Exhibit F - UTCRS

UTC Project Information	
Project Title	Improving Safety at Rural Highway-Rail Grade Crossings by Utilizing Light Detection and Ranging (LiDAR) Technology
University	University of Nebraska-Lincoln (UNL)
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Funding Source(s) and Amounts Provided (by each agency or organization)	Federal Funds (USDOT UTC Program): $75,284 Cost Share Funds (UNL): $37,642
Total Project Cost	$112,926
Agency ID or Contract Number	DTRT13-G-UTC59
Start and End Dates	November 2013 – December 2015
Brief Description of Research Project	The objective of this research is to test and validate the feasibility of a computer- based tool that safety analysts can use to quickly assess rural highway-rail grade crossings for large truck traffic in case of an emergency or route closure situation. The suitability of many rural highway-rail grade crossings for use by large trucks with trailers is a concern because of the possibility of trucks getting stuck on the rail tracks when excessive grade difference exists between the rails and approach surface of the crossing highway. While trucks usually ply on designated routes, emergencies and highway closures may necessitate re- routing of trucks to rural highways with grade crossings that may not have the safe geometry needed for large trucks with trailers. Therefore, it would be useful to have a computer-based tool and relevant data by which analysts could quickly assess crossing suitability without the need for field visits.

<table>
<tr><td></td><td>The availability of Light Detection and Ranging (LiDAR) data for most of NE makes the possibility of developing a computer-based tool that allows analysts to assess the suitability of highway-rail crossings for large vehicles a possibility. LiDAR data are usually collected using an appropriately-equipped airplane that flies and collects the locations of millions of points on the Earth’s surface. Using geographic information systems (GIS) software, the point cloud can be converted into a terrain model replicating the surface profile. LiDAR data are available for most of Nebraska and in many cases free of cost. This research will develop a computer-based tool utilizing LiDAR data that will allow users to assess the suitability of rural highway-rail grade crossings for use by large trucks. Field validation of the results from the tool will be carried out as part of this research.</td></tr>
<tr><td>Describe Implementation of Research Outcomes (or why not implemented)

Place Any Photos Here</td><td><u>Data Analysis</u>

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 geo-positioning system and a theodolite. The two corresponding groups of data were compared for relative accuracy. Figure 4.1 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.</td></tr>
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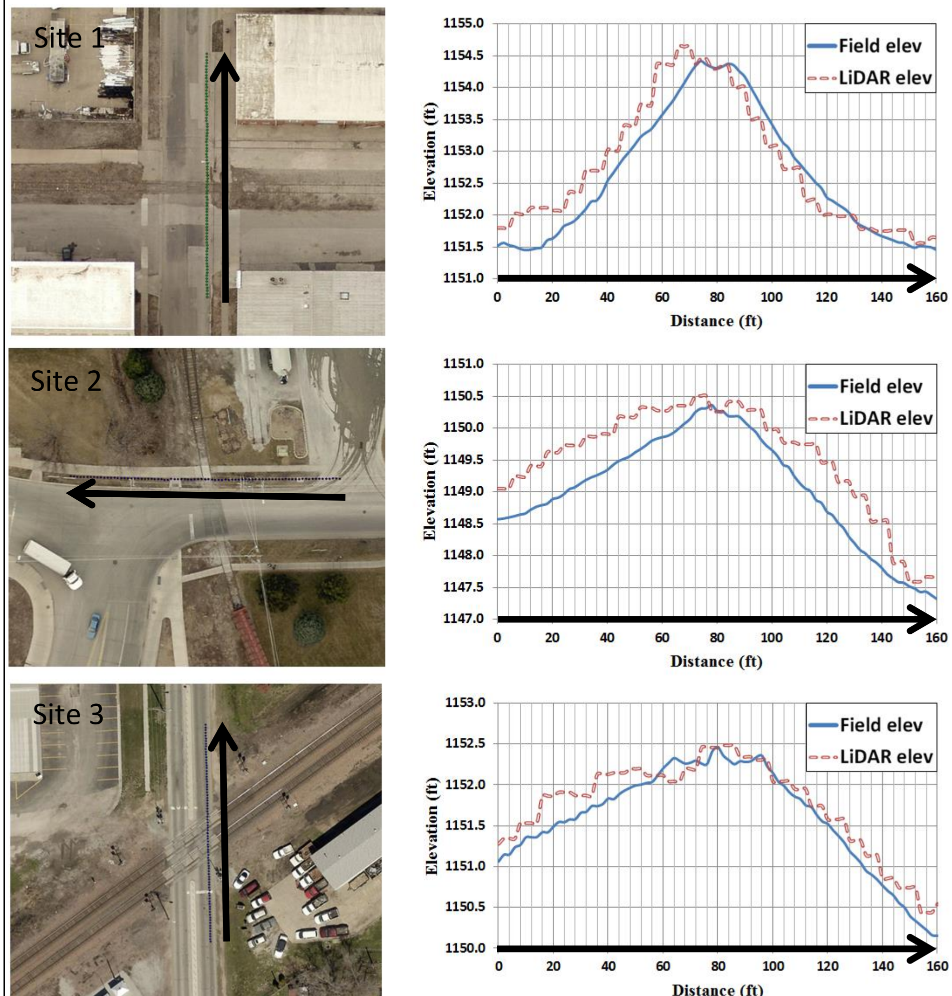

Figure 4.1 Comparison of vertical elevation profiles for LiDAR and field-measured data

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 4.1** presents dimensions of these vehicles.

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

Design Vehicle	Wheel Base [ft]	Front Overhang [ft]	Rear Overhang [ft]	Ground Clearance (in)		
				Wheel Base	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

Note: “-“ 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 4.2**. 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.

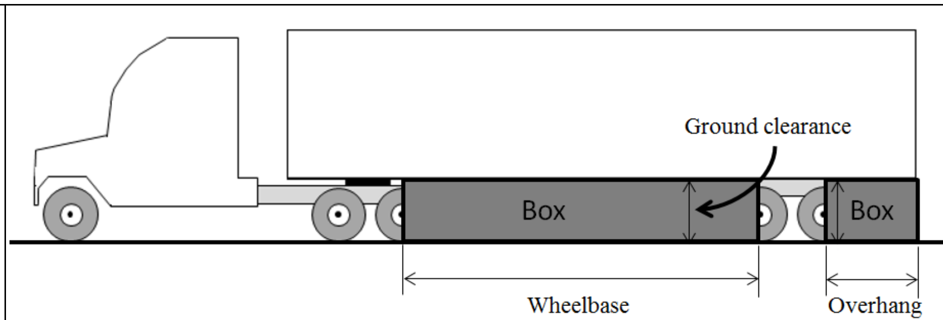

Figure 4.2 Semi-trailer with imaginary box under the trailer

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.

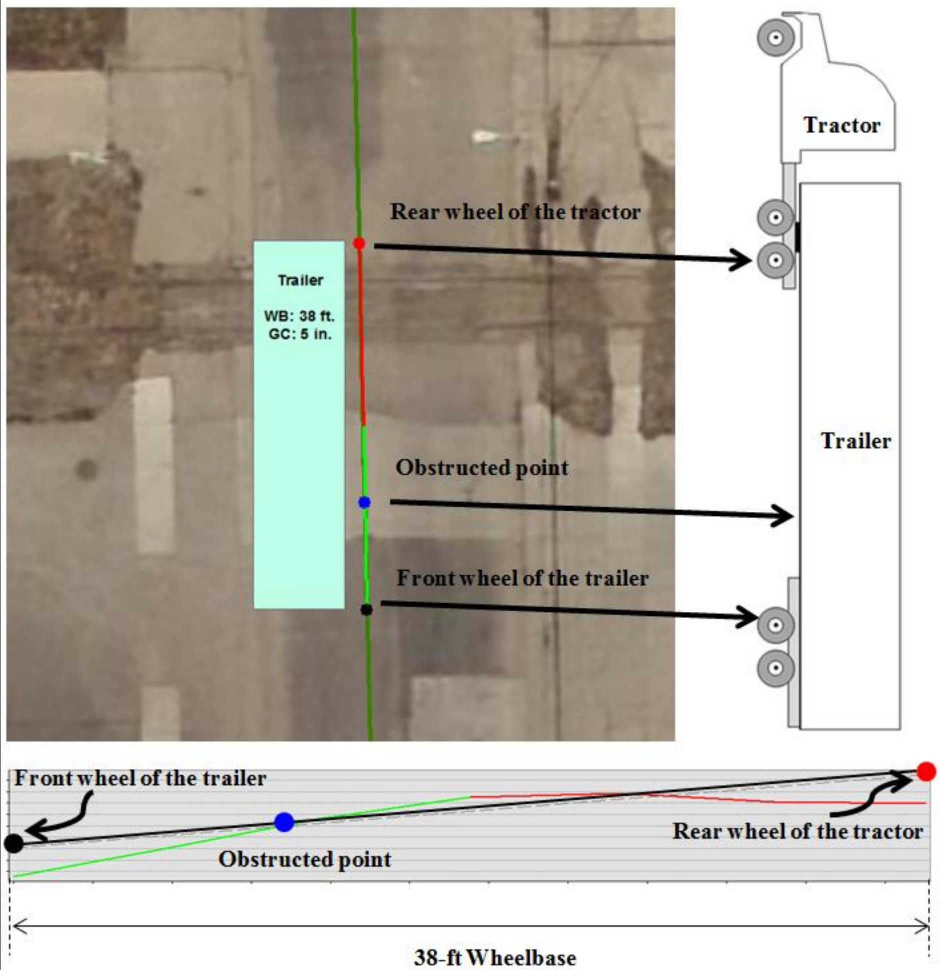

Figure 4.3 Identification of crossing suitability of a trailer with 38-ft wheelbase and 5 inches ground clearance at Site 1

Figure 4.3 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. In the vertical profile chart, as shown in **Figure 4.3**, 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 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

Table 4.2 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.

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 geo-positioning 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. **Figures 4.4** 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.

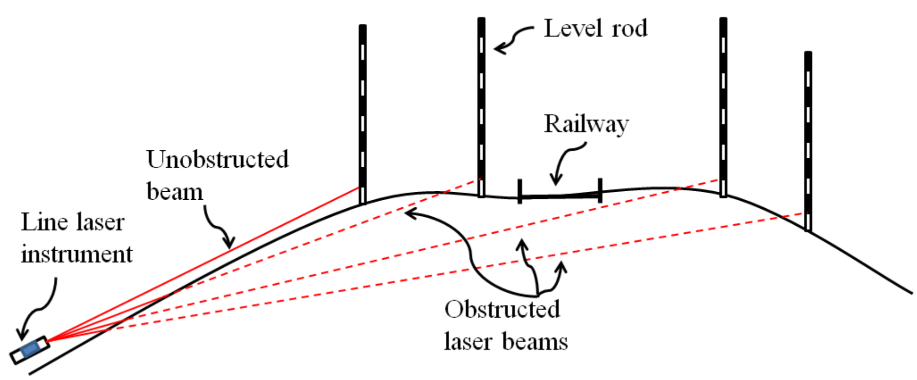

Figure 4.4 Illustration of the field validation of GIS-derived results

	 **Figure 4.5** Field validation of crossing suitability using a line laser and a retro-reflective lens
Impacts/Benefits of Implementation (actual, not anticipated)	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.

	Moreover, work on this project has resulted in one paper presentation at the Transportation Research Board 96th Annual Meeting: • Kang, Y. and Khattak, A., "A Cluster-Based Approach to Analyze Crash Injury Severity at Highway-Rail Grade Crossings," *Proceedings of the Transportation Research Board 96th Annual Meeting*, Washington, D.C., January 9, 2017. Additionally, a detailed report that summarizes all the work performed under this project is made available and can be downloaded from the UTCRS website using the link provided below.
Web Links • Reports • Project website	http://www.utrgv.edu/railwaysafety/_files/documents/reports/LiDAR_Project_Final_Report_022816.pdf http://www.utrgv.edu/railwaysafety/research/operations/ improving-safety-at-hrgc-by-using-lidar-technology/index.htm