

Remote Sensing (LIDAR) for Management of Highway Assets for Safety

APPLICATION OF ADVANCED REMOTE SENSING TECHNOLOGY
TO ASSET MANAGEMENT

Final Report—October 2003

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EXECUTIVE SUMMARY

The main objective of this study was to utilize Light Detection and Ranging (LIDAR) technology to obtain highway safety-related information. The safety needs of older drivers in terms of prolonged reaction times were taken into consideration. Older drivers were considered because their crash fatality rate is the highest among all age-based groups in the U.S. and the proportion of their population is increasing with time. The tasks undertaken in this study were (1) identification of crashes that older drivers are more likely to be involved in, (2) identification of highway geometric features that are important in such crashes, (3) utilization of LIDAR data for obtaining information on the identified highway geometric features, and (4) assessment of the feasibility of using LIDAR data for such applications.

A review of previous research indicated that older drivers have difficulty negotiating intersections, and it was recognized that intersection sight triangles were critical to safe intersection negotiation. LIDAR data were utilized to obtain information on potential sight distance obstructions at six selected intersections located on the Iowa Highway 1 corridor by conducting in-office line-of-sight analysis. Crash frequency, older driver involvement, and data availability were considerations in the selection of the six intersections. Results of the in-office analysis were then validated by visiting the intersections in the field. A video camera and passenger car were utilized during the validation process.

Sixty-six potential sight distance obstructions were identified by the line-of-sight analysis, out of which 62 (89.8%) were confirmed while four (5.8%) were not confirmed by the video. At least three (4.4%) potential sight distance obstructions were discovered in the video that were not detected by the line-of-sight analysis. The intersection with the highest crash frequency involving older drivers was correctly found to have obstructions located within the intersection sight triangles.

Based on research results, it is concluded that LIDAR data can be utilized for identifying potential sight distance obstructions at intersections. The safety of older drivers can be enhanced by locating and rectifying intersections with obstructions in sight triangles. LIDAR data are a relatively new source for enhancing highway safety, and further investigation regarding transportation safety-related applications is recommended.

1. INTRODUCTION

This study was focused on the assessment of Light Detection and Ranging (LIDAR) technology for collecting information on highway elements that are important from the user safety perspective. LIDAR is a technology that collects information about a surface by sending thousands of light beams per second and then catching them when the beams reflect off the surface. By so doing, the surface profile is collected as a “digital signature” that can be used in a variety of applications. Although LIDAR data have been used in mapping and contouring, their use for collection of highway-related information has not yet been fully investigated. Transportation agencies can potentially benefit from this new source of data in terms of acquisition of new capabilities and/or reduced data collection costs.

The main objective of this study was to utilize LIDAR data to obtain highway safety-related information. The safety needs of older drivers in terms of prolonged reaction times were taken into consideration. Older drivers were considered because their traffic crash fatality rate is the highest among all age-based groups in the U.S. and their proportion in the population is increasing with time. The tasks undertaken in this study were (1) identification of crashes that older drivers are more likely to be involved in, (2) identification of highway geometric features that are important in such crashes, (3) utilization of LIDAR data for obtaining information on the identified highway geometric features, and (4) assessment of the feasibility of using LIDAR data for such applications.

The organization of this report is as follows. Chapter 1 is the introduction. Chapter 2 presents findings from a literature review that targeted safety aspects of older drivers. A review of intersection sight distance and LIDAR technology is also part of this chapter. Chapter 3 describes the research methodology and data utilized in this research. This chapter also includes information on the various data merge processes undertaken to accomplish the line-of-sight analysis. Chapter 4 describes the line-of-sight analysis, its results, and the validation of those results. This chapter also provides brief information on the analysis costs. Chapter 5 presents the conclusions and recommendations from this research. Three appendices and a reference section complete this report.

2. LITERATURE REVIEW

Pertinent literature was reviewed on three major topics to obtain the needed background information for this research. These topics were safety of older drivers, intersection sight distance, and LIDAR technology. Major findings from the literature under each of the three topics are reported below. A summary is provided at the end of this chapter.

2.1. Older Driver Safety

According to the National Highway Traffic Safety Administration (NHTSA 2000), there were 18.5 million older licensed drivers in 1999, which was 10% of all licensed drivers. In 1999, 171,000 older individuals were injured in traffic crashes, accounting for 5% of all the people injured in traffic crashes during that year. These older individuals made up 13% of all traffic fatalities in 1999. Several studies have indicated that older drivers as a group experience one of the highest crash rates per vehicle mile of travel (Cerrelli 1992; Retchin and Anapolle 1993; Massie, Campbell, and Williams 1998).

According to NHTSA (1998), one of the principal concerns surrounding older drivers is their ability to safely maneuver intersections. Previous research appears to confirm this notion (Hakamies-Blomqvist 1993; Preusser et al. 1998). The NHTSA study further indicated that about one-third of older driver fatalities occurred at intersections, and this figure jumped to more than half for drivers over the age of 80 years. Further, McGwin and Brown (1998) indicated that perception and reaction related problems cause older drivers to have more problems on roadways where sight distances are restricted and the skill level required to negotiate hills and curves is higher.

In two reports to NHTSA by Staplin et al. (1998a, 1998b), intersection negotiation problems of older drivers stemming from various behaviors (e.g., failure to yield and failure to stop at a stop sign) have been categorized into five categories. These include behaviors related to signs and signals, behaviors related to lane use, behaviors related to turns, behaviors related to unsafe vehicle control, and unsafe behaviors when reacting to traffic. Table A.1 in Appendix A provides a summary of the various behaviors under these categories. Various physical capabilities that diminish with advancing age have been investigated and found significant in intersection-negotiation-related problems experienced by older drivers. These include sensory and perceptual capabilities, cognitive capabilities, and psychomotor capabilities (Staplin et al. 1998, 1998b). Vision has been found critical in many driving tasks, and a reduction in vision including acuity and spatial contrast sensitivity can lead to many of the behaviors reported in Table A.1.

2.2. Intersection Sight Distance

The topic of intersection sight distance was reviewed because older drivers experience significant problems negotiating intersections and reduced vision is one of the main reasons for these problems. According to the American Association of State Highway and Transportation Officials (AASHTO) *A Policy on Geometric Design of Highways and Streets* (2001, hereafter

referred to as the Green Book), the possibility of conflicts occurring at intersections can be greatly reduced through provision of proper sight distances. To avoid collisions, the driver of a vehicle approaching an intersection should have clear view of the entire intersection to allow safe stopping. The Green Book specifies that areas along intersecting roads must be clear of obstructions; these are known as intersection sight triangles. The dimensions of these triangles depend on traffic control (stop sign, yield sign, etc.), grades, and design speeds of the intersecting roads. Exhibit 9-50 from the Green Book illustrating clear sight triangles is reproduced below as Figure 2.1.

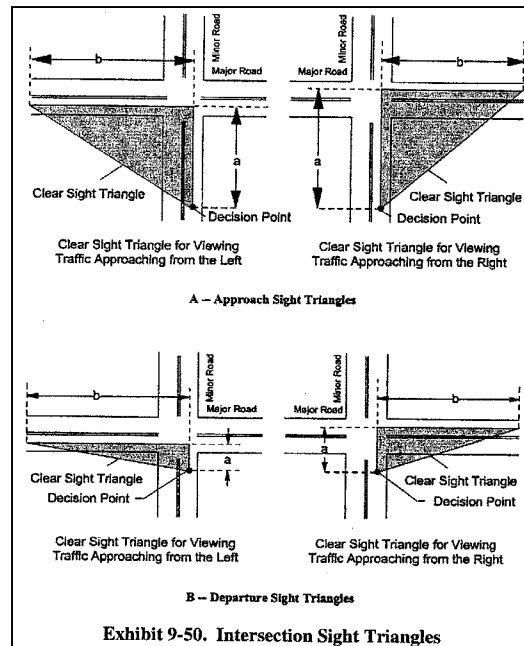


Figure 2.1. Illustration of the clear sight triangles

Depending on the type of intersection control, several cases are discussed in the Green Book. These include Case A, intersections with no control; Case B, intersections with stop control on the minor road; Case C, intersections with yield control on the minor road; Case D, intersections with traffic signal control; Case E, intersections with all-way stop control; and Case F, left turns from the major road. Cases B and C have subcases depending on left-turn, right-turn, or through maneuvers from the minor road. The Green Book provides guidance on the dimensions of sight triangles depending on the type of case.

2.3. LIDAR Technology

Traditional methods of infrastructure-related data collection, which primarily rely on someone making measurements in the field, are tedious and costly. Data acquisition from airborne or spaceborne vehicles provides new opportunities in this respect. Collection of data through remote sensing technology has yielded highly precise elevation data and high-resolution site data (Miotto 2000). Developments in laser technology and remote sensing complimented by developments in the global positioning system (GPS), precision inertial aircraft guidance, laser

range-finding, and high-speed computer processing have helped in the evolution of LIDAR technology for collection of elevation data. LIDAR uses the same principle as RADAR; the LIDAR instrument transmits light at a target. The transmitted light interacts with and is changed by the target. Some of this light is reflected/scattered back to the instrument where it is analyzed. The change in the properties of the light enables some property of the target to be determined. The time for light to travel to the target and back to the LIDAR is used to determine the distance between the LIDAR instrument and the target.

LIDAR is finding favor with agencies involved in the planning of corridor expansion projects and study of roadway features. The main advantage of using LIDAR to acquire elevation data is time-savings, which is demonstrated by a study reported by Langston and Walker (2001). Using a LIDAR-equipped helicopter, data were collected for digital terrain model (DTM) of a 42-mile long, 1,500-foot wide highway corridor. The process resulted in the saving of \$1.5 million and at least nine months time. Another cost saving study is reported by Stone (1999) in which the Savannah Area Geographic Information System (SAGIS) utilized LIDAR to collect countywide one to two foot contour intervals needed for drainage improvements to the Hardin Canal. The agency estimated savings of \$7 million in construction costs. Other benefits of LIDAR include the ability to survey without setting foot on the ground thus allowing access to inaccessible areas and reduced chance of injury to the survey crew.

The research team did not find highway safety-related applications of the LIDAR technology in the reviewed literature. The reason for this is might be the limited experience of transportation community with this technology.

2.4. Literature Summary

Literature on three topics relevant to this research was reviewed. From this review, it is clear that older drivers are over-involved in crashes and their injuries tend to be more severe compared to drivers of other ages. Older drivers experience significant problems while negotiating intersections. A variety of behaviors on part of older drivers contribute to unsafe driving conditions at intersections. Reductions in sensory and perceptual capabilities, cognitive capabilities, psychomotor capabilities, and dementia contribute to these behaviors. The topic of intersection sight distance was reviewed since older drivers experience intersection-negotiation problems and reduced vision is one of the main reasons for those problems. Finally, a review of literature on LIDAR technology indicated that use of the technology can result in considerable savings in data collection. However, its potential for safety-related applications needs exploration.

3. RESEARCH METHODOLOGY AND DATA CHARACTERISTICS

This chapter describes the methodology adopted for conducting this research. The focus was on developing a methodology that would allow the research team to evaluate clear sight triangles at intersections that have experienced significant older driver crashes 1996–2000. This chapter also provides information on the characteristics of the various data sets and processes utilized to combine those data sets in a geographic information system (GIS).

3.1. Research Methodology

Figure 3.1 presents the adopted methodology for this research. It consists of acquiring data from several sources and then combining those data in a GIS. The acquired data consisted of geocoded crashes, geocoded aerial images, and LIDAR output. After acquisition, these data were combined in ArcView (ESRI) GIS software for in-office analysis. The analysis was focused on utilizing the data to obtain information on obstructions in the intersection sight triangles at selected intersections. Results of the in-office analysis were then field validated.

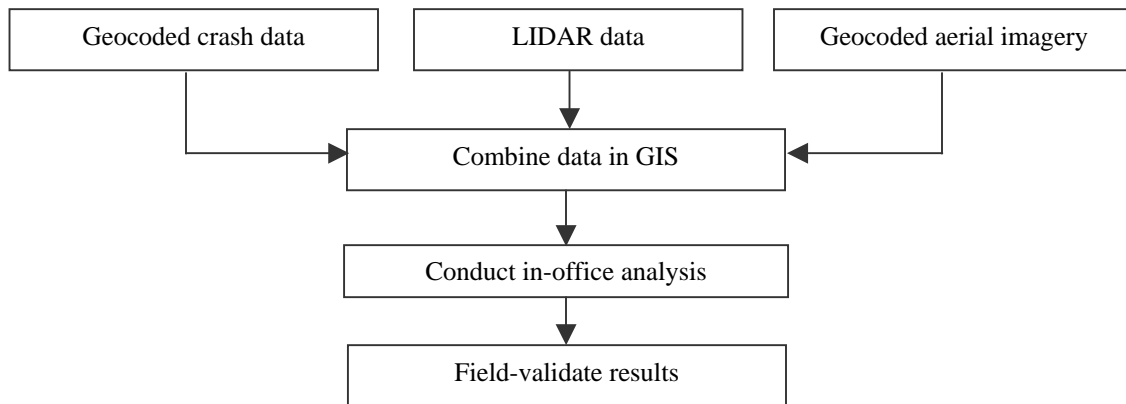


Figure 3.1. Adopted research methodology

3.2. Data Characteristics

The study corridor, passing through Linn and Johnson Counties, Iowa, consisted of the northern section of the Iowa Highway 1 Solon bypass (see Figure 3.2). Part of the study corridor is rural in nature while the part passing through the city of Solon is urbanized. The corridor receives significant traffic during morning and evening because of its proximity to the University of Iowa. As mentioned before, crash data, aerial images, and LIDAR data were acquired for the study area. Each data set, its reduction, and processes to merge the data sets are described below.

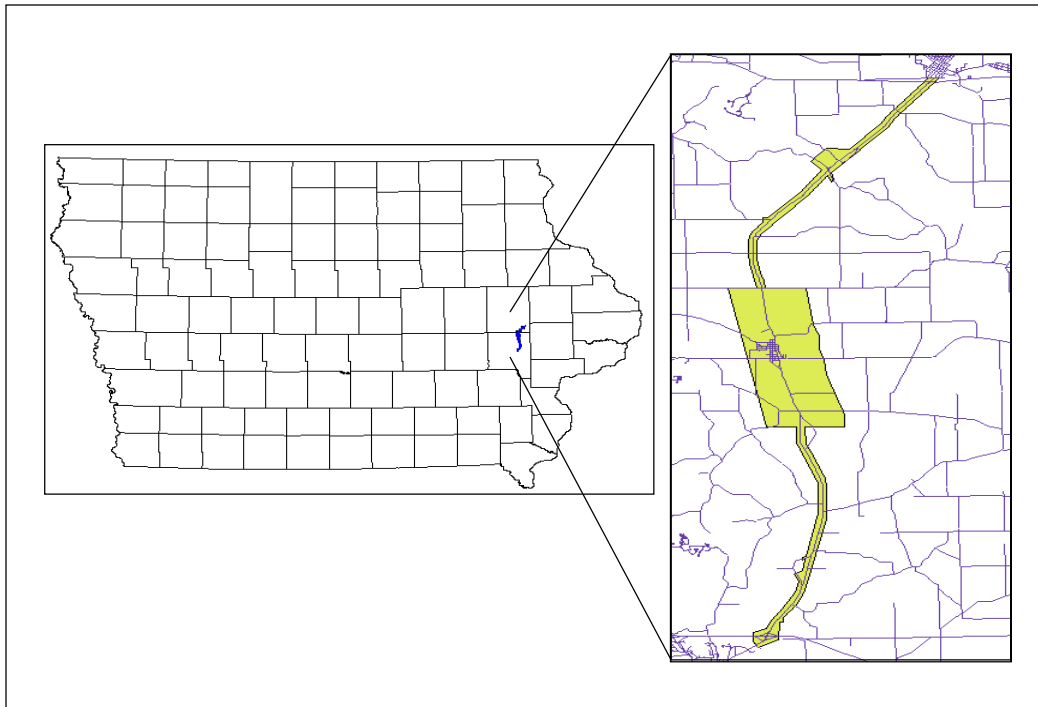


Figure 3.2. Study corridor

3.2.1. Crash Data

Five-year (1996–2000) crash data for the study corridor were acquired from the Center for Transportation Research and Education (CTRE) Accident Location and Analysis System (ALAS) in ArcView shapefile format (UTM projection). These crash data consisted of three files: one each for crash-related information, involved vehicles, and involved persons. Utilizing information contained in these files, crashes that occurred at intersections were identified. After identification of intersection-related crashes, the respective vehicle and person information for those crashes was extracted.

3.2.2. Aerial Imagery and LIDAR Data

EagleScan, Inc., collected aerial imagery and LIDAR data for the study corridor on two different days. The LIDAR data utilized in this project consisted of both the first return and the last return. The former constitutes x, y, z readings for points that LIDAR hits first (e.g., tree canopy), while the latter constitutes last hits of the LIDAR (e.g., returns that penetrate through tree canopy). The research team acquired these data from CTRE. Aerial images were in geotiff format with a spatial resolution of two meters while the LIDAR data were in ASCII format. The coordinate system utilized was state plane and map units were in meters. In view of the large size of the image and LIDAR data files, EagleScan divided the study area into smaller portions (bounds). The imagery consisted of 12 bounds while the LIDAR data consisted of 69 bounds. ASCII files for each LIDAR bound contained approximately 500,000 data points. These files were converted to ArcView shapefiles for subsequent analysis. This process was repeated for bounds needed in

the analysis utilizing both the first return and last return data. Figure 3.3 shows a sample orthophoto and LIDAR data converted to ArcView point shapefile format.

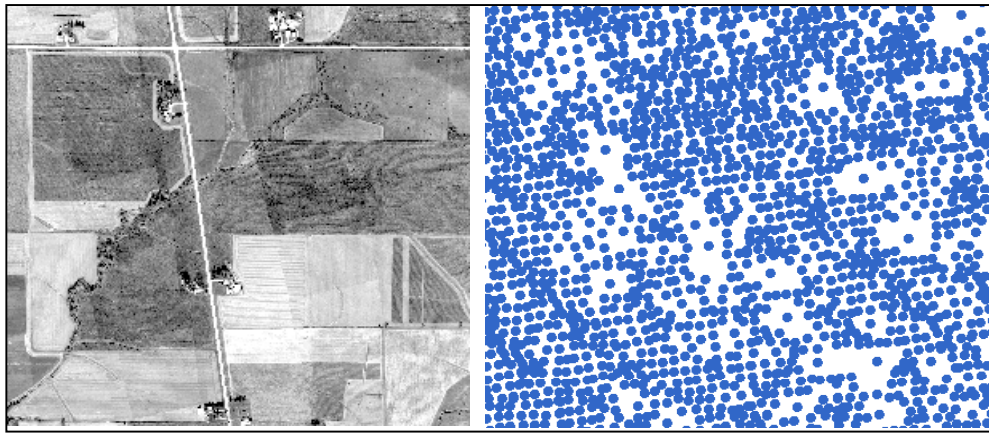


Figure 3.3. Sample orthophoto and converted LIDAR data

The LIDAR point shapefiles were converted to three-dimensional (3D) shapefiles by incorporating height information in ArcView and finally to triangular irregular networks (TINs). Figure 3.4 shows a sample 3D TIN of a small portion of the study corridor passing through the city of Solon, Iowa. Considerable time was needed for these conversions on a computer with a 1.0 gigahertz processor and 256 kilobytes of random-access memory.

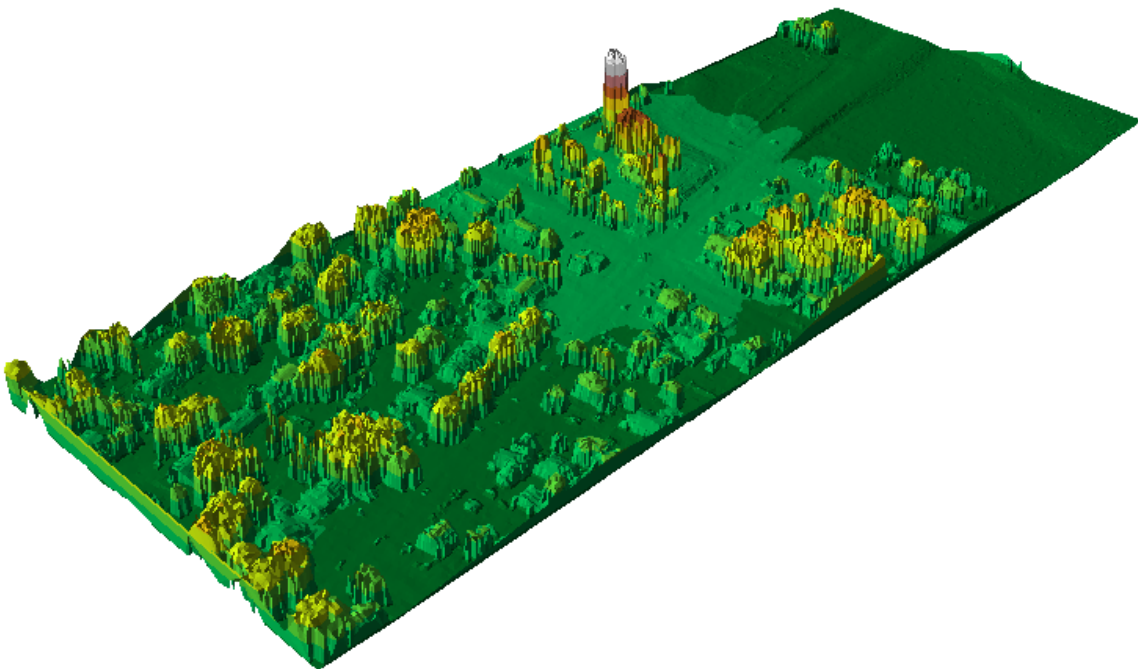


Figure 3.4. Sample 3D TIN of the study corridor passing through Solon, Iowa

3.2.3. Data Merge Processes

Intersection sight triangles that span different bounds are difficult to analyze in ArcView because sight lines cannot be drawn across bounds. Intersection number 433888, which had a history of high crash frequency, was contained in Bounds 27 and 28. To avoid problems associated with multiple bounds, the shapefiles of the two bounds were merged using ArcView’s geoprocessing tool.

The acquired data were in different projections (see Table 3.1). The desired projection was state plane since the LIDAR data and orthophotos were already in this projection. Therefore, the crash data and statewide boundary and the study corridor were converted to the state plane projection by using the ArcView’s projection utility. The map units were in meters and the distance units were set to feet in ArcView.

To line up 12 bounds of orthophotos to 69 bounds of and LIDAR data correctly in ArcView, a trial and error process was used. An orthophoto bound was opened in ArcView and all 69 LIDAR files superimposed on it to see which files corresponded to the opened orthophoto. The LIDAR files that corresponded to a particular orthophoto were renamed so that subsequent identification of orthophotos and LIDAR data was simple. The trial and error process was time-consuming because of the large number and large size of the files. Figure A.1 in Appendix A shows the various LIDAR bounds correctly matched to the orthophotos. After conversion of all data sets to the state plane projection and correct matching of orthophotos and LIDAR data, the various data were added to an ArcView project for analysis.

Table 3.1. Original and desired projections of the different data sets

Data source	Original projection	Desired projection
Crash data	UTM 1983, Zone 15	
Orthophotos	State plane, Iowa south, NAD 83	State plane, Iowa south, NAD 83
LIDAR data	State plane, Iowa south, NAD 83	
Study corridor and statewide boundary	UTM 1983, Zone 15	

4. DATA ANALYSIS

The study area contained a total of 72 intersections, out of which 29 were major intersections and 43 were driveways (mostly non-commercial). For each of those 72 intersections, the number of intersection-related crashes was found. Table 4.1 provides intersection-related crash frequency information. Due to higher entering traffic volumes, many more crashes were reported at major intersections than at driveways. Eight intersections with three or more crashes reported during 1996–2000 were identified for further analysis. Because crashes are rare events, intersections with three or more crashes were selected to focus on potentially problematic intersections. Table 4.2 shows the selected eight intersections. Of these eight selected intersections, two (142213 and 146552) had insufficient LIDAR coverage and therefore they were dropped from the analysis.

Table 4.1. Crash Frequency-related information for intersections in the study area

Study area attribute	Number	Crash Frequency	Mean frequency (std. dev.)
Major intersections	29	57	1.965 (2.822)
Driveways	43	4	0.930 (0.294)
Total intersections	72	61	0.847 (2.011)

Table 4.2. Intersections with three or more crashes reported 1996–2000

ID	Crash frequency	Location
142213	3	Ivanhoe Rd. and Iowa 1
146552	5	Palisades Rd., S. Seventh St, and Iowa 1
433389	12	E. Fifth St. and Market St.
433588	5	E. Third St. and Market St.
433788	4	E. First St. and Market St.
433888	3	Short St. and Market St.
433988	8	Main St. and Market St.
434288	5	E. Rock St. and Market St.

Figure 4.1 shows the six selected intersections for which complete LIDAR data coverage was available. The zoomed view of each intersection in Figure 4.1 shows the intersecting roads in greater detail. The crashes appear to be off the road but this is due to minor discrepancies in overlaying the crash layer on the aerial imagery. All six intersections, located within the city of Solon, had stop control on the minor intersecting road. Iowa Highway 1 running north-south through Solon is named Market Street and is the major road through the six intersections. Its intersections with East Third Street and East Rock Street are three-legged while the other four intersections are four-legged.

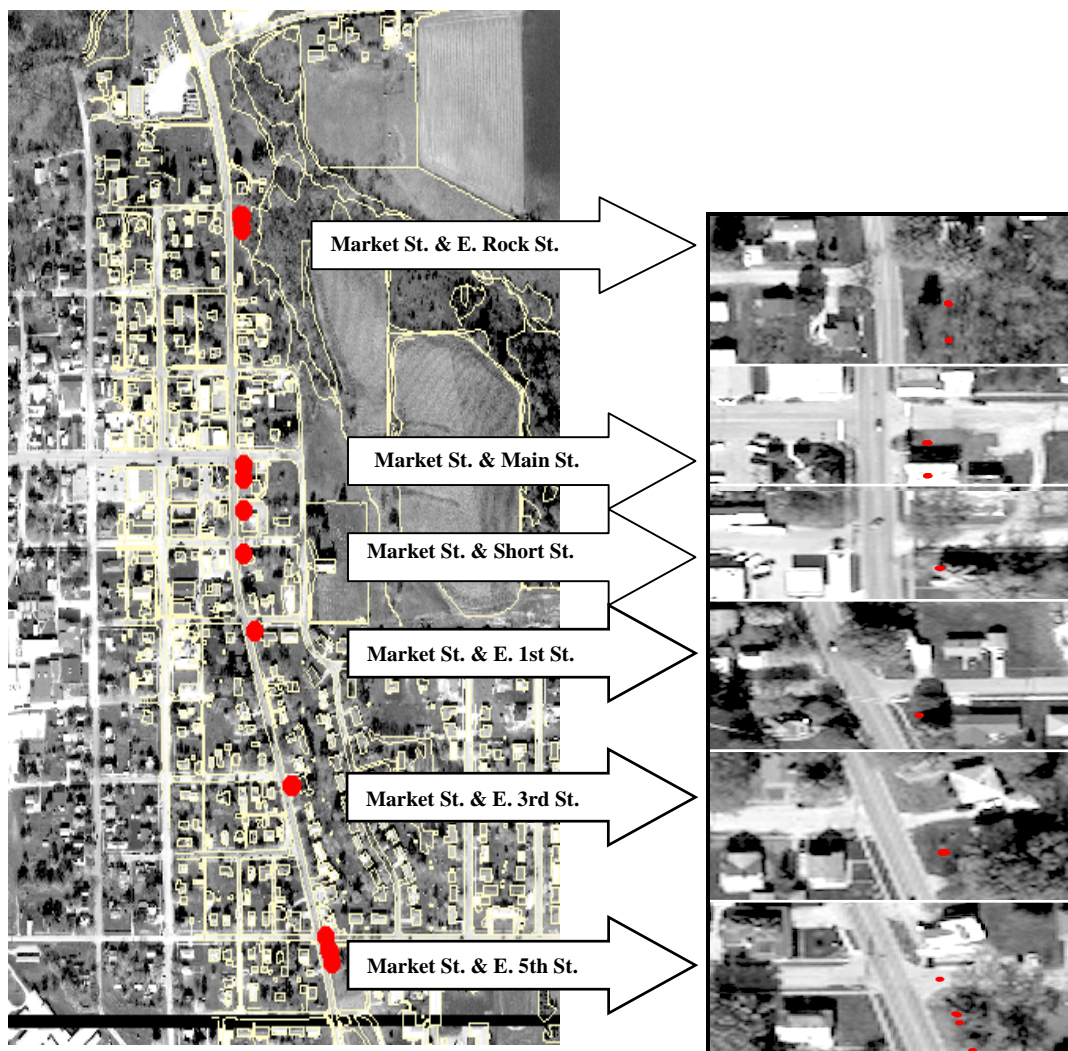


Figure 4.1. Six selected intersections and crash locations

Using the person file, information was obtained on driver age to ascertain if older drivers were involved. Table 4.3 presents information on the number of occupants involved and older driver age and gender. Crashes at the intersection of Market Street and East Fifth Street involved the most older drivers. Even though some of the intersections did not involve any older driver, they were not excluded from the analysis as the possibility of a future crash involving an older driver cannot be ruled out. Next, in-office line-of-sight analysis was carried out using both the first return and last return data.

Table 4.3. Crash information on occupants and age/gender of older drivers

Location	Crash frequency	No. of occupants involved	Age and gender of older drivers*
Market St. and E. Fifth St.	12	42	73M, 70M, 68M, 77F
Market St. and E. Third St.	5	18	74M, 76M
Market St. and E. First St.	4	11	68M
Market St. and Short St.	3	15	Unknown
Market St. and Main St.	8	23	<65
Market St. and E. Rock St.	5	22	<65

* M = male; F = female.

4.1. Line-of-Sight Analysis

Given a TIN, ArcView’s 3D analyst extension can analyze the sight line of an observer looking at a target. An analyst specifies the location of an observer, the observer’s eye height, the location of a target, and the height of the target. Utilizing this input, ArcView calculates if the observer has a clear line of sight to the target and if not, identifies the locations of obstructions. Line-of-sight analysis capabilities of ArcView were utilized to verify intersection sight triangles at the selected six intersections using TINs created from both the first return and last return data.

Observer eye height and target height information was obtained from the Green Book. The observer’s eye height (synonymous with the driver’s eye height) is specified at 3.5 feet above the roadway surface while the target to be seen is also specified as 3.5 feet above the roadway surface. The use of equal heights for both driver’s eye and target ensures that if a driver on the minor road can see a driver on the main road then the driver on the main road can also see the driver on the minor road.

Calculation of the dimensions of intersection sight triangles was based on Case B since all of six selected intersections had stop control on the minor intersecting roads. The Green Book recommends that departure sight triangles for intersections with stop control on the minor road should be considered for three situations: Case B1, left turn from the minor road; Case B2, right turn from the minor road; and Case B3, crossing the major road from a minor-road approach. The situation that requires the largest clear sight triangle is termed the critical case since satisfaction of its requirements ensures that the other two cases are also satisfied. Intersection sight triangles needed for the three cases were calculated based on guidance from the Green Book and a design speed of 40 mph for the major road (Iowa 1), passenger car as the design vehicle, and the driver’s decision point located 20.4 feet from the center of the closest major road lane. Appendix B provides the intersection sight triangle calculations for all three cases. These calculations indicated that Case B1 (left turn from the minor road) was critical.

Multiple lines of sight were drawn to evaluate obstructions within sight triangles at the six selected intersections utilizing TINs created from both the first return and last return data. A

distance of 100 feet along the major road was maintained between successive sight lines. Travel-way edge lines, median line, and shoulder edge lines were drawn over orthophotos for the six intersections with the help of the graphic tool in ArcView. This aided in the clear demarcation of the traveled way edge lines, which were otherwise difficult to recognize. The vertex of the sight triangle (decision point for the driver on the minor road) was located at 20.4 feet (distance “a” in Figure 2.1) from the center of the closest main road lane. Leg “b” (445 feet) of the sight triangle was marked along the center of the nearest lane in the northern direction to provide enough sight distance to view vehicles approaching from the north. Similarly, a distance of 445 feet was measured along the center of the farthest lane in the southern direction to provide sight distance for viewing vehicles approaching from the south. Sight lines were drawn over TIN themes, starting at the stopped driver’s position until the marked target position at 445 feet, and then at every 100 feet intervals along leg “b” of the sight triangles (see Figure 4.2).

Figure 4.2 shows sight triangles drawn on the northern side of the intersection of Market and East Fifth Streets. The analysis is based on a TIN created from the first return data. The light gray and dark gray portions of a sight line indicate the visible and non-visible portions of the driver’s field of view. An obstruction of a sight line is marked by a dark gray point (dot) representing the location of a potential sight distance obstruction. The distances between the dark gray dots and the location of the driver stopped on the minor road were measured. For example, in the eastern sight triangle in Figure 4.2, an obstruction was detected at about 127 feet from the location of the driver on the minor road. Following a similar process, all six intersections were analyzed using TINs created from both first return and last return data. Table 4.4 presents a summary of the findings from the line-of-sight analysis.

The driver position in Table 4.4 is the side of the intersection where a driver on the minor road will stop before negotiating the intersection. Since all of the minor intersecting roads run east-west, the stopped driver’s position can be either east or west of the Market Street. The sight triangle position refers to the location of the sight triangle on either side of the minor road and it can be north or south of the minor road. The distance of the detected potential obstructions refers to the distance of the blue dots obtained during the line-of-sight analysis from the driver stopped on the minor road. For example, analysis of first return data indicated a potential sight obstruction north of East Fifth Street at 127 feet from the driver stopped on the east side of Market Street. Looking at the distance from the driver at which these possible obstructions were detected indicates that the detected possible obstructions are not always the same in the first return and last return data sets.

The results of in-office line-of-sight analysis of the five intersections indicated 66 potential obstructions on the various minor approaches while no potential obstructions were detected on three of the minor approaches. To validate the existence of these obstructions, the city of Solon was visited and intersection sight triangles verified using video equipment. The next section presents details of the validation process.

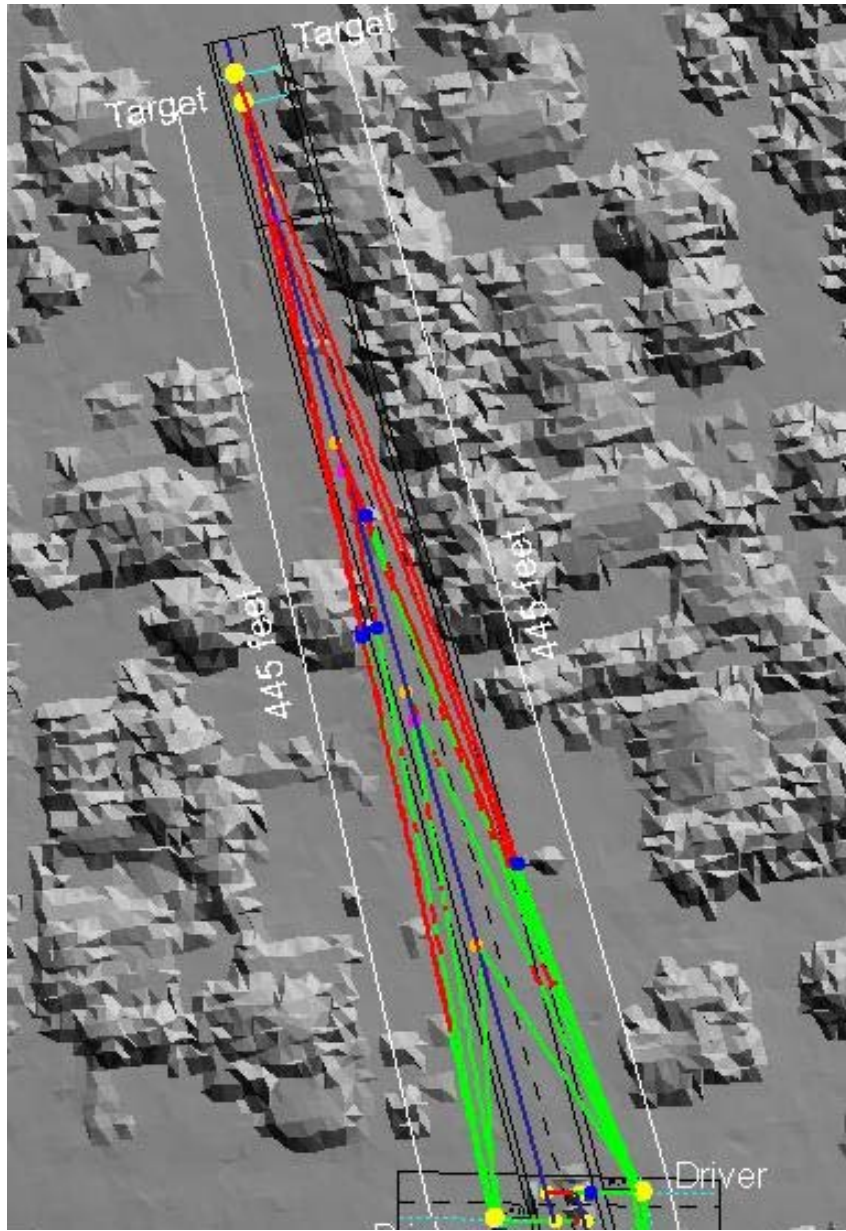


Figure 4.2. Multiple lines of sight at 100-ft interval along the major road (Market St. and E. Fifth St.)

Table 4.4. Summary results of intersection sight triangle analysis

Location	Driver position	Sight triangle position	Distance of detected potential obstruction from driver stopped on minor road (ft)						
			First return				Last return		
Market St. and E. Fifth St.	East	North	127	-	-	-	224	228	-
	East	South	54	59	56	-	59	61	-
	West	North	213	225	-	-	230	-	-
	West	South	5	8	-	-	87	94	132
Market St. and E. Third St.	West	North	32	38	-	-	52	107	
	West	South	341	375	-	-	376	-	-
Market St. and E. First St.	East	North	20	23	-	-	24	-	-
	East	South	74	97	-	-	74	98	
	West	North	47	-	-	-	-	-	-
	West	South	30	-	-	-	29	-	-
Market St. and Short St.	East	North	3	14	-	-	7	-	-
	East	South	33	-	-	-	46	53	-
	West	North	22	35	-	-	50	58	88
	West	South	13	-	-	-	-	-	-
Market St. and Main St.	East	North	26	-	-	-	33	-	-
	East	South	36	41	56	-	76	154	-
	West	North	54	60	-	-	60	67	-
	West	South	55	-	-	-	80	90	-
Market St. and E. Rock St.	West	North	116	143	309	330	116	323	-
	West	South	-	-	-	-	46	-	-

4.2. Field Validation

To validate the results of in-office line-of-sight analysis, a three-person crew utilized a digital video camera and a passenger car to identify obstructions in the sight triangles. The field validation setup is illustrated in Figure 4.3. A digital video camera was placed on a tripod at Point A at a height of 3.5 feet and 20.4 feet from the center of the main road's closest lane. A passenger car with 3.5 feet marked on each side was driven by one of the crew members at a constant speed of 25 mph in both directions on the main road. Points B and D were locations when the passenger car was first visible to the camera operator. While the vehicle was driven, another crew member recorded its motion between points B and C1 (vehicle southbound) and points D and C2 (vehicle northbound). The last crew member, responsible for the safety of the camera operator, directed traffic on the minor road.

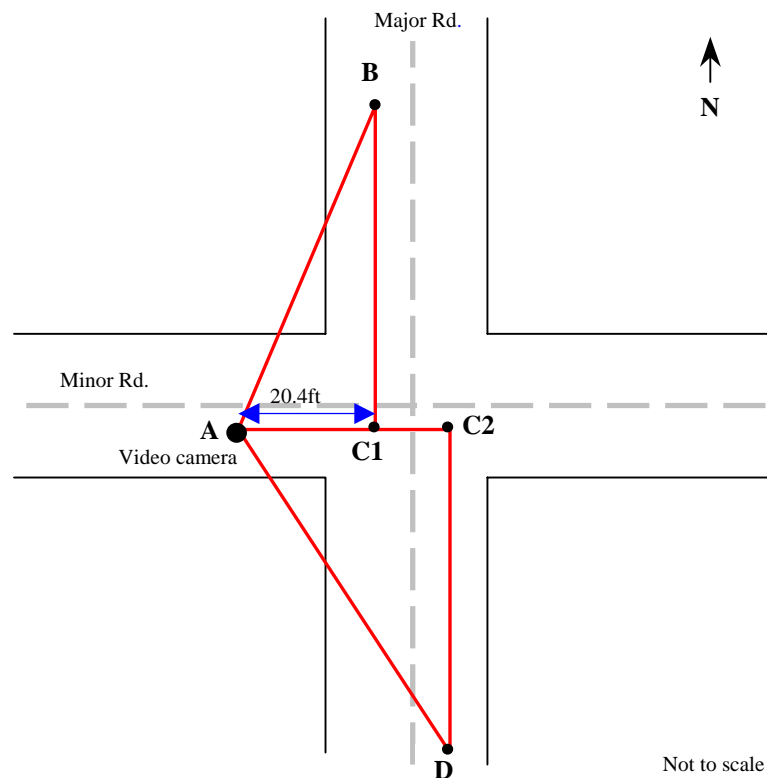


Figure 4.3. Field validation setup

Driving the vehicle at a constant 25 mph speed ensured that distances could be calculated during video editing by noting the travel time of the vehicle. All six intersections were videotaped in this manner. After video capture, it was transferred to a desktop computer for editing and a frame-by-frame analysis. The MGI Video Wave 3 (Roxio, Inc.) video editing software was utilized. Using MGI Video Wave 3, time was recorded when the 3.5-foot-high marked side of the vehicle was first visible. The vehicle was followed in each video frame and time noted when it finally passed Point C1/C2. If the vehicle marking was not obstructed after first becoming visible then the clear distance is given by

$$D = 36.67*(t_1 - t_2) \tag{4.1}$$

where D = clear sight distance available to the driver stopped on the minor road (feet), t_1 = time when 3.5-foot-high marking on the vehicle first became visible, t_2 = time when the vehicle passed Point C1/C2, and 36.67 is the factor needed to convert 25 mph to feet per second.

The locations of any potential obstructions visible in the video were noted and their distance from the driver on the minor road calculated using Equation 4.1. This process was repeated for both east and west sides of the minor roads and vehicle movement from north to south and vice versa, for all six intersections. Potential obstructions located beyond 445 feet from the stopped driver did not affect the intersection sight triangle and were not taken into further consideration. Obstructions that were closer than 445 feet to the stopped driver were compared to obstructions identified by the line-of-sight analysis. The distance from the stopped driver to the potential obstruction helped in matching line-of-sight obstructions to the video obstructions. Appendix C provides a few examples of obstructions detected in the line-of-sight analysis that were confirmed by the video images.

Most of the potential obstructions identified in the line-of-sight analysis were validated by the video as potential sight distance obstructions. Generally these obstructions included tree branches that had the potential to block the sight of a driver stopped on the minor road (see Figure C.2 in Appendix C). In some cases, actual sight distance obstructions were correctly identified; these included tree trunks, utility poles, and utility appurtenances. Figures C.1, C.3, and C.4 in Appendix C present examples of actual sight distance obstructions that were correctly identified by the line-of-sight analysis. However, in some cases potential sight distance obstructions that were noted in the video were not detected by the line-of-sight analysis and a few potential obstructions identified via line-of-sight analysis were not confirmed by the video analysis.

See Table 4.5 for validation results. The intersection of Market Street and East Fifth Street experienced the highest crash frequency involving older drivers. This intersection appears to have obstructions on the two south-side intersection sight triangles, as indicated by the line-of-sight analysis and video validation. It is possible that these obstructions are responsible for the higher crash involvement of older drivers at this intersection. Note that all drivers would be affected by these obstructions but older drivers comparatively much more so because of their slower reactions.

To judge the effectiveness of the line-of-sight analysis, a comparison of obstructions identified by it and confirmed/not confirmed by the video as well as obstructions missed by the line-of-sight analysis was undertaken. Table 4.6 presents the results of this comparison. Sixty-six potential sight distance obstructions were identified by the line-of-sight analysis, out of which 62 (89.8%) were confirmed while four (5.8%) were not confirmed by the video. At least three (4.4%) potential sight distance obstructions were discovered in the video analysis that were not detected by the line-of-sight analysis.

Table 4.5. Validation results

Location	Driver position	Sight triangle position	Confirmation of obstructions at specified distances (ft)						
			First return				Last return		
Market St. and E. Fifth St.	East	North	127 •	-	-	-	224 •	228 •	-
	East	South	54 •	59 *	56 *	-	59 *	61 *	-
	West	North	213 •	225 •	-	-	230 •	-	-
	West	South	5 *	8 *	-	-	87 •	94 •	132 •
Market St. and E. Third St.	West	North	32 •	38 •	-	-	52 •	107 •	-
	West	South	341 x	375 x	-	-	376 x	-	-
Market St. and E. First St.	East	North	20 *	23 *	-	-	24 *	-	-
	East	South	74 •	97 •	-	-	74 •	98 •	-
	West	North	47 •	-	-	-	- +	-	-
	West	South	30 •	-	-	-	29 •	-	-
Market St. and Short St.	East	North	3 •	14 x	-	-	7 •	-	-
	East	South	33 *	-	-	-	46 *	53 *	-
	West	North	22 •	35 •	-	-	50 •	58 •	88 •
	West	South	13 •	-	-	-	- +	-	-
Market St. and Main St.	East	North	26 *	-	-	-	33 *	-	-
	East	South	36 •	41 •	56 •	-	76 •	154 •	-
	West	North	54 •	60 •	-	-	60 •	67 •	-
	West	South	55 •	-	-	-	80 •	90 •	-
Market St. and E. Rock St.	West	North	116 •	143 •	309 •	330 •	116 •	323 •	-
	West	South	- +	-	-	-	46 •	-	-

Notes: • = correctly identified potential sight distance obstruction; * = correctly identified actual sight distance obstruction; x = incorrectly identified potential sight distance obstruction; + = obstruction detected by video analysis that was missed by line-of-sight analysis.

Table 4.6. Confirmed and unconfirmed potential and actual sight distance obstructions

		Video validation	
		Confirmed	Unconfirmed
Line-of-sight analysis	Identified	62	4
	Not identified	3	0

4.3. Cost of LIDAR Data Analysis

An estimate of the LIDAR data analysis effort was made to get an idea about the costs involved. About \$30,000 was spent in terms of man-hours on the analysis and validation. Additional costs include a computer and camera equipment (\$3,000), software (\$1,200) and LIDAR data collection (about \$35,000). It must be noted that subsequent analyses may be not as time-consuming because the analysis processes have been tested and streamlined.

5. CONCLUSIONS AND RECOMMENDATIONS

After the data analysis, there is the task of reaching meaningful conclusions and recommendations from the effort. However, prior to this, the objective of this research is briefly reviewed to put conclusions and recommendations into perspective. The objective was to utilize LIDAR data to obtain highway safety-related information by taking into consideration the safety needs of older drivers in terms of prolonged reaction times. Intersection negotiation was identified as one particular issue faced by older drivers and it was recognized that intersection sight triangles were critical to safe intersection negotiation. LIDAR data were utilized to obtain information on potential sight distance obstructions at six selected intersections by conducting in-office line-of-sight analysis. Crash frequency, older driver involvement, and data availability were considerations in selection of the six intersections. Results of the in-office analysis were then validated by videotaping in the field. Results indicated that about 90% of the potential and actual obstructions were correctly identified by the line-of-sight analysis. In particular, the intersection with the highest crash frequency of older driver involvement was found to have obstructions located within the two southern sight triangles.

Based on the results of the research effort, it is concluded that LIDAR data can be utilized for identifying potential sight distance obstructions at intersections. The analysis must be based on both the first return and the last return data sets. Chances of detecting potential obstructions that do not actually exist and missing potential obstructions that actually exist are reasonably low. LIDAR data quality and terrain are likely to influence the final results. The in-office line-of-sight analysis is useful for detecting intersections where older drivers might experience difficulty due to potential sight obstructions in the intersection sight triangles. These intersections can then be inspected in the field and rectified if found to have obstructions.

Future recommendations include analysis using a sight plane instead of a sight line. This would make the process more efficient and accurate. Obtaining LIDAR data and aerial images simultaneously would enable analysts to detect obstructions such as on-road vehicles in the analysis, thereby reducing the detection of false obstructions. Finally, LIDAR data are a relatively new source for enhancing highway safety and further investigation regarding transportation safety-related applications is recommended.

APPENDIX A. INTERSECTION RELATED UNSAFE BEHAVIORS

Table A.1. Unsafe driving behaviors performed by older drivers at intersections

Unsafe behaviors related to signs and signals	Unsafe behaviors in lane use	Unsafe behaviors during turns	Unsafe vehicle control behaviors	Unsafe behaviors when reacting to traffic
<ul style="list-style-type: none"> • disregard for yield sign • running stop signs • rolling through a stop sign • proceeding without clearance after stopping at a stop sign • poor vehicle positioning at stop signs • jerky/abrupt stops • running red lights • running amber lights • proceeding through an intersection on a green light without verification that the intersection is clear • stopping at green lights • lack of enough caution at traffic lights • failure to understand signs • blocking oncoming traffic in the middle of an intersection after the signal has changed • braking every time a sign or signal is sighted 	<ul style="list-style-type: none"> • lane straddling • failure to check blind spot when changing lanes • use of a turning lane for passing • cruising in the passing lane • choosing the incorrect lane for turning or through maneuver • making left turn from a center (through) lane or curb (through or right) lane • making right turn from a non-curb through lane • continuing through the intersection in a turn-only lane • center two-way left-turn lane not used at all for turning • center two-way left-turn lane entered too far in advance of turn • driving on the wrong side of the road • going the wrong way on a one way street • failure to observe lane markings • unsafe gap acceptance when changing lanes 	<ul style="list-style-type: none"> • failure to signal intention to turn • signaling too early or too late • unsafe gap acceptance when turning left (head-on opposing conflict vehicle) • unsafe gap acceptance when turning right (conflict vehicle approaching at 90 from left) • unsafe gap acceptance when crossing • entering the wrong lane on the receiving leg of an intersection • swinging too wide when turning • turning too short and "clipping" a vehicle on the left, or hitting the curb on the right • turning into a lane of opposing traffic • turning suddenly and accelerating slowly after the turn • turning where turns are prohibited • exceeding lane boundaries during turns 	<ul style="list-style-type: none"> • excessive braking • jamming on the brakes for no apparent reason • delayed braking at intersections and crosswalks • applying the accelerator instead of the brake • putting the car in the wrong gear • activating the wrong turn signal • driving with both brake and accelerator depressed 	<ul style="list-style-type: none"> • failure to yield • following too closely • unnecessary and unexpected stopping in traffic (braking unsafely) • driver inattention • failure to maintain adequate distance vision ("improper lookout") • performing a maneuver while being waved on by another driver, without regard for other traffic or traffic control • interfering with the traffic flow by entering too fast or too slow • driving too slowly • looked but did not see potential conflict vehicles/did not look • delay in decision making and maneuver initiation • seeing a car coming but unable to respond • panicking when emergency vehicles approach

Source: Staplin et al. 1998b.



Figure A.1. Sixty-nine LIDAR bounds superimposed on 12 orthophoto bounds

APPENDIX B. INTERSECTION SIGHT DISTANCE ANALYSIS FOR CASE B

Case B1. Left Turns from the Minor Road

According to the Green Book (2001), the vertex of the departure sight triangle on the minor road is 20.4 feet from the center of the closest main road lane. This represents the typical position of the minor-road driver's eye when a vehicle is stopped relatively close to the major road. The length of the sight triangle along the minor road is the sum of the distance from the major road plus 1/2 lane width for vehicle approaching from the left, or 1-1/2 lane width for vehicles approaching from the right. The intersection sight distance along the major road in both directions is given by the following equation:

$$ISD = 1.47 V_{\text{major}} t_g \quad (\text{B.1})$$

where ISD = intersection sight distance (length of the leg of sight triangle along the major road, in feet), V_{major} = design speed of major road (in mph), and t_g = time gap for minor road vehicle to enter the major road (in seconds).

Exhibit 9-55 in the Green Book provides the needed intersection sight triangle dimensions for various design speeds, assuming no median and grade less than 3%. For major road design speed of 40 mph, a value of 445 feet was obtained as dimension "b" in Figure B.1.

Case B2. Right Turns from the Minor Road

The intersection sight distance for right turns was determined similar to Case B1 except that the time gap (t_g) was adjusted. The time gap was decreased by 1.0 second for right-turn maneuvers in accordance with the Green Book's recommendation. The Green Book indicates slightly shorter time gaps for right turns than those accepted by drivers making left turns. An intersection sight distance of 352.8 feet is needed along the major road in the left direction while making right turns on to the major road (see Figure B.2).

Case B3. Crossing the Major Road from a Minor-Road Approach

The Green Book states that the departure sight triangles for left and right turns onto the major road, as described for Case B1 and B2, will provide adequate sight distance for minor road to cross the major road. However, in the following situations it is advisable to check the availability of sight distance for crossing maneuvers:

- where left and/or right turns are not permitted from a particular approach and the crossing maneuver is the only legal maneuver;
- where the crossing vehicle would cross the equivalent width of more than six lanes; or

- where substantial volumes of heavy vehicles cross the highway and steep grades that might slow the vehicle while its back portion is still in the intersection are present on the departure roadway on the far side of the intersection.

The Green Book recommends a time gap of 6.5 seconds for a passenger car to safely complete a crossing maneuver from the minor road. Substituting the required time gap, 382.2 feet of clear sight distance is required in both left and right directions, as shown in Figure B.3.

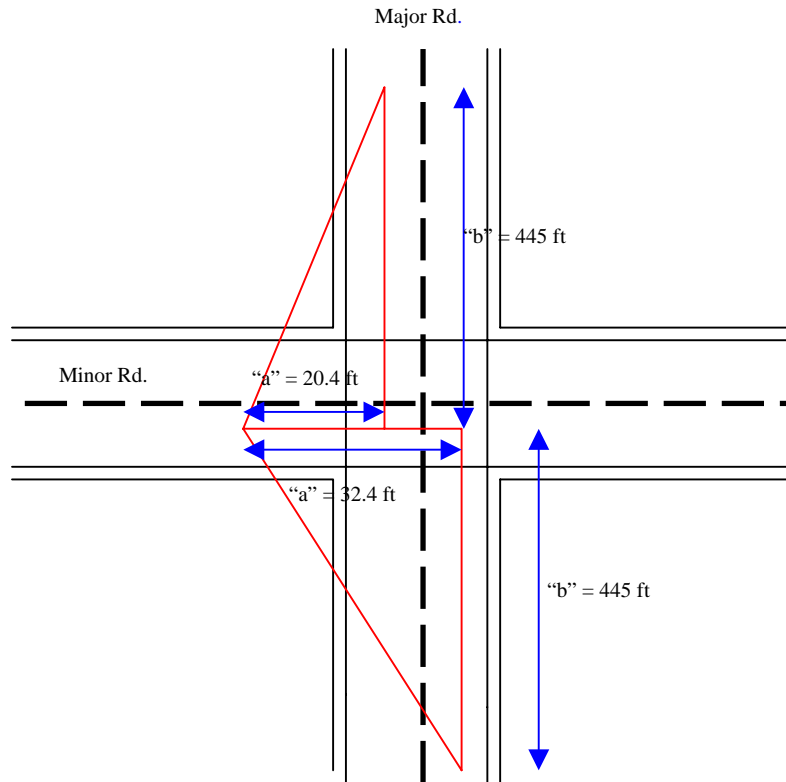


Figure B.1. Sight triangles for Case B1, left turn from the minor road

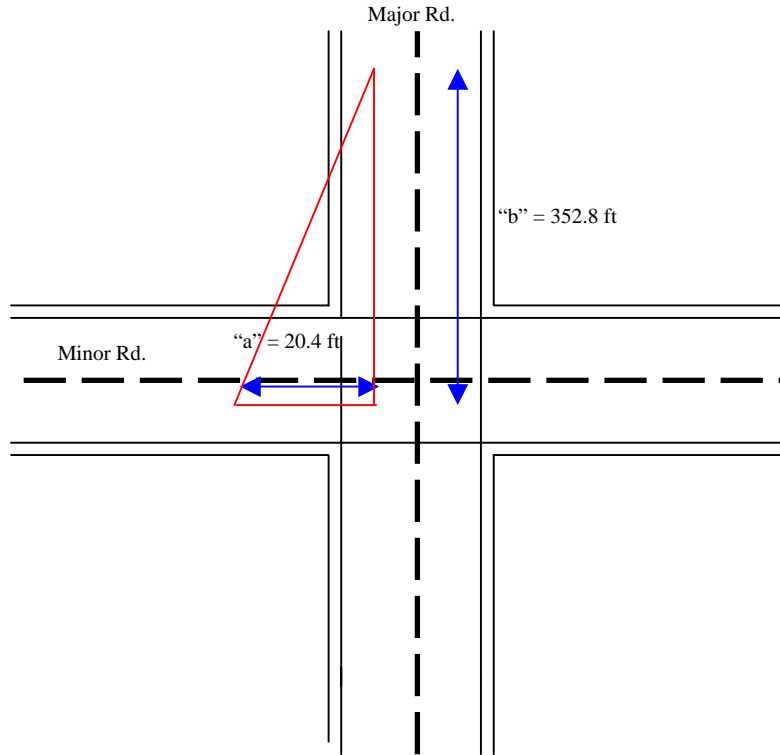


Figure B.2. Sight triangle for Case B2, right turn from the minor road

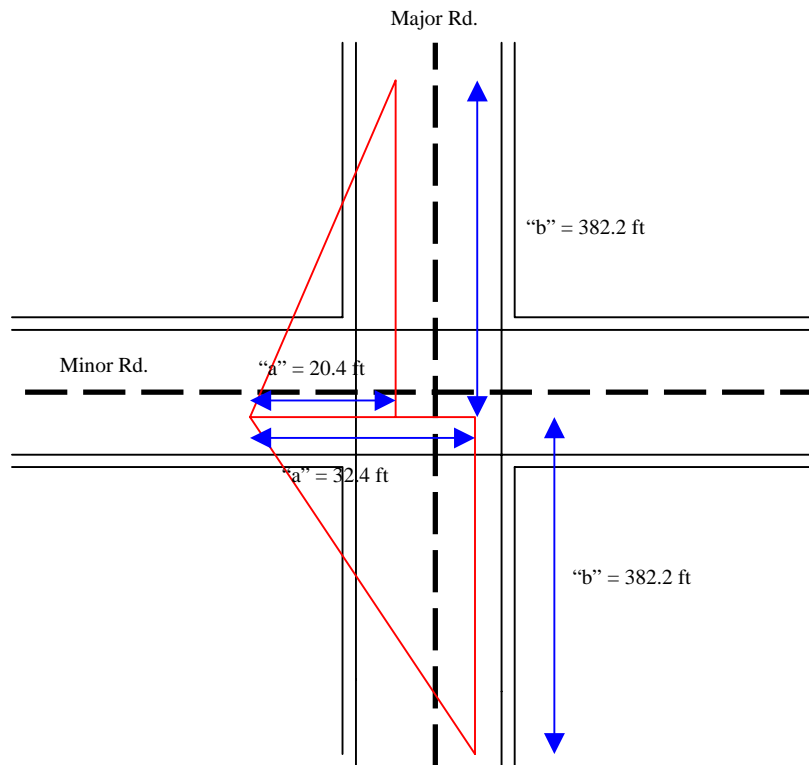


Figure B.3. Sight distance triangles for Case B3, crossing the major road

APPENDIX C. INTERSECTIONS WITH BLOCKED DRIVER'S LINE OF SIGHT

The camera that took the image in Figure C.1 was located at a point where the driver on the minor road is expected to stop. The camera was mounted at a height of 3.5 feet from the pavement, which is the supposed height of the driver's eye. The location is the intersection of Market Street and East Fifth Street, which has the highest crash frequency involving older drivers. The camera is positioned to the west of Market Street, and the sight triangle under investigation is south of the East Fifth Street. The two utility poles with a utility box in between effectively block the driver's view of the main road traffic.



Figure C.1. Stopped driver's view at the intersection of Market and East Fifth streets

The camera in Figure C.2 was positioned at 3.5 feet height from the pavement, east of Market Street, and the sight triangle under investigation was north of East First Street. Note that the tree trunk effectively hides oncoming vehicles from the driver's view while the overhanging branches present a potential obstruction.



Figure C.2. Stopped driver's view at the intersection of Market St. and E. First St.

Figure C.3 shows the driver's view at the intersection of Market Street and Short Street. The camera is located west of Market Street, and the sight triangle under investigation is south of Short Street. Note that the tree is wide enough to hide oncoming vehicles on the major road. The time a vehicle is hidden behind the tree would depend on the size of vehicle on the main road, tree trunk diameter at 3.5 feet height from the surface, and proximity of the tree to the stopped vehicle.



Figure C.3. Stopped driver's view at the intersection of Market St. and Short St.

The image in Figure C.4 shows a driver's view when stopped on the Main Street at the intersection of Market Street and Main Street. The camera is positioned east of Market Street, and the intersection sight triangle under investigation is north of Main Street. Notice that the driver's sight is blocked by a utility pole and a building wall.



Figure C.4. Stopped driver's view at the intersection of Market St. and Main St.

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