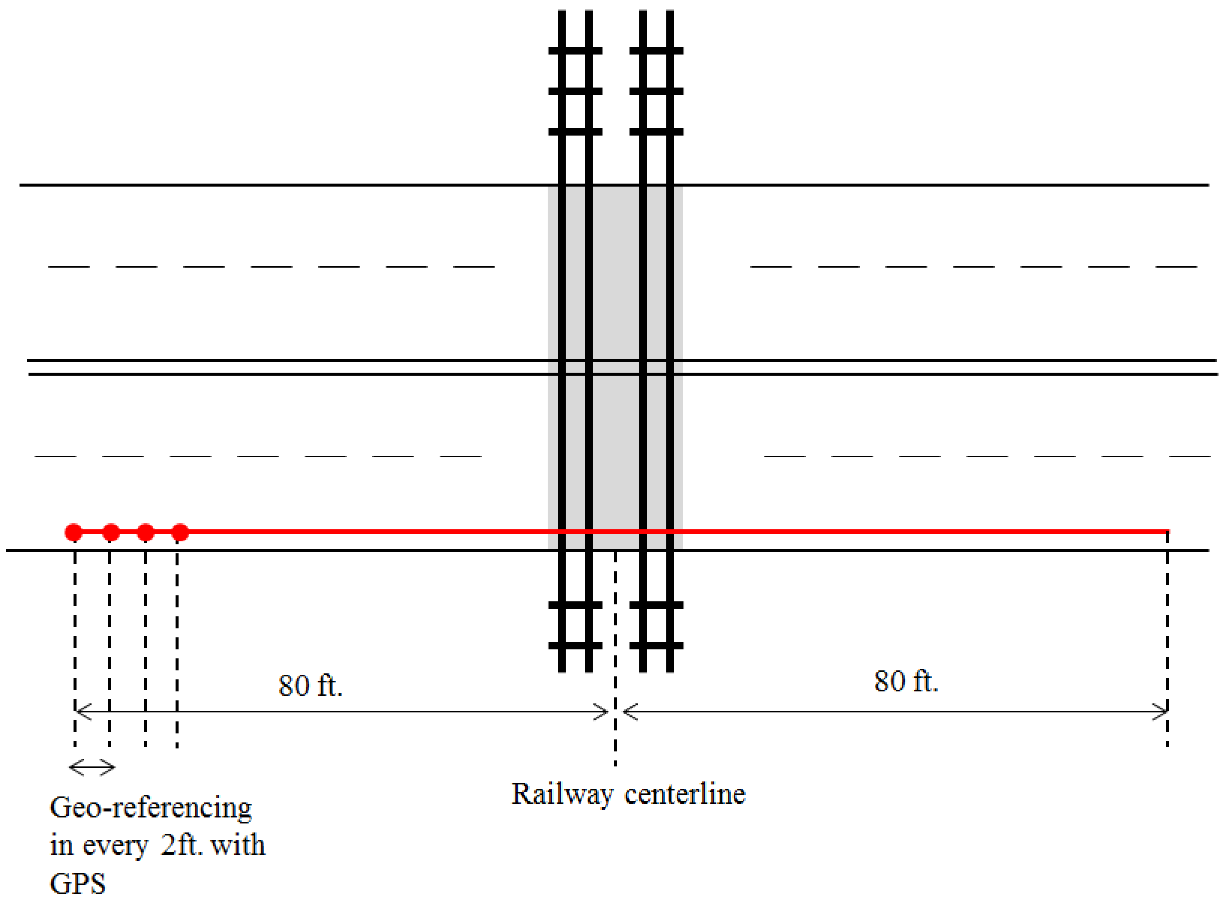

Figure 3.3 Geo-referencing at a rail grade crossing

3.2.2 Orthophotos and LiDAR Data

The ArcGIS online provided a 2013 orthophoto aerial image for Lincoln, Nebraska. The image was overlapped with LiDAR elevation data to illustrate and locate the target rail grade crossing areas. The LiDAR elevation data for the study area were obtained from the Nebraska

Department of Natural Resources (DNR). The data cover eastern Nebraska including Lancaster County, providing high-resolution digital elevation data with a ground sample distance (GSD) of 1.4 meters. The vertical accuracy was specified as having a root-mean-square error (RMSE) of 0.185 meters, while the horizontal accuracy was specified to meet a 0.60 meter RMSE. The LiDAR points included laser return information of class 1 (unclassified returns), class 2 (ground returns), and class 7 (low point and noise returns). The LiDAR point clouds were manipulated by Nebraska DNR to provide a 2 meter resolution digital elevation model (DEM) raster (cell size is 1 square meter). The coordinate system for the orthophotos and the LiDAR was NAD 1983 UTM Zone 14N for the representation of Lancaster County, Nebraska.

Chapter 4 Data Analysis

Geo-referenced points of 160-ft ranges for crossing roads and a 2 meter resolution LiDAR elevation raster were integrated in the study area orthophoto using ArcGIS. An autonomous relative accuracy test of the data was conducted to see how accurately the data represented elevation of the study area. To conduct the assessment, LiDAR elevation data pertaining to the geo-referenced points in the three rail grade crossings were obtained from the GIS database and verified against field observations obtained using a geopositioning system and a theodolite. The two corresponding groups of data were compared for relative accuracy.

Figure shows the aerial photos of the rail grade crossing geometry and vertical elevation profiles between LiDAR data and field-measured data. The geo-referenced points were obtained along the arrows shown in the figure. In a range of 160-ft, point spacing for each was 2-ft resulting in 81 elevation points at each site. For the three sites, there were 243 elevation sample points for both LiDAR and field measured elevation data. A list of the total LiDAR and field elevation geo-referenced points appears in Appendix B. RMSE for each pair of all 243 points were only 0.30-ft, so the authors decided to proceed with further analysis.

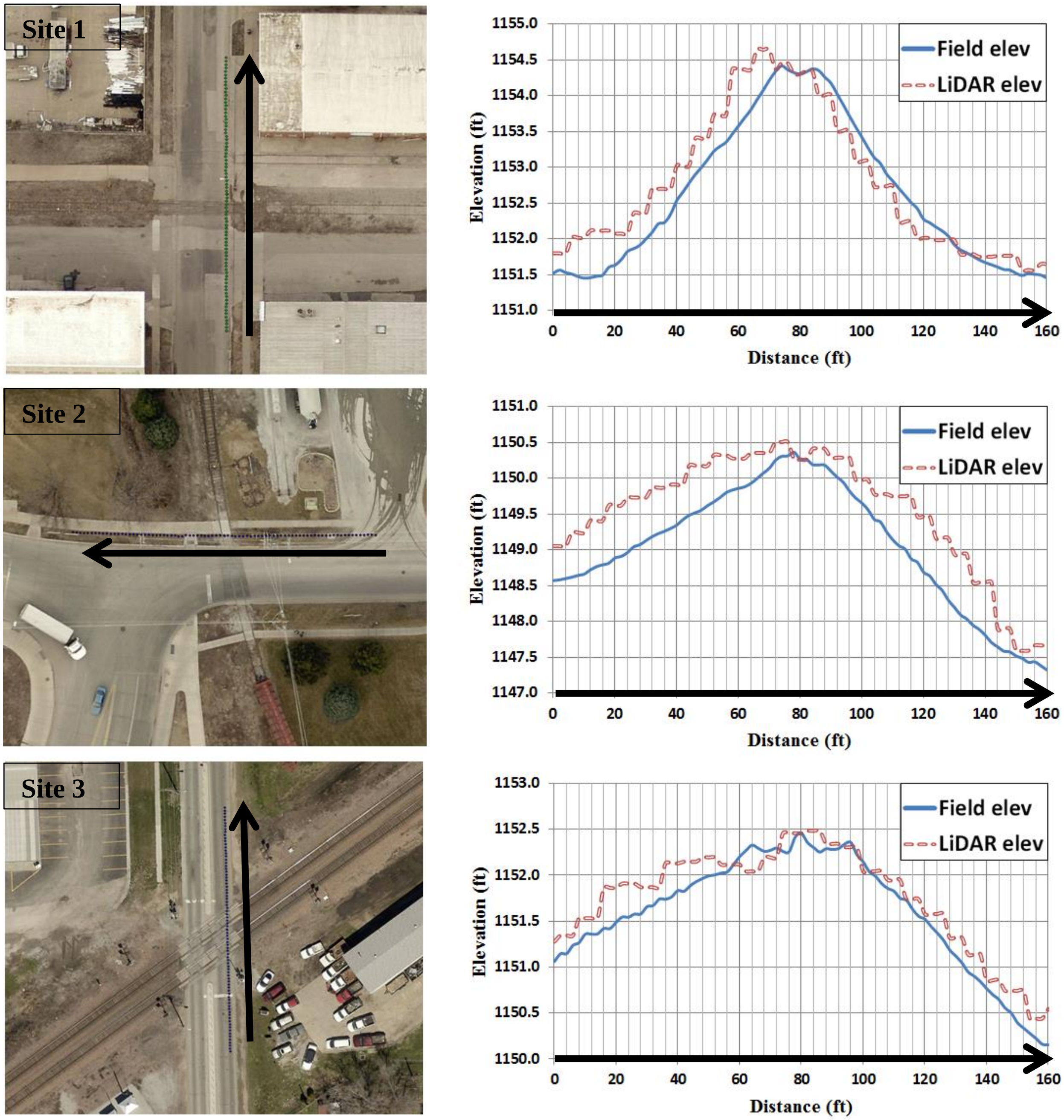

Figure 4.1 Comparison of vertical elevation profiles for LiDAR and field-measured data

4.1 Assessment of Crossing Suitability

Several design vehicles and their dimensions were utilized to assess crossing suitability. Reviewed literature provided information on the chosen design vehicles. Specifically, the selected vehicles were rear-loaded garbage trucks, aerial fire trucks, pumper fire trucks, school buses, lowboy trailers, and car carrier trailers; Table presents dimensions of these vehicles.

Table 4.1 Selected design vehicle dimensions [Source: French et al. (2002)]

Design Vehicle	Wheelbase [ft]	Front Overhang [ft]	Rear Overhang [ft]	Ground Clearance [in]		
				Wheelbase	Front Overhang	Rear Overhang
Rear-Load Garbage Truck	20	-	10.5	12	-	14
Aerial Fire Truck	20	7	12	9	11	10
Pumper Fire Truck	22	8	10	7	8	10
School Bus	23	-	13	7	-	11
Lowboy Trailers <53 feet	38	-	-	5	-	-
Car Carrier Trailer	40	-	14	4	-	6

Notes: - indicates no hang-up problems due to this part of the vehicle

Crossing suitability analysis was conducted using an imaginary box placed under the target vehicle such that the wheelbase and vehicle ground clearance were the two sides of a rectangular box, as shown in Figure . For design vehicles having critical values in their front and rear overhang parts, the box was also placed under the vehicle in that overhang length and vehicle ground clearance were the two sides of the box. The rule for safe passage across a humped highway-rail grade crossing was that the top side of the rectangular box should not touch any part of the rail crossing surface. If the straight line representing the top side of the rectangular box intersects with the crossing surface, the vehicle theoretically gets lodged on the rail crossing. Line-of-sight analysis capabilities of 3D Analyst in ArcGIS was used to identify if the straight line was obstructed. This analysis shows a graphic line between two points, and obstructions, if any, are noted. If obstructed, the 3D Analyst provides the location of the point of obstruction. Ground clearance of the designated design vehicles was represented in the line-of-sight analysis by setting the heights of observer and target equal to the ground clearance of the design vehicle.

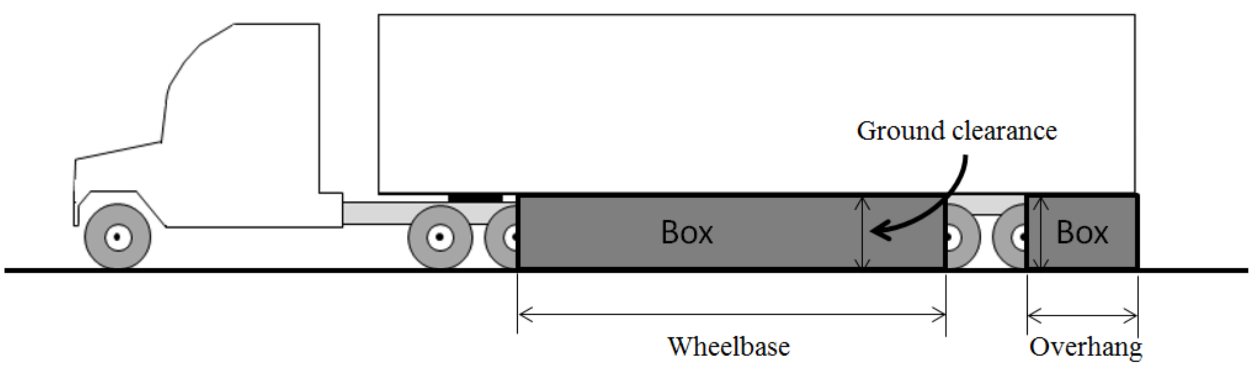

Figure 4.2 Semi trailer with imaginary box under the trailer

Small incremental placements of the rectangular box (representing a certain wheelbase and ground clearance or an overhang length and ground clearance) in GIS across a rail crossing allowed identification of a selected vehicle's crossing suitability at that crossing. Figure presents the crossing suitability of a trailer having a 38-ft wheelbase and a 5 inch ground clearance using the line-of-sight analysis at site 1. The imaginary trailer was moved in 2-ft increments along the roadway centerline until the tail part of the trailer completely passed the crossing to identify any obstructions. The observer point in the analysis was the front wheel of the trailer, and the target point was the rear wheel of the tractor. The result showed that a trailer would lodge or scratch the pavement at this site due to the identification of an obstructed point in the wheelbase.

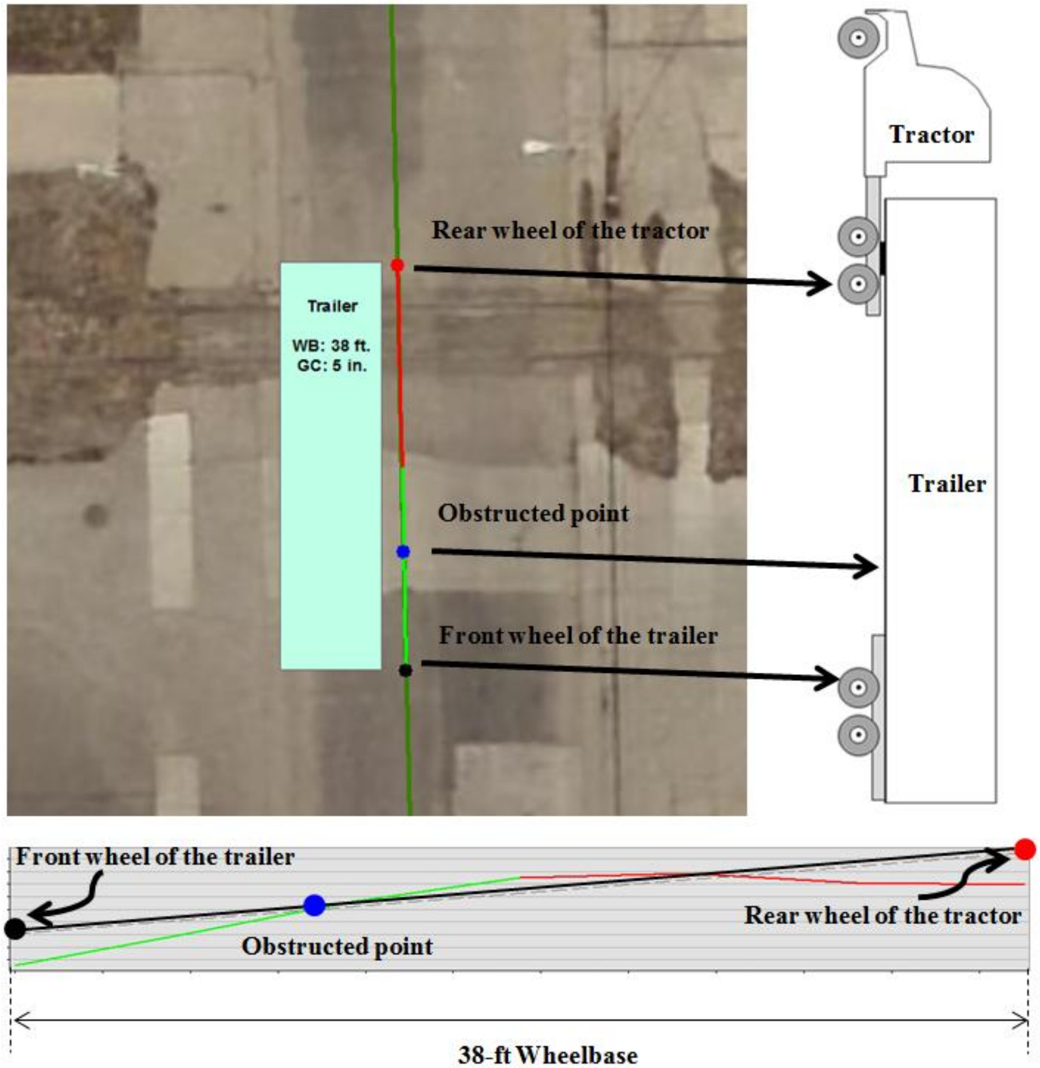

Figure 4.3 Identification of crossing suitability of a trailer with 38-ft wheelbase and 5 inches ground clearance at site 1

In the vertical profile chart, as shown in Figure , the straight line between the two wheels is obstructed by the surface of the highway-rail grade crossing, showing a potentially unsafe situation. In a similar manner, line-of-sight analysis was conducted for vehicles of different dimensions. It was noted that some design vehicles had front and rear overhang parts, which were taken into account during the analysis. For example, a rear-loaded garbage truck has a long rear overhang part for waste collection, which may drag on the pavement or cause the vehicle to become lodged on a crossing. Table presents the results of crossing suitability analysis for the three highway-rail grade crossing sites with different design vehicle dimensions. Vehicle hang-up problems were identified at site 1 for a lowboy trailer and a car carrier trailer that lodged at both site 1 and site 2. The front and rear parts of the considered design vehicles did not present issues at any of the sites based on this analysis.

Table 4.2 Result of crossing suitability of selected design vehicles

Design Vehicles	Site 1			Site 2			Site 3		
	Wheel Base	Front overhang	Rear overhang	Wheel Base	Front overhang	Rear overhang	Wheel Base	Front overhang	Rear overhang
Rear-Load Garbage Truck	No hang-up	NA	No hang-up	No hang-up	NA	No hang-up	No hang-up	NA	No hang-up
Aerial Fire Truck	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up
Pumper Fire Truck	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up	No hang-up
School Bus	No hang-up	NA	No hang-up	No hang-up	NA	No hang-up	No hang-up	NA	No hang-up
Lowboy Trailers <53 feet	Hang-up	NA	NA	No hang-up	NA	NA	No hang-up	NA	NA
Car Carrier Trailer	Hang-up	NA	No hang-up	Hang-up	NA	No hang-up	No hang-up	NA	No hang-up

NA: Not Applicable

4.2 Field Validation of Crossing Suitability Results

The GIS-derived crossing suitability assessment results were validated in the field using a level line laser instrument, a geopositioning surveying tool, and level rods. When a line laser was set at a certain distance from the railway centerline, the wheelbase distance of design vehicles were used to set a level rod from the line laser instrument. The height of the line laser instrument was set to be the ground clearance of the vehicle. Then it was observed if the laser beam reached the level rod at the same height of ground clearance without any obstruction from the crossing surface. If the straight line between the level line laser and level rod was uninterrupted, it implied a safe passage situation for the design vehicle (i.e., no hang-up issue). If the straight line between the level line laser and level rod was interrupted then the obstruction location was noted for later comparison with the crossing suitability results from the GIS. Figure and 4.5 illustrate field validation with the line laser instrument. A retro reflective lens was also used in a replacement of the level rod under the bright sunlight since laser beams were more clearly viewed by using it. Field validation results showed that all hang-up spots identified from the field validation process corresponded with the line-of-sight analysis results from the GIS, indicating that the adopted methodology successfully identified vulnerable rail grade crossings for the vehicle hang-up issue.

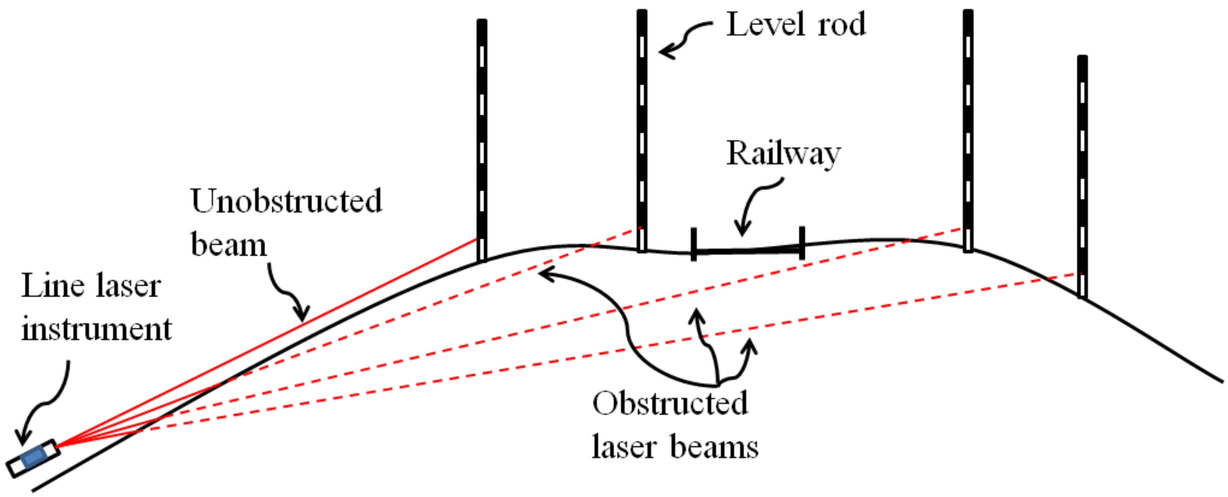

Figure 4.4 Illustration of the field validation of GIS-derived results

Figure 4.5 Field validation of crossing suitability using a line laser and a retro-reflective lens

Chapter 5 Conclusions and Recommendations

The objective of the research was to test and validate the feasibility of assessing humped highway-rail grade crossings for safe passage of vehicles with low ground clearance using LiDAR data. From amongst the selected design vehicles, the lowboy trailer was found susceptible to lodging at site 1 while the car carrier trailer was susceptible to lodging at sites 1 and 2. The passage of the other design vehicles (a rear-loaded garbage truck, two types of fire trucks, and a school bus) was not an issue at any of the three highway-rail grade crossing sites. Validation of the GIS-derived results in the field showed that all the identified blockage spots were correctly identified. The conclusion from the conducted research was that LiDAR data can be used for identifying potential hang-up issues at rail grade crossings.

This proposed method is efficient and safer because it avoids making measurements in the field where highway and train traffic may pose hazards to the safety of personnel. However, it is acknowledged that current updates to LiDAR data are infrequent and may not keep up with changes in the highway/rail networks. Therefore, any changes at or near highway-rail grade crossings after LiDAR data collection will likely require field assessment. This research only analyzed three highway-rail grade crossings; in future studies, more sites may be evaluated so the findings are more generalizable.

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Appendix A Specified Dataset Derived from TOPCON HiPer II (Geopositioning System)

Site 1			Site 2			Site 3		
Lattitude	Longitude	Distance (ft)	Lattitude	Longitude	Distance (ft)	Lattitude	Longitude	Distance (ft)
40.82335	-96.68994641	0	40.82455	-96.69540466	0	40.84081	-96.67276915	0
40.82335	-96.68994655	2	40.82455	-96.69539806	2	40.84082	-96.67276974	2
40.82336	-96.68994624	4	40.82455	-96.69539081	4	40.84082	-96.67276942	4
40.82337	-96.68994632	6	40.82455	-96.69538356	6	40.84083	-96.67276916	6
40.82337	-96.68994669	8	40.82455	-96.69537657	8	40.84084	-96.67276902	8
40.82338	-96.68994676	10	40.82455	-96.69536891	10	40.84084	-96.67276904	10
40.82338	-96.6899467	12	40.82455	-96.69536196	12	40.84085	-96.67276884	12
40.82339	-96.68994681	14	40.82455	-96.69535486	14	40.84085	-96.67276898	14
40.82339	-96.68994663	16	40.82455	-96.69534779	16	40.84086	-96.67276886	16
40.8234	-96.68994662	18	40.82455	-96.69534045	18	40.84086	-96.67276852	18
40.8234	-96.68994652	20	40.82455	-96.69533308	20	40.84087	-96.67276918	20
40.82341	-96.68994669	22	40.82455	-96.69532591	22	40.84087	-96.67276926	22
40.82341	-96.68994671	24	40.82455	-96.69531872	24	40.84088	-96.67276906	24
40.82342	-96.68994684	26	40.82455	-96.69531119	26	40.84088	-96.67276861	26
40.82343	-96.68994689	28	40.82455	-96.69530446	28	40.84089	-96.6727694	28
40.82343	-96.68994669	30	40.82454	-96.69529734	30	40.84089	-96.67276896	30
40.82344	-96.68994666	32	40.82454	-96.69528993	32	40.8409	-96.67276922	32
40.82344	-96.68994663	34	40.82454	-96.69528266	34	40.84091	-96.67276898	34
40.82345	-96.6899472	36	40.82454	-96.69527486	36	40.84091	-96.67276938	36
40.82345	-96.68994701	38	40.82454	-96.69526774	38	40.84092	-96.6727687	38
40.82346	-96.68994726	40	40.82454	-96.6952606	40	40.84092	-96.67276877	40
40.82346	-96.68994688	42	40.82454	-96.69525342	42	40.84093	-96.67276907	42
40.82347	-96.68994681	44	40.82454	-96.69524643	44	40.84093	-96.67276842	44
40.82347	-96.68994723	46	40.82454	-96.69523867	46	40.84094	-96.6727686	46
40.82348	-96.68994729	48	40.82454	-96.695232	48	40.84094	-96.67276866	48
40.82349	-96.6899473	50	40.82454	-96.69522536	50	40.84095	-96.67276875	50
40.82349	-96.68994704	52	40.82454	-96.6952178	52	40.84096	-96.67276888	52
40.8235	-96.68994712	54	40.82454	-96.69521086	54	40.84096	-96.67276895	54
40.8235	-96.68994697	56	40.82454	-96.69520427	56	40.84097	-96.67276874	56
40.82351	-96.68994692	58	40.82454	-96.6951973	58	40.84097	-96.67276888	58

40.82351	-96.68994693	60	40.82454	-96.69519022	60	40.84098	-96.67276912	60
40.82352	-96.68994677	62	40.82454	-96.69518251	62	40.84098	-96.67276947	62
40.82352	-96.68994666	64	40.82454	-96.6951754	64	40.84099	-96.67276914	64
40.82353	-96.68994687	66	40.82454	-96.69516831	66	40.84099	-96.67276954	66
40.82354	-96.68994672	68	40.82454	-96.69516091	68	40.841	-96.67276955	68
40.82354	-96.6899461	70	40.82454	-96.6951541	70	40.84101	-96.6727693	70
40.82355	-96.68994676	72	40.82454	-96.695147	72	40.84101	-96.67276949	72
40.82355	-96.68994611	74	40.82454	-96.69513996	74	40.84102	-96.67276914	74
40.82356	-96.68994616	76	40.82454	-96.69513274	76	40.84102	-96.67276949	76
40.82356	-96.68994553	78	40.82454	-96.6951257	78	40.84103	-96.67276962	78
40.82357	-96.68994503	80	40.82454	-96.69511787	80	40.84103	-96.67276946	80
40.82357	-96.68994572	82	40.82454	-96.69511036	82	40.84104	-96.6727688	82
40.82358	-96.68994609	84	40.82454	-96.69510296	84	40.84104	-96.67276839	84
40.82358	-96.68994581	86	40.82454	-96.69509621	86	40.84105	-96.6727686	86
40.82359	-96.68994575	88	40.82454	-96.69508876	88	40.84105	-96.672768	88
40.8236	-96.68994753	90	40.82454	-96.69508168	90	40.84106	-96.67276878	90
40.8236	-96.68994756	92	40.82454	-96.69507403	92	40.84107	-96.67276887	92
40.82361	-96.68994767	94	40.82454	-96.69506668	94	40.84107	-96.67276769	94
40.82361	-96.6899476	96	40.82454	-96.69505992	96	40.84108	-96.67276856	96
40.82362	-96.68994719	98	40.82454	-96.69505286	98	40.84108	-96.67276852	98
40.82362	-96.68994753	100	40.82454	-96.69504575	100	40.84109	-96.67276831	100
40.82363	-96.68994763	102	40.82454	-96.695038	102	40.84109	-96.67276833	102
40.82363	-96.68994726	104	40.82454	-96.69503127	104	40.8411	-96.67276809	104
40.82364	-96.68994714	106	40.82454	-96.69502364	106	40.8411	-96.67276739	106
40.82364	-96.68994665	108	40.82454	-96.6950165	108	40.84111	-96.67276766	108
40.82365	-96.68994641	110	40.82454	-96.69500926	110	40.84112	-96.67276799	110
40.82366	-96.68994584	112	40.82454	-96.69500179	112	40.84112	-96.67276763	112
40.82366	-96.6899458	114	40.82454	-96.69499414	114	40.84113	-96.67276787	114
40.82367	-96.68994785	116	40.82454	-96.69498738	116	40.84113	-96.6727679	116
40.82367	-96.68994797	118	40.82454	-96.69498054	118	40.84114	-96.67276703	118
40.82368	-96.68994709	120	40.82454	-96.69497324	120	40.84114	-96.67276793	120
40.82368	-96.68994719	122	40.82454	-96.69496592	122	40.84115	-96.67276799	122
40.82369	-96.68994752	124	40.82454	-96.69495921	124	40.84115	-96.67276788	124
40.82369	-96.6899478	126	40.82454	-96.69495152	126	40.84116	-96.67276778	126

40.8237	-96.68994777	128	40.82454	-96.694945	128	40.84116	-96.67276777	128
40.8237	-96.68994786	130	40.82454	-96.69493777	130	40.84117	-96.67276758	130
40.82371	-96.68994761	132	40.82454	-96.69493068	132	40.84117	-96.67276774	132
40.82372	-96.68994769	134	40.82454	-96.69492299	134	40.84118	-96.67276809	134
40.82372	-96.68994763	136	40.82454	-96.69491574	136	40.84119	-96.67276778	136
40.82373	-96.68994701	138	40.82454	-96.6949088	138	40.84119	-96.67276789	138
40.82373	-96.68994779	140	40.82454	-96.69490143	140	40.8412	-96.67276811	140
40.82374	-96.68994756	142	40.82454	-96.69489466	142	40.8412	-96.67276849	142
40.82374	-96.68994801	144	40.82454	-96.6948873	144	40.84121	-96.67276749	144
40.82375	-96.68994804	146	40.82454	-96.69487983	146	40.84121	-96.67276745	146
40.82375	-96.68994811	148	40.82454	-96.6948728	148	40.84122	-96.67276755	148
40.82376	-96.68994777	150	40.82454	-96.69486556	150	40.84122	-96.67276753	150
40.82376	-96.68994764	152	40.82454	-96.69485845	152	40.84123	-96.67276799	152
40.82377	-96.68994754	154	40.82453	-96.69485141	154	40.84124	-96.67276733	154
40.82378	-96.68994758	156	40.82454	-96.69484403	156	40.84124	-96.67276741	156
40.82378	-96.68994739	158	40.82454	-96.69483674	158	40.84125	-96.67276763	158
40.82379	-96.68994757	160	40.82453	-96.69482916	160	40.84125	-96.6727673	160

Appendix B LiDAR and Field Elevation Data on Geo-referenced Points at Three Rail Grade Crossings in the Study Area

Site 1			Site 2			Site 3		
Distance (ft)	Field elevation (ft)	LiDAR elevation (ft)	Distance (ft)	Field elevation (ft)	LiDAR elevation (ft)	Distance (ft)	Field elevation (ft)	LiDAR elevation (ft)
0	1151.520	1151.798	0	1148.570	1149.052	0	1151.060	1151.276
2	1151.563	1151.798	2	1148.580	1149.052	2	1151.145	1151.345
4	1151.528	1151.798	4	1148.598	1149.052	4	1151.146	1151.345
6	1151.508	1152.014	6	1148.618	1149.239	6	1151.236	1151.345
8	1151.472	1152.014	8	1148.643	1149.239	8	1151.266	1151.532
10	1151.450	1152.014	10	1148.661	1149.239	10	1151.358	1151.532
12	1151.457	1152.113	12	1148.721	1149.409	12	1151.359	1151.532
14	1151.476	1152.113	14	1148.766	1149.409	14	1151.361	1151.532
16	1151.493	1152.113	16	1148.791	1149.409	16	1151.421	1151.864
18	1151.603	1152.113	18	1148.814	1149.619	18	1151.419	1151.864
20	1151.633	1152.074	20	1148.887	1149.619	20	1151.487	1151.864
22	1151.708	1152.074	22	1148.908	1149.619	22	1151.545	1151.909
24	1151.823	1152.074	24	1148.960	1149.728	24	1151.543	1151.909
26	1151.862	1152.356	26	1149.040	1149.728	26	1151.578	1151.909
28	1151.909	1152.356	28	1149.071	1149.728	28	1151.578	1151.87
30	1151.997	1152.356	30	1149.127	1149.728	30	1151.658	1151.87
32	1152.089	1152.697	32	1149.183	1149.866	32	1151.670	1151.87
34	1152.209	1152.697	34	1149.226	1149.866	34	1151.741	1151.87
36	1152.227	1152.697	36	1149.258	1149.866	36	1151.739	1152.129
38	1152.343	1152.697	38	1149.298	1149.908	38	1151.765	1152.129
40	1152.533	1153.018	40	1149.345	1149.908	40	1151.833	1152.129
42	1152.653	1153.018	42	1149.422	1149.908	42	1151.825	1152.149
44	1152.779	1153.018	44	1149.482	1150.174	44	1151.886	1152.149
46	1152.897	1153.399	46	1149.518	1150.174	46	1151.931	1152.149
48	1152.995	1153.399	48	1149.555	1150.174	48	1151.965	1152.195
50	1153.105	1153.399	50	1149.618	1150.174	50	1151.993	1152.195
52	1153.221	1153.727	52	1149.669	1150.322	52	1152.003	1152.195
54	1153.290	1153.727	54	1149.729	1150.322	54	1152.024	1152.116
56	1153.349	1153.727	56	1149.798	1150.322	56	1152.036	1152.116
58	1153.462	1154.364	58	1149.834	1150.276	58	1152.115	1152.116
60	1153.574	1154.364	60	1149.858	1150.276	60	1152.202	1152.116
62	1153.690	1154.364	62	1149.879	1150.276	62	1152.267	1152.044
64	1153.800	1154.364	64	1149.927	1150.351	64	1152.328	1152.044

66	1153.939	1154.639	66	1149.995	1150.351	66	1152.295	1152.044
68	1154.071	1154.639	68	1150.069	1150.351	68	1152.261	1152.195
70	1154.212	1154.639	70	1150.139	1150.351	70	1152.272	1152.195
72	1154.334	1154.37	72	1150.250	1150.502	72	1152.297	1152.195
74	1154.415	1154.452	74	1150.305	1150.502	74	1152.261	1152.457
76	1154.360	1154.452	76	1150.311	1150.502	76	1152.255	1152.457
78	1154.320	1154.301	78	1150.362	1150.263	78	1152.415	1152.457
80	1154.301	1154.301	80	1150.263	1150.263	80	1152.457	1152.457
82	1154.330	1154.344	82	1150.265	1150.263	82	1152.356	1152.484
84	1154.371	1154.344	84	1150.189	1150.407	84	1152.302	1152.484
86	1154.351	1154.006	86	1150.185	1150.407	86	1152.253	1152.484
88	1154.257	1154.006	88	1150.180	1150.407	88	1152.290	1152.343
90	1154.173	1154.006	90	1150.095	1150.285	90	1152.280	1152.343
92	1154.021	1153.511	92	1150.013	1150.285	92	1152.290	1152.343
94	1153.870	1153.511	94	1149.940	1150.285	94	1152.339	1152.306
96	1153.714	1153.511	96	1149.817	1150.285	96	1152.357	1152.306
98	1153.563	1153.081	98	1149.721	1149.974	98	1152.223	1152.306
100	1153.422	1153.081	100	1149.653	1149.974	100	1152.147	1152.044
102	1153.272	1153.081	102	1149.558	1149.974	102	1152.039	1152.044
104	1153.136	1152.733	104	1149.425	1149.777	104	1151.990	1152.044
106	1153.055	1152.733	106	1149.388	1149.777	106	1151.910	1152.044
108	1152.906	1152.733	108	1149.250	1149.777	108	1151.856	1151.949
110	1152.809	1152.733	110	1149.139	1149.744	110	1151.827	1151.949
112	1152.704	1152.238	112	1149.055	1149.744	112	1151.749	1151.949
114	1152.606	1152.238	114	1149.010	1149.744	114	1151.729	1151.739
116	1152.505	1152.238	116	1148.872	1149.744	116	1151.632	1151.739
118	1152.422	1152.011	118	1148.825	1149.465	118	1151.553	1151.739
120	1152.275	1152.011	120	1148.686	1149.465	120	1151.522	1151.578
122	1152.225	1152.011	122	1148.634	1149.465	122	1151.443	1151.578
124	1152.165	1151.982	124	1148.515	1149.16	124	1151.372	1151.578
126	1152.111	1151.982	126	1148.433	1149.16	126	1151.295	1151.578
128	1152.040	1151.982	128	1148.295	1149.16	128	1151.188	1151.322
130	1151.918	1151.982	130	1148.196	1148.934	130	1151.121	1151.322
132	1151.845	1151.788	132	1148.091	1148.934	132	1151.046	1151.322
134	1151.805	1151.788	134	1148.033	1148.934	134	1150.947	1151.139
136	1151.758	1151.788	136	1147.946	1148.543	136	1150.900	1151.139
138	1151.707	1151.749	138	1147.889	1148.543	138	1150.841	1151.139
140	1151.669	1151.749	140	1147.805	1148.543	140	1150.766	1150.856
142	1151.639	1151.749	142	1147.705	1148.543	142	1150.699	1150.856
144	1151.607	1151.762	144	1147.644	1147.894	144	1150.645	1150.856
146	1151.572	1151.762	146	1147.584	1147.894	146	1150.553	1150.742

148	1151.564	1151.762	148	1147.573	1147.894	148	1150.499	1150.742
150	1151.519	1151.762	150	1147.517	1147.592	150	1150.394	1150.742
152	1151.487	1151.565	152	1147.484	1147.592	152	1150.335	1150.742
154	1151.516	1151.565	154	1147.429	1147.592	154	1150.278	1150.44
156	1151.504	1151.565	156	1147.436	1147.664	156	1150.223	1150.44
158	1151.495	1151.647	158	1147.380	1147.664	158	1150.160	1150.44
160	1151.452	1151.647	160	1147.321	1147.664	160	1150.153	1150.545