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INVESTIGATION OF METHODS AND APPROACHES FOR COLLECTING AND RECORDING HIGHWAY INVENTORY DATA

Prepared By

Huaguo Zhou
Mohammad Jalayer
Jie Gong
Shunfu Hu
Mark Grinter

Southern Illinois University Edwardsville

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16. Abstract

Many techniques for collecting highway inventory data have been used by state and local agencies in the U.S. These techniques include field inventory, photo/video log, integrated GPS/GIS mapping systems, aerial photography, satellite imagery, virtual photo tourism, terrestrial laser scanners, mobile mapping systems (i.e., vehicle-based LiDAR, and airborne LiDAR). These highway inventory data collection methods vary in terms of equipment used, time requirements, and costs. Each of these techniques has its specific advantages, disadvantages, and limitations. This research project sought to determine cost-effective methods to collect highway inventory data not currently stored in IDOT databases for implementing the recently published *Highway Safety Manual* (HSM). The highway inventory data collected using the identified methods can also be used for other functions within the Bureau of Safety Engineering, other IDOT offices, or local agencies. A thorough literature review was conducted to summarize the available techniques, costs, benefits, logistics, and other issues associated with all relevant methods of collecting, analyzing, storing, retrieving, and viewing the relevant data. In addition, a web-based survey of 49 U.S. states and 7 Canadian provinces has been conducted to evaluate the strengths and weaknesses of various highway inventory data collection methods from different state departments of transportation. To better understand the importance of the data to be collected, sensitivity analyses of input variables for the HSM models of different roadway types were performed. The field experiments and data collection were conducted at four types of roadway segments (rural two-lane highway, rural multi-lane highway, urban and suburban arterial, and freeway). A comprehensive evaluation matrix was developed to compare various data collection techniques based on different criteria. Recommendations were developed for selecting data collection techniques for data requirements and roadway conditions.

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Rob Robinson, IDOT, Co-Chair

Kim Kolody, CH2M HILL, Co-Chair

Priscilla Tobias, IDOT, Bureau of Safety Engineering

Travis Lobmaster, IDOT

Roseanne Nance, IDOT, Bureau of Safety Engineering

Mike Gillette, IDOT, Bureau of Safety Engineering

Filiberto Sotelo, IDOT, Bureau of Safety Engineering

Irene S. Soria, IDOT, Bureau of Safety Engineering

Tim Hemmen, IDOT District 7

Harold Dameron, IDOT Operations

Wei Xu, CH2M HILL

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EXECUTIVE SUMMARY

The *Highway Safety Manual* (HSM) provides decision makers and engineers with information and tools to evaluate safety when making decisions related to designing and operating roadways. The first edition of the HSM, published in 2010, provides predictive methods for three types of facilities: rural two-lane, two-way roads; rural multi-lane highways; and urban and suburban arterials.

The main purpose of this research project was to identify cost-effective methods for collecting highway inventory data not currently stored in IDOT databases and for implementing the recently published HSM. The highway inventory data collected can also be used for other functions within the Bureau of Safety Engineering, other IDOT offices, and local agencies.

State and local agencies have adopted a variety of techniques for collecting highway inventory data. Field inventories, photo/video logs, integrated GPS/GIS mapping systems, satellite/aerial imagery, virtual photo tourism, terrestrial laser scanners, mobile mapping systems (i.e., vehicle-based LiDAR, and airborne LiDAR) are examples. Each of these methods has its strengths and weaknesses. Furthermore, the utility of these methods in terms of collecting HSM-related road inventory data is not well understood by state departments of transportation (DOTs). Accordingly, a comprehensive literature review was conducted to determine promising methods for collecting HSM-related road inventory data.

The main findings are as follows: (1) field inventory and integrated GPS/GIS mapping methods can collect all the feature data, but they require a long data collection time and expose data collection crews to dangerous road traffic; (2) photo/video logs and aerial imagery can collect only part of the required feature data, but a combination of them can collect most of the data except roadside slope; and (3) mobile LiDAR can collect all required feature data in a short time but requires an extensive data reduction effort.

A web-based survey was developed to evaluate how state DOTs currently collect safety data and their perceptions of the strengths and weaknesses of their chosen system. The survey results suggested that no single technology stands out as the obvious choice of methods for roadside-feature data collection, and most agencies perceive that their inventory methods could be substantially improved.

The value of individual data parameters of HSM-related road inventory data was further defined by conducting sensitivity analyses. The results showed that safety performance functions (SPFs) have varied sensitivity to each of the data elements. The sensitivities of SPFs to HSM variables that are not currently stored in the IDOT databases are ranked so that decision makers can consider these important attributes in their fund allocations. Specifically, driveway density, fixed-object density, roadside hazard rating (slope and object density), lighting, and skew angle for intersections showed more sensitivity than any other parameters.

Upon identification of promising data collection methods, a group of selected methods were field tested to further evaluate their utility. Five collection methods (GPS data logger, robotic total station, GPS-enabled photo/video log, satellite/aerial imagery, and mobile LiDAR) were used to collect HSM-related road inventory data along four 2-mi road segments. The findings of this research suggest that the GPS data logger, robotic total station, and mobile LiDAR or a combination of the video/photo log and aerial imagery methods are capable of collecting required HSM-related roadside information.

An evaluation matrix of highway data collection techniques was developed and used in this research to compare different methods. High equipment cost and significant data reduction requirements limited the adoption of mobile LiDAR as a highway inventory method. The GPS data logger and GPS-enabled photo/video log methods ranked higher than other methods. In addition, cost analysis of various data collection methods showed that photo/video logs and satellite/aerial imagery are more economical when compared with other methods.

This research explored various options that state DOTs can use to collect the highway inventory data necessary for implementing an HSM. The research results will help state DOTs understand the advantages and disadvantages of each highway inventory data collection method. It is expected that decision makers can leverage the findings of this research to select the most cost-effective method for different purposes.

CONTENTS

FIGURES

TABLES

ABBREVIATIONS

2U	Two-lane undivided arterials
4U	Four-lane undivided arterials
4D	Four-lane divided arterials
3T	Three-lane with two-way left-turn-lane (TWLTL) arterials
5T	Five-lane with TWLTL arterials
3SG	Three-leg signalized intersection
4SG	Four-leg signalized intersection
3ST	Three-leg unsignalized intersection
4ST	Four-leg unsignalized intersection
AADT	Annual average daily traffic
CMF	Crash modification factor
DOT	Department of Transportation
ESRI	Economic and Social Research Institute
FHWA	Federal Highway Administration
HSM	*Highway Safety Manual*
IDOT	Illinois Department of Transportation
LiDAR	Light detection and ranging
NAVTEQ	Navigation Technologies Corporation
NCHRP	National Cooperative Highway Research Program
PDO	Property damage only
POI	Point of interest
RHR	Roadside hazard rating
RTOR	Right turn on red
S-c Lane	Speed-change Lane
SIUE	Southern Illinois University Edwardsville
SPF	Safety performance function
TWLTL	Two-way left-turn lane
VDOT	Virginia Department of Transportation
VMT	Vehicle miles traveled

CHAPTER 1 INTRODUCTION

The objective of this research project was to identify cost-effective methods for collecting highway inventory data not currently stored in IDOT databases, to aid in implementing the recently published *Highway Safety Manual* (HSM) models. The highway inventory data collected using the identified methods can also be used for other functions within the IDOT Bureau of Safety Engineering, other IDOT offices, and local agencies.

Many techniques for collecting highway inventory data have been used by state and local agencies in the United States. These techniques include field inventory, photo/video logs, integrated GPS/GIS mapping systems, aerial photography, satellite imagery, virtual photo tourism, terrestrial laser scanners, and mobile mapping systems (i.e., vehicle-based LiDAR, and airborne LiDAR). These highway inventory data collection methods vary in the equipment used, time requirements, and costs.

Each technique has its specific advantages, disadvantages, and limitations. For example, vehicle-mounted LiDAR, a relatively new type of mobile mapping system, is capable of collecting large amounts of detailed 3D highway inventory data, but it requires expensive equipment and significant data reduction to extract the desired highway inventory data. On the other hand, a traditional field survey requires minimal training, equipment investment, and data reduction efforts. However, this method is time consuming and labor intensive, and it exposes data collection crews to dangerous roadway environments.

The efforts and costs for collecting various data with different techniques vary greatly. The utility of these techniques to IDOT’s specific needs has not been determined. In addition to data collection methods, the safety performance functions (SPFs) have varied sensitivities to each of the new data elements. This research investigates methods and approaches for collecting and recording highway inventory data and assesses the various data elements for cost and utility in evaluating safety.

A two-phase approach was proposed for this study. In Phase 1, the research team established database requirements and evaluated available data collection and analysis techniques through a literature review and a nationwide survey. Four major tasks were addressed during this phase: (1) identify the input data required for HSM models; (2) conduct a thorough literature review and a nationwide survey to summarize available techniques, costs, benefits, and logistics associated with all relevant methods of collecting, analyzing, storing, retrieving, and viewing data; (3) conduct laboratory testing of promising highway inventory data collection techniques; and (4) provide a summary of the this information and recommend one or more methods for evaluating data collection and analysis techniques through field studies on IDOT roads. The results of the four tasks in Phase 1 are summarized in Chapters 2, 3, and 4 of this report.

In Phase 2, the research team conducted field tests of its recommended techniques on four types of roads. Six major tasks were conducted in this phase: (1) identify a set of roadway segments and sites that represent the challenges faced in a statewide implementation; (2) conduct field experiments on these road segments and sites to evaluate the ability of recommended techniques to collect roadway inventory data; (3) convert the data collected from each of these techniques into the designed database format; (4) conduct foot-on-ground surveys of the locations to verify assets, for comparison with data collected by alternate technologies; (5) perform an assessment of data quality, collection and analysis productivity, utility, and costs, in order to determine the most advantageous technique, or combination of techniques, for IDOT roads; and (6) summarize the findings and recommendations into a final report and a technical presentation. The results of the six tasks in Phase 2 are summarized in Chapters 5, 6, 7, and 8 of this report.

In addition to data collection methods, the SPFs show varied sensitivities to each of the data elements. A sensitivity analysis was therefore conducted to evaluate various data elements for different SPFs, so that the trade-off between the cost of collecting a particular type of data and its utility in evaluating safety could be considered. Detailed results of the sensitivity analysis are presented in the appendices.

CHAPTER 2 DATA NEEDS FOR THE *HIGHWAY SAFETY MANUAL*

The *Highway Safety Manual* (HSM) provides decision makers and engineers with information and tools for considering safety in making decisions related to designing and operating roadways. In the first edition of the HSM, predictive methods were provided for three types of highways: rural two-lane, two-way roads; rural multi-lane highways; and urban and suburban arterials. A National Cooperative Highway Research Program (NCHRP) 17-45 project recently developed safety prediction models for freeways and interchanges. The data required for the new safety models were evaluated and included in this chapter.

2.1 INPUTS FOR SAFETY PERFORMANCE FUNCTIONS

The HSM can be used to predict the safety performance of a roadway segment or an intersection. The safety performance is evaluated by using a system of equations, known as safety performance functions (SPFs), to estimate the average crash frequency. The input data for different types of roadway segments and intersections are quite different. The following is the HSM list of roadway and intersection types for urban and rural areas:

- 2U (two-lane undivided road segment)
- 4U (four-lane undivided road segment)
- 4D (four-lane divided road segment)
- 3T (three-lane with two-way-left-turn-lane [TWLTL] road segment)
- 5T (five-lane with TWLTL road segment)
- 3SG (three-leg signalized intersection)
- 4SG (four-leg signalized intersection)
- 3ST (three-leg unsignalized intersection)
- 4ST (four-leg unsignalized intersection)
- Freeway segments
- Freeway ramp segments
- Ramp terminals

More details about the input data for the HSM predictive models are contained in Appendix A.

2.1.1 Rural Two-Lane Highway

The input data for rural two-lane highway segments consist of length of segment, annual average daily traffic (AADT), lane width, shoulder type/width, length of horizontal curve, radius of curve, superelevation variance, spiral transition curve, grade, driveway density, centerline rumble strips, passing lanes, two-way left-turn lanes (TWLTL), roadside hazard rating (RHR), segment lighting, and auto speed enforcement. Most of these inputs, except for RHR, can be collected or estimated from the existing IDOT database.

RHR includes seven scales, which can be determined by three variables: clear zone length, side slope, and roadside objects. Note that the HSM predictive models define a roadside object as any object at least 4 in. in diameter and on the roadside within 30 ft of the traveled way. In addition, multiple roadside objects located within 70 ft of one another are counted as a single object. Fences, glare screens, guardrails, barriers, walls, rock outcroppings, mail boxes, milepost paddles, sign supports, trees, utility poles, fire hydrants, and junction boxes are examples of roadside objects.

For the rural two-lane highway intersections, AADTs for both major and minor approaches, skew angle, the number of approaches with left-turn and right-turn lanes, and the status of lighting at the intersection need to be collected. Most of this information can be directly collected or estimated from the existing IDOT GIS database.

2.1.2 Rural Multi-Lane Highway

The input data for the rural multi-lane roadway segments consist of length of segment, AADT, lane width, shoulder type/width, median width, side slope, automatic speed enforcement, and lighting. Most of this information, except side slope, can be collected from the existing IDOT database. For an intersection along this type of road, the data input is the same as rural two-lane highway intersections, except for the number of approaches with left-turn and right-turn lanes. For rural two-lane intersections, the model needs the number of signalized or uncontrolled approaches with left-turn and right-turn lanes; for rural multi-lane intersections, the model only needs the number of non-stop-controlled approaches with left-turn and right-turn lanes.

2.1.3 Urban and Suburban Arterials

The input data for the urban and suburban segments consist of AADT, the type of on-street parking, the proportion of curb length with on-street parking, lighting, automatic speed enforcement, the number of major/minor commercial driveways, the number of major/minor industrial driveways, the roadside fixed-object density, and the offset to roadside fixed objects.

The input data for the intersections consist of AADTs for both major and minor approaches, lighting, the number of approaches with left-turn and right-turn lanes, the number of approaches with left-turn signal phasing, the type of left-turn signal phasing, the number of approaches with right turn on red (RTOR) prohibited, intersection red-light cameras, the sum of all pedestrian crossing volumes, the maximum number of lanes crossed by a pedestrian, the number of bus stops within 300 m, presence of a school within 300 m, and the number of liquor stores within 300 m of an intersection.

2.1.4 Freeways

The new freeway models require data inputs for alignment, cross section, roadside information, ramp access, traffic volume, and crash frequency for 5 yr. Input data differ for various types of roadways (including freeway segments, ramps, and ramp terminals). The input data for freeway segments consist of basic roadway data (length of segment, the number of through lanes), alignment data (length of curve, curve radius), cross section data (lane width, shoulder width, median width, rumble strips, length and width of barrier in median, distance of barrier to traveled way in median), roadside data (clear zone, length and width of barrier, distance of barrier to traveled way), ramp access data (length of ramp entrance, entrance side, length of ramp exit, exit side, presence of type B weaving in segment, length of weaving section), traffic data (AADT, proportion of AADT during high-volume hours, entrance and exit AADTs for ramps), crash data (multiple-vehicle crashes, single-vehicle crashes, ramp-entrance-related crashes, ramp-exit-related crashes for fatal, injury and property damage only (PDO) crashes);

The input data for ramps consist of basic roadway data (length of segment, the number of through lanes, average traffic speed on the freeway, type of control at crossed ramp terminal), alignment data (length of curve, curve radius), cross section data (lane width, shoulder width, presence of lane add or drop, length of taper), roadside data (length of barrier, distance of barrier to traveled way), ramp access data (type of ramp entrance, length of entrance s-c lane, type of ramp exit, length of exit s-c lane, weave section in collector-distributor road segment, length of weaving section), traffic data (AADT), and crash data (multiple-vehicle crashes, single-vehicle crashes for fatal, injury, and PDO crashes).

The input data for ramp terminals consist of basic intersection data (ramp terminal configuration, ramp terminal traffic control mode, presence of non-ramp public streets at the terminals), alignment data (exit ramp skew angle, distance to the next public street intersection on the outside crossed leg, distance to the adjacent ramp terminal), traffic control (left-turn and right-turn operational mode), cross section data (median width, number of lanes for crossroad-both approach and crossroad-inside approach and crossroad-outside approach, right-turn channelization, left-turn lane or bay, right-turn lane or bay), access data (number of driveways and public street on the outside crossroad leg), traffic data (AADT for inside crossroad leg, outside crossroad leg, exit ramp, and entrance ramp), and crash data (count of fatal, injury, and PDO crashes).

2.2 EXISTING IDOT ROADWAY INVENTORY DATABASE

The existing IDOT roadway inventory data were studied to determine how input data for the HSM models can be collected. Currently, IDOT maintains three major databases: the IDOT GIS database, the IDOT road inventory database, and the NAVTEQ database. The existing IDOT GIS database contains comprehensive roadway information for the state of Illinois in ESRI ArcView shapefile format, including 876,089 polyline segments and 90 attribute fields (Table 2-1). Among the 90 attribute fields, AADT, functional class, shoulder width, the number of lanes, segment length, median type/width, on-street parking, and speed limit are readily available for use in the HSM models. Detailed data available for the four roadway segments are provided in Table 2-2.

Table 2-1. Variables in the IDOT GIS Database

IDOT GIS Database Key Route	
IDOT Key Route Begin Station	Heavy Commercial Volume Count
IDOT Key Route End Station	Single-Unit Volume Count
Annual Average Daily Traffic Count Year	Multi-Unit Volume Count
Annual Average Daily Traffic Volume	Functional Class Name
Number of Through Lanes	Road Name
Length of Segment	Shoulder Width
Speed Limit	Median Type
Lane Width	Median Width
Shoulder Type	County Highway Number

The NAVTEQ GIS database for the state of Illinois provides extensive street centerlines, census boundaries, parcels, points of interest (POI), and administration boundaries. Core POI or POICore offers 92,164 business locations such as banks/credit unions/ATMs, restaurants, gas stations, supermarkets/grocery stores, hotels, automotive services, hospitals, pharmacies, postal offices, golf courses/clubs, schools, and libraries. In addition, individual GIS layers provide POI such as businesses (a total of 729 businesses listed in 2012 database), school locations (6,195), parking (316), and lighting (4,991). Appendix B provides a few screen shots of these types of GIS layers.

2.3 DATA REQUIRED

Some of the input data for the HSM predictive models can be directly obtained or estimated from the existing IDOT GIS database; others must be collected in the field.

2.3.1 Rural Two-Lane Segments

Available data from the existing GIS database for the HSM consist of AADT (veh/day), lane width (ft), shoulder width/type, centerline rumble strips, passing lanes, TWLTL. Data that can be estimated from the existing databases are length of horizontal curve (ft), length of segment (mi), radius of curvature (ft), spiral transition curve, superelevation variance (ft/ft), grade (%), driveway density, and lighting. Additional data that need to be collected are slope and roadside objects.

2.3.2 Rural Multi-Lane Segments

Most of the data needed for rural multi-lane highways are available from the existing GIS database, including roadway type, length of segment (mi), AADT (veh/day), lane width (ft), shoulder width (ft)/type, lighting, and median width (ft). Only roadside slope needs to be collected.

2.3.3 Urban and Suburban Roadway Segments

Data that need to be collected for urban and suburban roadways consist of roadside fixed-object density (fixed objects/mi) and offset to roadside fixed objects (ft). The input data that can be extracted from the existing IDOT GIS database are roadway type, AADT, length of segment, speed category, type of on-street parking, and median width. Data that can be estimated include proportion of curb length with on-street parking, driveway type and number, and lighting.

2.3.4 Interstate Freeway Segments

Available data from the existing GIS database for the freeway modules consist of length of segment (mi), number of through lanes, lane width (ft), outside shoulder width (ft), inside shoulder width (ft), median width (ft), rumble strips on outside shoulders, and presence of barriers in medians. Data to be estimated consist of ramp entrances, horizontal curves, curve radius (ft), length of curve (ft), and length of rumble strips. Data to be collected are length of barrier (ft), distance from edge to barrier face (ft), median barrier width (ft), nearest distance from edge to barrier face, and clear zone width (ft).

Table 2-2 summarizes a list of available data, data to be estimated, and data to be collected (in Bold) for all types of facility segments. Tables for detailed data needs for each facility type are contained in the Appendix C.

Table 2-2. Data Required for All Types of Facilities Segments

Data Available	Data to be Estimated or Collected
Roadway type	Proportion of curb length with on-street parking
AADT	Length of horizontal curve
Length of segment	Radius of curvature
Lane width	Spiral transition curve
Shoulder width	Driveway density
Shoulder type	Driveway type and number
Centerline rumble strips	Lighting
Passing lanes	Ramp entrance in segment
Two-way left-turn lane	Entrance/exit side
Speed category	Ramp entrance/exit
Type of on-street parking	Length of ramp entrance /exit
Median width	Distance from beginning milepost to upstream entrance ramp gore
Number of through lanes	Distance from end milepost to downstream exit ramp gore
Presence of barrier in median	Length of weaving section
Rumble strips on outside shoulder	Length of taper
Passing lanes	**Roadside slope**
—	**Roadside fixed-object density**
—	**Offset to roadside fixed objects**
—	**Grade**
—	**Length of barrier**
—	**Distance from edge to barrier face**
—	**Median barrier width**
—	**Nearest distance from edge to barrier face**
—	**Clear zone width**
—	**Superelevation variance**

Based on Table 2-2 and the tables in Appendix C, it can be concluded that (1) roadside objects and slopes are the main input data that need to be collected in the field; (2) some input data such as driveway types and density and roadway alignment features can be estimated from the existing data sources, such as satellite/aerial imagery; and (3) most input data for intersections can be estimated from the existing IDOT GIS database. Some inputs (skew angle, left and right lane, alcohol/liquor stores, bus stops, and school proximity) that do not exist in the current IDOT GIS database can be estimated from other existing data sources.

2.4 SENSITIVITY ANALYSIS

The importance of each data category was examined by conducting sensitivity analyses of input variables for the SPFs of different roadway and facility types. The method for sensitivity analysis consists of three basic steps: (1) run SPFs for the base conditions; (2) increase one parameter at an incremental rate until it reaches its maximum value, and record the predicted average crash frequency corresponding to each value; and (3) use the normalization method by dividing each input value by its maximum value to compare and rank variables in terms of elasticity.

The elasticity is defined as the percentage change in crash frequency for a 1% change in the input variable. For example, to estimate the sensitivity of AADT: (1) set all of the parameters as the base conditions; (2) run the model for different AADT levels from minimum to maximum to estimate predicted crash frequencies; and (3) calculate variable elasticity to determine percentage change in crash frequency for the 1% change in AADT. Table 2-3 shows the predicted crash frequency and corresponding AADTs. Figure 2-1 shows this elasticity for AADTs for suburban two-lane undivided segments. It indicates that a 1% increase in AADT will predict a 0.13% increase in total crashes.

Table 2-3. Sensitivity Analysis for AADT for Two-Lane Undivided Suburban Segment

	Crash Frequency (crashes/mi/yr)		
AADT (veh/day)	Fatal and Injury Crash (FI)	Property Damage Only Crash (PDO)	Total Crash
1,000	0.1	0.1	0.2
5,000	0.3	0.6	0.9
10,000	0.6	1.5	2.0
15,000	1.0	2.5	3.5
20,000	1.4	3.8	5.3
25,000	2.0	5.3	7.3
27,000	2.2	5.9	8.2
30,000	2.6	7.0	9.6
32,600	3.1	7.9	10.9

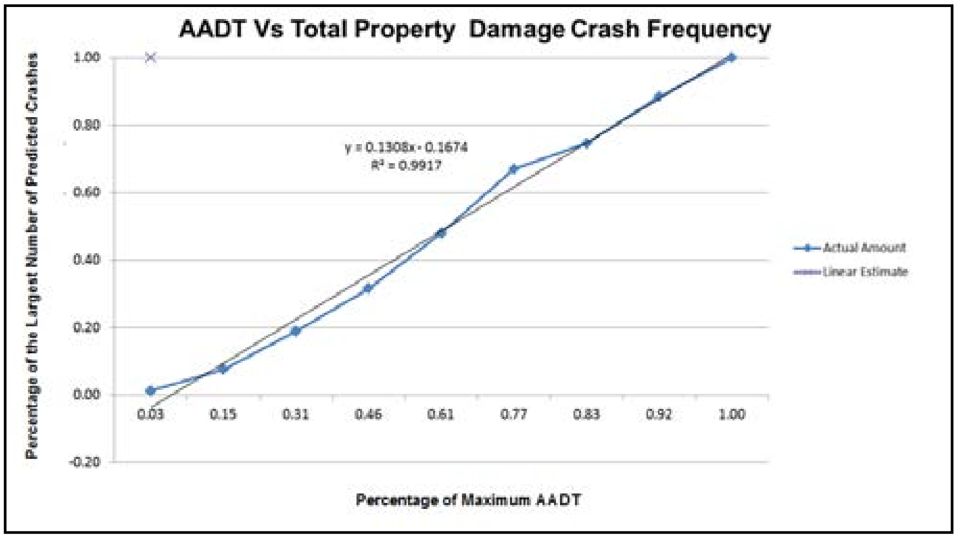


Figure 2-1. Elasticity of AADT vs. total property damage crash for two-lane undivided suburban segments.

The base conditions for urban and suburban roadway segments were on-street parking (none), median width (15 ft), lighting (not present), automatic speed enforcement, roadside object density (none), and offset to roadside fixed objects (30 ft). The base conditions for intersections were lighting (not present, present); red-light cameras (none); right- and left-turn lanes (none); school, bus stop, or liquor store near the intersection; and left-turn signal phasing (permissive phase). Roadside fixed-object density sensitivity analysis for three scenarios with offsets 5, 10, and 20 ft was conducted.

For the rural two-lane segment, the base conditions were lane width (12 ft), shoulder width (6 ft), paved shoulder type; horizontal curves (none present); superelevation variance (less than 0.01); grade (0), driveway density (5), roadside hazard rating (3), lighting (none), auto speed enforcement (none), TWLTL, passing lane; and centerline rump strips. These conditions for intersections were lighting (none), intersection skew angle (0), and approaches with right- and left-turn lanes (none).

For the rural multi-lane roadway segment, the base conditions were roadway type (undivided), lane width (12 ft), shoulder width (8 ft), paved shoulder type, median width (30 ft), side slope (1:7), lighting (none), and auto speed enforcement (none). These conditions for intersections were lighting (none), intersection skew angle (0), and approaches with right- and left-turn lanes (none).

Table 2-4 shows the sensitivity analysis results for two-lane undivided urban and suburban segments. AADT, major industrial driveway, and major commercial driveway variables had the greatest effects on the safety rating of this type of road. Type of on-street parking and proportion of length of on-street parking were the two least sensitive variables in the prediction of accidents for urban and suburban segments. The sensitivity analysis results for all other types of HSM models are included in Appendix D.

Table 2-4. Ranking of Inputs for Two-Lane Undivided Urban/Suburban Segment

Parameter	Elasticity	Rank
AADT	0.130	1
Major Industrial Driveway	0.120	2
Major Commercial Driveway	0.116	3
Lighting	0.075	4
Major Residential Driveway	0.065	5
Minor Commercial Driveway	0.057	6
Auto Speed Enforcement	0.056	7
Minor Industrial Driveway	0.030	8
Roadside Fixed-Object Density (Offset 5)	0.027	9
Minor Residential Driveway	0.017	10
Roadside Fixed-Object Density (Offset 10)	0.016	11
Roadside Fixed-Object Density (Offset 20)	0.007	12
Type of On-Street Parking	—	13
Proportion of Curb Length with On-Street Parking	—	14

2.5 SUMMARY

In this task, researchers studied the existing highway inventory database provided by IDOT and identified the data required for the HSM models. The input data for different types of roadway segments and intersections vary. Most of the required data for intersections can be directly collected or estimated from the existing database (see data required for intersections in Appendix E). Some key input data for roadway segments have to be collected in the field, such as roadside objects and roadside slopes. Examples of roadside objects include fences, glare screens, guardrails, trees, barriers, walls, utility poles, sign supports, etc. Some input data can be estimated from the existing data sources, including driveway types, driveway density, and alignment features (curve radius and length).

A further analysis was conducted to test the sensitivity of each data element for predicting crash frequency. This sensitivity analysis identified the top-ranked roadside parameters as driveway density, fixed-object density, RHR (slope and object density), lighting, and skew angle. Low-ranked parameters were pedestrian volume, superelevation rates, spiral transition curves, and proximity to bus stops, liquor stores, schools.

CHAPTER 3 LITERATURE REVIEW

The research team reviewed existing and ongoing research studies to summarize the available techniques, costs, benefits, and logistics issues associated with relevant methods of collecting, analyzing, storing, retrieving, and viewing the HSM data. To date, state DOTs and local agencies have used a variety of methods for collecting roadside features. These methods vary based on equipment used, time requirements for data collection, data reduction, and costs. These methods include, but are not limited to, field inventory, photo/video log, integrated GPS/GIS mapping systems, aerial photography, satellite imagery, terrestrial laser scanners, mobile LiDAR, and airborne LiDAR. Based on the underlying technologies and the sensing platform, these methods can be categorized as shown in Figure 3-1. A brief description of these methods and related studies are provided in Table 3-1.

	GPS	GPS + Imaging*	GPS + Imaging + LiDAR*
Land based	• Field Inventory • Integrated GPS/ GIS Mapping	• Photo/Video Log	• Static Terrestrial Laser Scanning • Mobile Terrestrial Laser Scanning
Air or Space based		• Satellite Imagery • Aerial Imagery	• Airborne LiDAR

Figure 3-1. Categorization of roadside inventory data collection methods.

Table 3-1. Existing Roadside Inventory Data Collection Methods and Related Studies

Method	Description	Related Studies
Field Inventory	Using GPS survey and conventional optical equipment to collect desired information in the field	Khattak et al. (2000)
Photo/Video Log	Driving a vehicle along the roadway while automatically recording photos/videos, which can be examined later to extract information	Wang et al. (2010), Hu et al. (2002), Wu and Tsai (2006), Degray and Hancock (2002), Jeyapalan (2004), Maerz and McKenna (1999), Jeyapalan and Jaselskis (2002), Tsai (2009), and Robyak and Orvets (2004)
Integrated GPS/GIS Mapping Systems	Using an integrated GPS/GIS field data logger to record and store inventory information	Caddell et al. (2009)
Aerial/Satellite Photography	Analyzing high-resolution images taken from aircraft or satellites to identify and extract highway inventory information	Hallmark et al. (2001) and Veneziano (2001)
Terrestrial Laser Scanning	Using direct 3D precision point information (3D point clouds) acquired from stationary 3D laser scanners to extract highway inventory data	Pagounis et al. (2009), California State Department of Transportation (2011), and Slattery and Slattery (2010)
Mobile LiDAR	Driving an instrumented vehicle while collecting direct 3D precision point information, using either land-based LiDAR systems or photogrammetry systems, while traveling at highway speeds	Tang and Zakhor (2011), Huber et al. (2008), Lehtomäki et al. (2010), Lato et al. (2009), Kämpchen (2007), Barber et al. (2008), Pfeifer and Briese (2007), Garza et al. (2009), Yen et al. (2011a), Graham (2010), Vosselman et al. (2004), Yen et al. (2011b), Laflamme et al. (2006), and Tao (2000)
Airborne LiDAR	Using direct 3D precision point information acquired from aircraft-based LiDAR systems to derive highway inventory data	Uddin (2008), Hu et al. (2002), Chow and Hodgson (2009), Hatger and Brenner (2003), Pfeifer and Briese (2007), Souleyrette et al. (2003), McCarthy et al. (2007), Jensen and Cowen (1999), Zhang and Frey (2006), and Shamayleh and Khattak (2003)

Four major comprehensive studies have also evaluated remote sensing technologies for road inventory data collection. A pilot study by the Iowa Department of Transportation in 2001 evaluated remotely sensed images for use in inventorying roadway infrastructure features. In that study, remotely sensed images with resolutions of 2, in., and 24 in. and 1 m were evaluated for extracting highway inventory data (Veneziano 2001). A total of 21 features were collected using these four image datasets. The results showed that most objects were recognized in the 2 and 6 in. datasets, at 100% and 80%, respectively. For the 24 in. and 1 m datasets, a considerable number of features were missed. The author of the study concluded that the main advantages and disadvantages of using remote sensing imagery for inventory data collection are the reduction in time and cost and the elimination of foot-on-ground surveys.

Another study, sponsored by the California Department of Transportation (Caltrans), concentrated on the evaluation of technologies for the inventory of roadside features (Ravani et al. 2009). The results of a nationwide survey in that study showed that the integrated GPS/GIS mapping method appears to have a short-term advantage over other methods, but remote sensing methods such as satellite imagery are attractive in the long term.

The Florida Department of Transportation (FDOT) conducted a study in 2004 to evaluate commercially available remote sensing methods for development of a highway feature and characteristic database. The results of that study suggested that the combined use of remote sensing, aerial imagery, and vehicle-based mobile mapping system is an appealing method for transportation data acquisition (Xiong and Floyd 2004).

Recently, the Missouri Department of Transportation (MoDOT) sponsored a study to evaluate available LiDAR technologies for collecting road inventory data. The study compared the efficiency and cost of road inventory data collection associated with static terrestrial laser scanning, mobile LiDAR, airborne LiDAR, conventional photogrammetry, and conventional surveying methods. The researchers found that all the evaluated LiDAR technologies met the accuracy and information content required for asset inventory. However, these methods tend to collect enormous amounts of point cloud data that are extremely difficult to process and manage (Vincent and Ecker 2010).

Other studies have shown that the utility of a particular inventory technique depends on the types of features to be collected. Cost performances of these methods were reported in multiple DOT-funded studies. Table 3-2 provides a brief overview of the studies.

Table 3-2. Examples of State DOT Road Inventory Programs

State DOT	Inventory Techniques		Inventory Data	Cost (if available)
	Collection	Storage		
Washington	Photo log, integrated GPS/GIS mapping systems	GIS	Cable barriers, concrete barriers, culverts, culvert ends, ditches, drainage inlets, glare screens, guardrails, impact attenuators, miscellaneous fixed objects, pipe ends, pedestals, roadside slope, rock outcroppings, special-use barriers, supports, trees, tree groupings, walls	\$16.4/feature; \$2,179/mi
Michigan	Integrated GPS/GIS mapping systems, field inventory	GIS	Guardrails, pipes, culverts, culvert ends, catch basins, impact attenuators	\$4.34/mi/yr, with an initial investment of \$26/mi/yr
Ohio	Photo log, integrated GPS/GIS mapping Systems	GIS	Wetland delineation, vegetation classification	N/A
Iowa	Airborne LiDAR, aerial photography	GIS	Landscape, sloped areas, individual counts of trees, side slope, grade, contour	N/A
Idaho	Video log	MS Access	Guardrails	
FHWA Baltimore-Washington Parkway	Mobile mapping	Point Cloud Software, GIS	Corridors, signs	Collecting: \$3,500 per day; 20–60 mi per hr Processing: \$100 per hr

Based on the literature review, the common road inventory data collection methods are compared to determine their capabilities and limitations to support data collection tasks in this research. The findings are as follows:

1. The field inventory data method has some advantages and disadvantages. Advantages include low initial cost, low data reduction effort, and capability of collecting rich road inventory data. Disadvantages are crew exposure to traffic, long field data collection time, and less accurate data.
2. The integrated GPS/GIS method has advantages of low initial cost, low data reduction effort, and the ability to transfer inventory data back to the home office through a 3G connection. Disadvantages include crew exposure to traffic, long field collection time, and GPS outage problems caused by trees.
3. The photo/video log method has the advantages of less exposure to traffic and short field data collection times; disadvantages are the inability to measure feature dimensions and need for large data reduction efforts.
4. Satellite/aerial imagery data collection systems eliminate field work. The advantages include reduced data collection time, no traffic exposure, no disruption to traffic, and compatibility of ortho-rectified images with GPS. The most significant disadvantage is

that features such as signs or traffic signals, which are usually represented as points on a map, are difficult or impossible to identify from overhead imagery.

5. Static terrestrial laser scanning is a reliable system that can operate in daylight or darkness. Some advantages of this method include high data accuracy, and extremely rich and accurate data collection that is valuable to multiple DOT programs. Disadvantages include long field data collection time, exposure to traffic, high initial cost, long data reduction time, and large data size.
6. Mobile LiDAR is capable of collecting huge amounts of data in a very short time. For example, mobile LiDAR is able to reduce the amount of time for collecting data for a 20-mi segment of a highway from 10 days to 30 min when compared with conventional survey methods. Survey crew safety is superior compared with traditional survey methods. The disadvantages include the need for expensive equipment and the long data extraction time.
7. Airborne LiDAR has the advantages of no exposure to traffic, short field data collection time, and collection of rich data in a short amount of time. The disadvantages include high initial cost, large data size, and long data reduction time.

The ability of each method to collect the required data is summarized in Figure 3-2. It can be concluded that (1) field inventories and integrated GPS/GIS mapping methods can collect all the feature data, but they require a long data collection time and expose data collection crews to dangerous road traffic; (2) photo/video logs and aerial imagery can collect only part of the required feature data, but combining them allows collection of most data parameters except roadside slope; and (3) mobile LiDAR can collect all required feature data in a short time, but it requires a long data processing time.

	Field Inventory	Integrated GPS/GIS Mapping	Photo/Video Log	Staellite/Aerial Imagery	Terrestrial Laser Scanning	Mobile LiDAR	Airborne LiDAR
Driveway	√	√	√	√	√	√	√
Distance from edge to barrier	√	√		√	√	√	√
Roadside objects (Intensity and Offset) - Fences - Guardrails - Trees - Sign Supports -	√	√	√* (*no offset information)	√* (*vertial ol (*Vertical Objects not visible	√	√	√
Roadside slope	√	√			√	√	√

Figure 3-2. Roadside features to be collected vs. data collection methods.

CHAPTER 4 NATIONAL SURVEY

4.1 SURVEY DATA COLLECTION

A web-based survey was conducted to evaluate highway inventory data collection methods used by state DOTs. The survey was sent to all 50 U.S. states and 7 Canadian provinces. As part of the survey, the respondents were asked to indicate their primary data collection method and for their opinions on their adopted methods regarding cost, time, accuracy, safety, and data storage requirements. These methods included field inventory, GPS/GIS, photo/video log, static terrestrial laser scanning, mobile LiDAR, airborne LiDAR, and aerial/satellite imaging.

The survey questionnaire (Appendix G) included three major parts: (1) highway inventory data platform technology; (2) inventory data collection method technology used; and (3) final data evaluation. Highway inventory data platform technology consisted of GIS, Oracle, SQL, Excel, and others. The evaluation considered equipment cost, data accuracy, data completeness, crew hazard exposure, data collection cost and time, data reduction time and cost, and data storage requirement. Respondents assigned one of five ratings ranging from unacceptable to excellent.

Some of the features addressed in the survey included roadside objects (bridge rails, driveway intersections, fences, fire hydrants, glare screens, guardrails, impact arrestors, jersey barriers, junction boxes, light poles, luminaires, milepost paddles, on-street parking, rock outcroppings, rumble strips, shoulders, sign supports, signals, trees, tree groups, utility poles, walls), and roadside slopes (slide areas, horizontal curve data, and longitudinal slope data). The respondents were asked to indicate what type of method was used by their agencies to collect data on each type of object. A total of 31 states responded to the survey request (Figures 4-1 and 4-2).

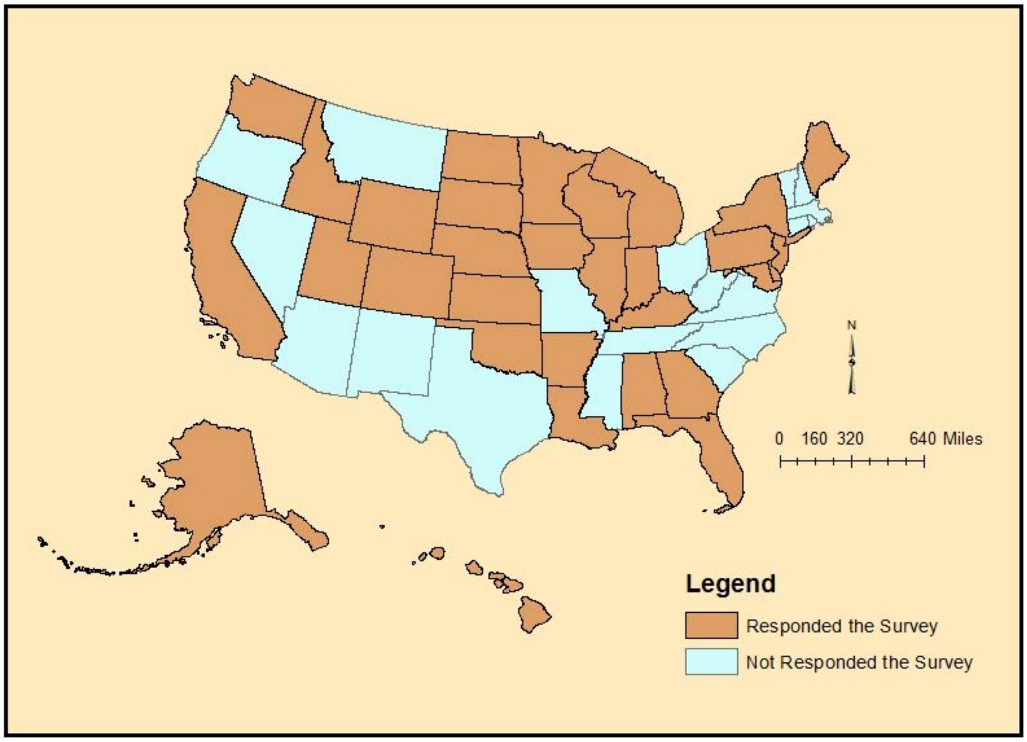


Figure 4-1. State DOTs that responded and did not respond to the survey.

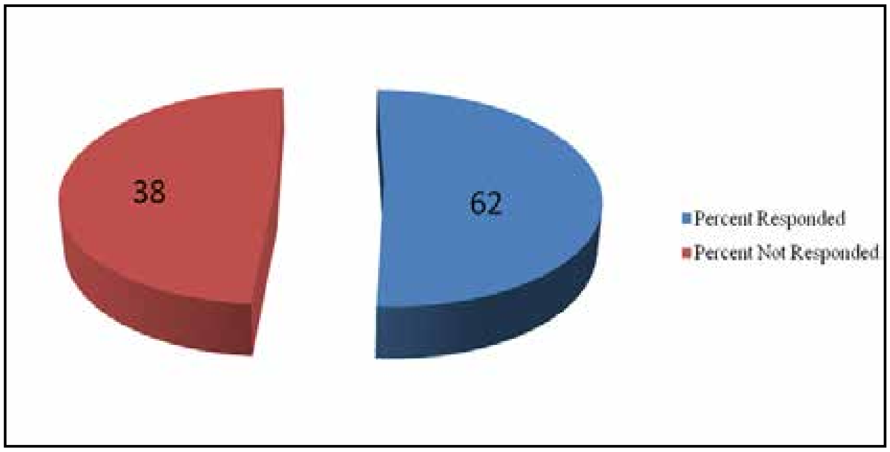


Figure 4-2. Percentage of responses to the survey request.

4.2 ANALYSIS OF SURVEY DATA

Oracle was the predominant data storage platform; however, many agencies used Oracle in combination with other systems. Figure 4-3 and Table 4-1 show the percentage use of each data storage platform by state DOTs.

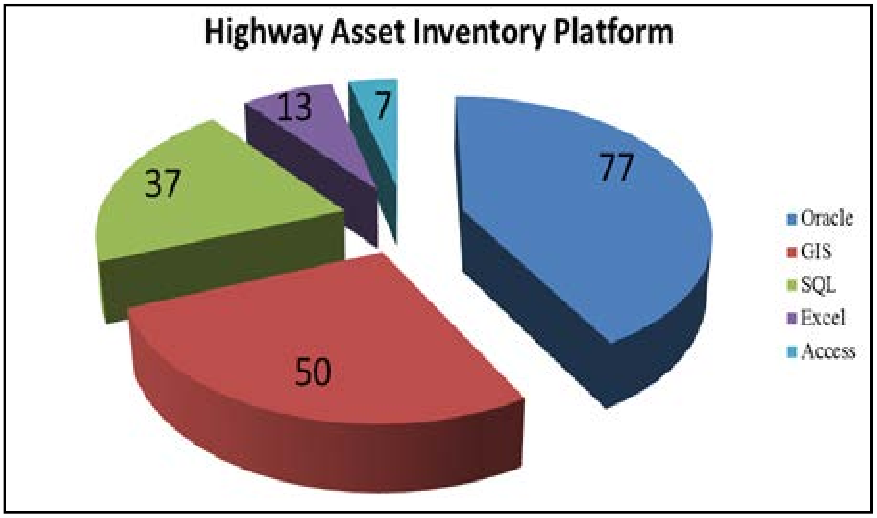


Figure 4-3. Percentage use of each data storage platform by state DOTs.

Table 4-1. Data Storage Platform by Each State DOT

State	GIS	Oracle	SQL	Excel	Other
Alaska	■	■			
Arkansas			■		
California		■			
Colorado	■	■	■		
Delaware		■			
Florida	■	■	■		
Georgia		■			
Hawaii		■			
Idaho	■	■	■		
Illinois	■		■		
Indiana	■	■			
Iowa		■			
Kansas	■	■	■	■	■
Kentucky	■	■	■		
Louisiana	■				
Maine		■			
Maryland	■	■			
Michigan	■	■	■	■	
Minnesota	■	■	■	■	
Mississippi		■			
Nebraska				■	■
New Jersey	■	■	■		
New York		■			
North Dakota	■		■		
Oklahoma		■			
Pennsylvania					
South Dakota			■		
Utah		■			
Washington	■				
Wisconsin	■	■			
Wyoming		■			

Table 4-1 shows that ten states use only Oracle while four states use ArcGIS and Oracle together. Also, two states use only ArcGIS and SQL to store their data. A combination of ArcGIS, Oracle, and SQL are being used by eight states. Figure 4-4 shows the percentage of states using each type of road inventory data collection method. Respondents indicated their satisfaction with their primary inventory technology method. Field inventory remains the predominant method. The result showed that more than 60% of states surveyed have adopted field inventory, integrated GPS/GIS mapping, video log, and aerial imagery for collecting roadside-feature data. Also, photo logs have been gradually replaced by video logs.

The survey results clearly indicate that satellite imagery and airborne LiDAR are less popular choices among state DOTs. Mobile LiDAR is also not commonly used among state DOTs but is becoming more popular. More specifically, Iowa and Hawaii confirmed that they have used mobile LiDAR for collecting roadside information. Arkansas recently added this relatively new method to their road inventory data collection toolbox (Table 4-2).

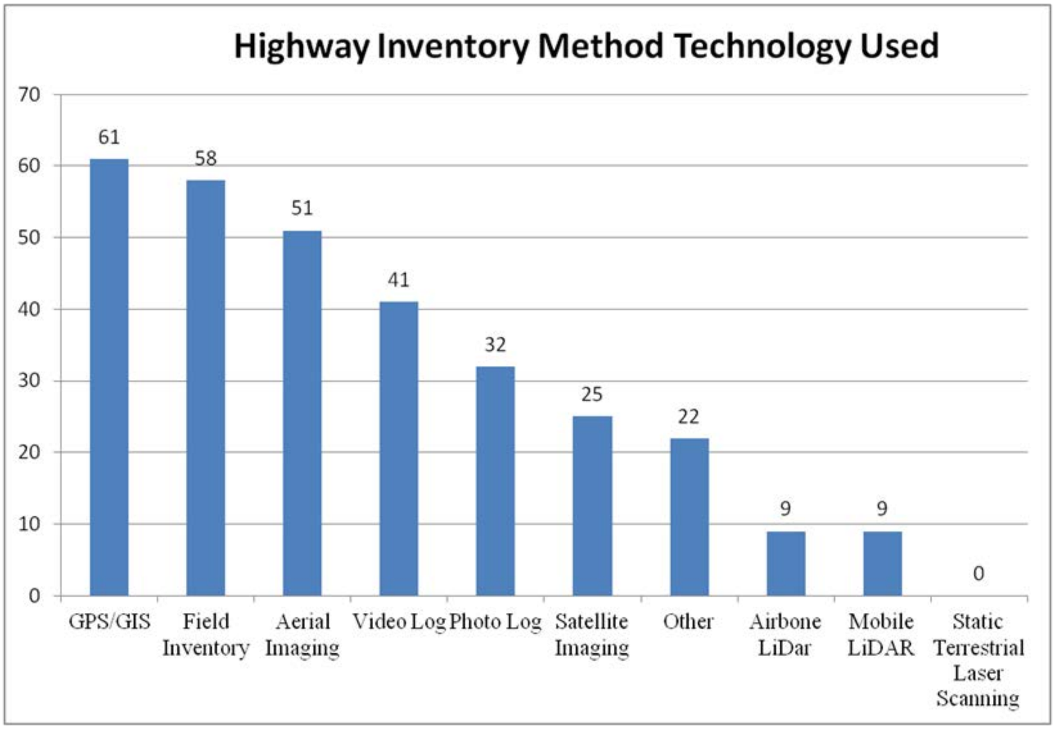


Figure 4-4. Technology adoption percentage in respondent states.

Table 4-2. Highway Inventory Data Collection Methods in Each State DOT

State	Field Inventory	GPS/GIS	Video Log	Photo Log	Static Terrestrial Laser Scanning	Mobile LiDAR	Airbone LiDAR	Aerial Imaging	Satellite Imaging	Other
Alaska			■					■	■	■
Arkansas	■		■					■		
California				■						■
Colorado	■	■		■				■	■	
Delaware	■		■					■		
Florida	■		■							■
Georgia	■	■						■		
Hawaii	■	■	■	■		■		■	■	
Idaho	■		■					■		
Illinois	■	■		■				■		
Indiana		■		■			■	■		
Iowa	■	■	■			■	■	■		
Kansas	■	■	■	■			■	■	■	■
Kentucky	■	■		■				■		■
Louisiana		■	■							
Maine		■								
Maryland									■	
Michigan		■		■				■	■	■
Minnesota	■	■	■			■				
Mississippi	■									
Nebraska	■							■		
New Jersey		■								
New York	■	■		■						
North Dakota	■	■		■				■		
Oklahoma	■	■	■					■		
Pennsylvania			■							
South Dakota		■								
Utah		■								■
Washington		■								
Wyoming	■		■							

It is interesting that most of the responding states indicated the use of a combination of several methods for road inventory data collection to meet their inventory data needs. One part of the survey investigated the capability of each data collection method. To obtain a better understanding of what types of features are collected by what types of data collection methods, the surveyed states were asked to indicate specific features collected by each adopted method. Figure 4-5 shows the frequency of different road inventory data collection methods that were used to collect specific types of features. Note that field inventory and integrated GPS/GIS mapping methods were used to collect most of the features described at the beginning of this section.

Glare screens, guardrails, and shoulders are the most predominant objects being collected. Less than 1% of states collected roadside slope and curvature alignments. Note that roadside slope information is an important roadside feature for rural two-lane and rural multi-lane highways.

According to the survey results, four types of methods—field inventory, integrated GPS/GIS mapping, video log, and mobile LiDAR—have been used by responding states to collect roadside slope information. It is not clear that how video logs can be used to collect roadside slope information. One possible way would be to estimate side slope information by examining video records.

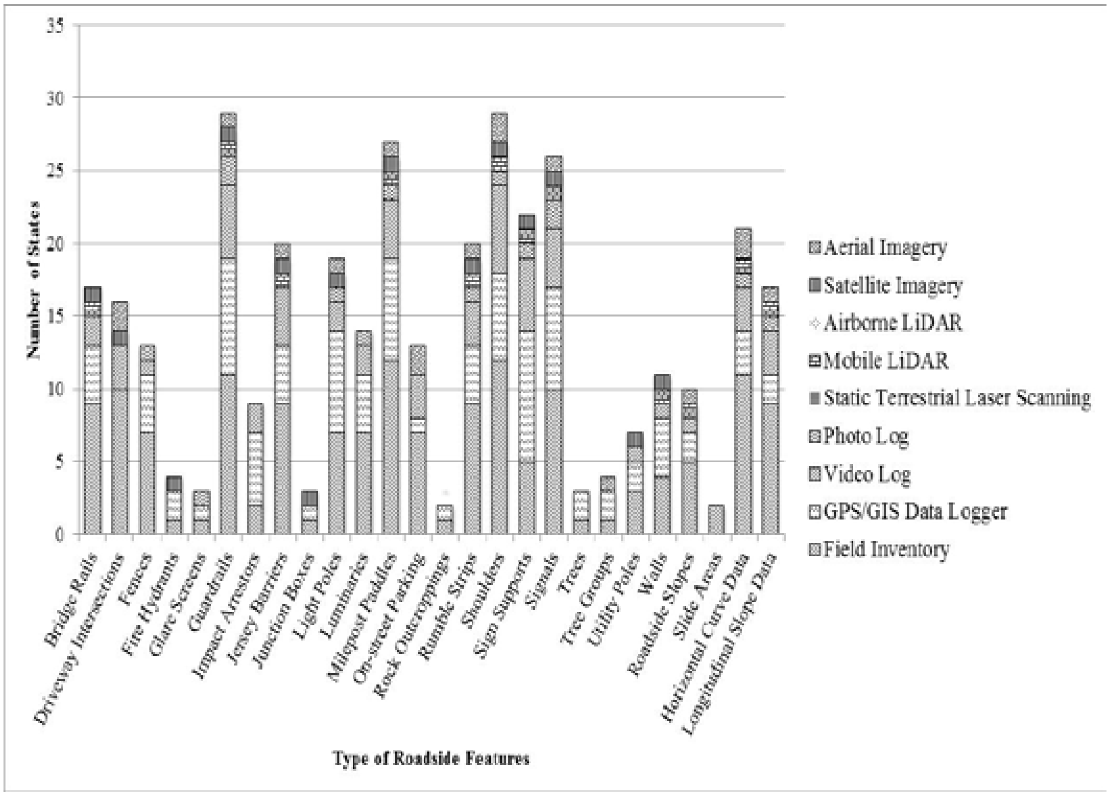


Figure 4-5. Type of technologies used by different states to collect various features.

The survey respondents were requested to indicate their level of satisfaction with their primary collection method using a scale of 1 to 5 (representing unacceptable, fair, good, very good, and excellent, respectively). Table 4-3 shows the results for the nine satisfaction indicators considered in the survey: cost, data accuracy, data completeness, crew hazard exposure, data collection cost, data collection time, data reduction time, data reduction cost, and data storage requirement.

Table 4-3. Levels of Satisfaction for Primary Collection Method of State DOTs

Satisfaction Factors	Unacceptable (%)	Fair (%)	Good (%)	Very Good (%)	Excellent (%)	Sum (%)
Equipment Cost Rating	0	21	58	21	0	100
Data Accuracy Rating	0	7	41	45	7	100
Data Completeness Rating	7	17	34	34	7	100
Crew Hazard Exposure Rating	4	29	39	21	7	100
Data Collection Cost Rating	3	24	55	17	0	100
Data Collection Time Rating	3	34	48	14	0	100
Data Reduction Time Rating	11	26	30	26	7	100
Data Reduction Cost Rating	4	39	29	21	7	100
Data Storage Requirement Rating	0	14	52	31	3	100

The data shown in Table 4-3 and Figure 4-6 indicate that most agencies rated their current systems from fair to good for most performance categories. Satellite imaging, photo logs, and aerial imagery scored highest on all of the evaluation elements. Examination of the scores of different evaluation elements reveals that most methods had lower rankings for data reduction time, data collection time, and data collection cost. This clarifies that the focus of concern of state DOTs is on the time required for data collection and reduction, and the associated cost. Somewhat surprisingly, state DOTs who used either airborne LiDAR or mobile LiDAR expressed less satisfaction toward these two methods. Their concerns are clearly related to the data reduction time associated with the methods. Both methods collect a tremendous volume of data that is difficult to process. Some of the other interesting findings were that New York State DOT rates its GPS/GIS system as unacceptable to fair in several categories, and California State DOT appears generally dissatisfied with its photo log system.

No single technology stands out as the obvious choice of methods for roadside-feature data collection. Overall, most agencies perceive that their inventory methods could be substantially improved.

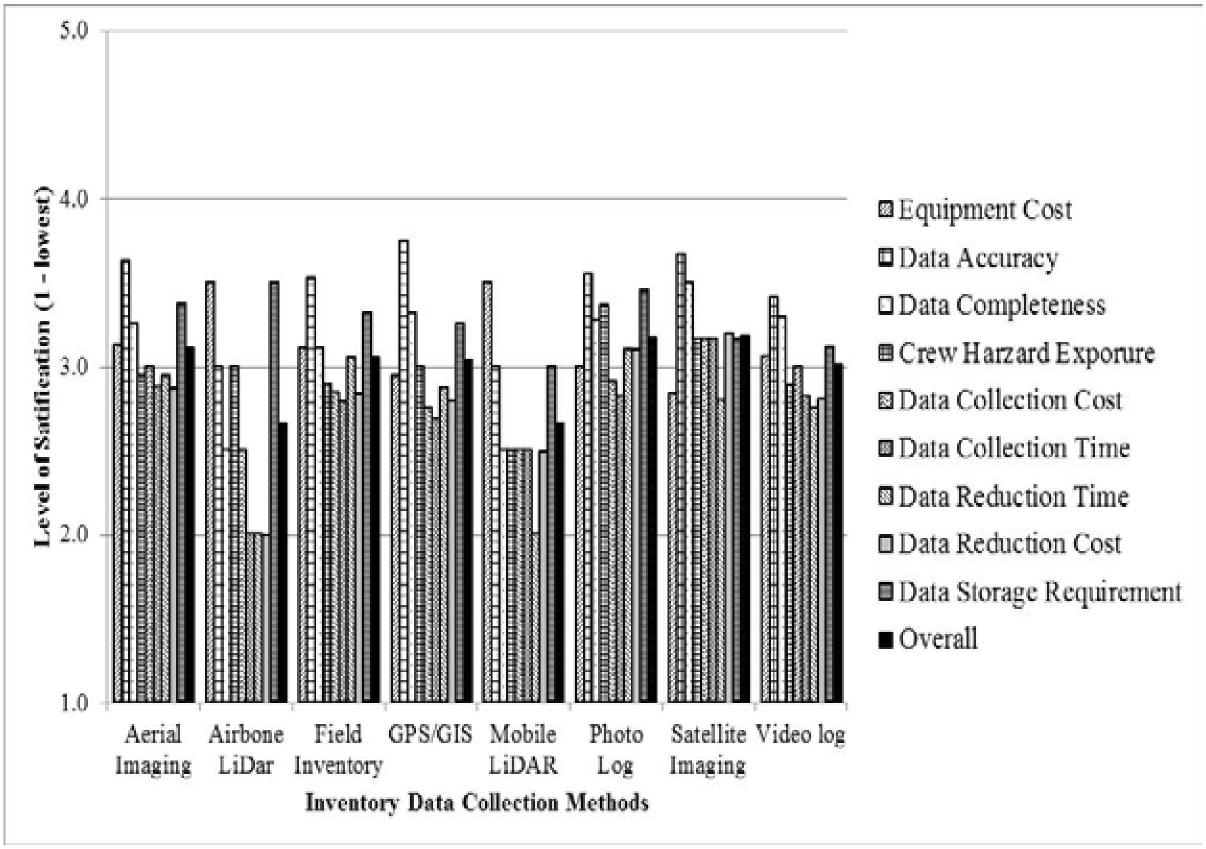


Figure 4-6. Level of satisfaction with adopted inventory data collection methods by state DOTs.

CHAPTER 5 FIELD EXPERIMENT AND DATA COLLECTION

This part of the study involved field experiments conducted by the research team on selected methods for roadside inventory data collection, including GPS data logger, robotic total station, GPS-enabled photo/video log, satellite/aerial imagery, and mobile LiDAR, along the following four road segments (Figure 5-1):

- Site 1—Rural multi-lane highway: South University Drive from University Park Drive to I-270
- Site 2—Freeway segment: I-270 from IL-157 to IL-159
- Site 3—Rural two-lane highway: IL-140 from IL-159 to IL-157
- Site 4—Urban and suburban arterials: Governor's Parkway from Esic Road to District Drive

Site 1: South University Drive as Rural Multi-Lane Highway

Site 3: IL 140 Highway from IL 159 to IL 157 as Rural 2-Lane Highway

Site 2: I-270 Highway from IL-157 to IL -159 as Freeway

Site 4: Governor Pkwy from Esic Road to District Dr. as Urban/Suburban Arterials

Figure 5-1. Aerial views of four selected segments.

5.1 GPS DATA LOGGER

GPS data logging is carried out with a handheld GPS unit that records time of observation, location, elevation, and crew-entered notes. The data logger is equipped with an internal camera, allowing images of recorded locations to be stored and associated with the location data. Output from the data logger may be viewed on a mapping application such as Google Earth. Ten-cm accuracy can be achieved with the Trimble GeoCollector data collector used for this project. Figure 5-2 shows the GPS data logger device in use during the field survey process.

GPS data logging is accomplished by placing the device next to the object to be recorded. At the beginning of data collection work, the device must be initialized, a process that requires approximately 5 min. Once the device has initialized, a menu screen is used to instruct the device to record its current elevation and location. The operator then uses the device keyboard to enter descriptive data related to the object, a discrete number associated with the location, and a photograph of the object (optional). Data collection time at the object requires approximately 1 sec. Entering descriptive data requires an additional 5 to 20 sec per object. The use of standard abbreviations can reduce manual data entry time to less than 5 sec per object. Travel to the next object varies with the distance between objects and the nature of the terrain. The use of a four-wheel all-terrain vehicle allowed data collection rates on the order of one data point every minute. Note that the initializing setup time occurs only at startup; the time for each recorded observation thereafter averages less than 10 sec per object, with the remainder of the time spent traveling to the next point.

Like all GPS devices, the data logger requires a relatively clear view of the sky. Consequently, the device is not able to provide data in areas next to buildings or in areas that are under the tree canopy. On the three road segments tested, two segments were nearly free of overhead obstructions and allowed a complete survey of the segments with the data logger. However, along Site 3, several hundred feet of the alignment was overhung by trees, preventing use of the device along this portion of the segment. Recent improvements in GPS data logger devices include the integration of a laser range finder and a solid state inclinometer and compass. These improved devices allow the user to remain in an open sky area and record elevation and location data on an object up to 100 m away. These new-generation devices will likely expand the use and utility of GPS data logging. This method does not require the use of nearby differential GPS stations. For GIS-level precision, differential GPS corrections are not required. However, virtual reference station (VRS) corrections via Wi-Fi or cell phone connections are largely replacing on-site differential GPS corrections, allowing centimeter-level precision.

Crew exposure to traffic is an issue with GPS data logging. Warning signs, traffic cones, high-visibility clothing, and site-specific safety analysis were all employed during the course of this study. Setting up, moving, and taking down warning signs and traffic cones consumed a significant percentage of the time required to survey each segment.

Figure 5-2. Sample GPS data logger device for data collection.

A total of 495 features were collected for three segments. Table 5-1 shows a summary for the data logger methods. Signs, guardrails, driveways, and mailboxes were some of the objects collected.

Table 5-1. Summary of GPS Data Logger Methods for Highway Inventory Data Collection

Satisfaction Factors	Number of Crew	Number of Objects	Data Collection Productivity (ft/hr)	Data Collection Productivity (objects/hr)	Length of Test Segment (ft)
Site1—Rural Multi-Lane Highway: South University Dr. from University Park Dr. to I-270	1	144	840	72	1680
Site 3—Rural Two-Lane Highway: IL-140 from IL-159 to IL-157	1	194	889	86	2000
Site 4—Urban and Suburban Arterials: Governor's Pkwy. from Esic Rd. to District Dr.	1	157	1754	80	3450

5.2 ROBOTIC TOTAL STATION

During the late 1980s, electronic distance measuring equipment was successfully integrated with electronic theodolites to create “total station” surveying instruments. With the addition of electronic data collection in the early 1990s, survey data gathering productivity has increased by an order of magnitude. A typical crew consists of three people: an instrument man to point the instrument and initiate measurement, a party chief to direct the work and sketch additional data, and a rodman to walk to the object to be recorded and plumb the reflector prism equipped survey rod over the object to be recorded. Early efforts to have the instrument automatically track the survey rod were less than successful. However, improvements in tracking algorithms, radio links, and robotic servos now allow one person to operate a robotic total station. The instrument man and party chief responsibilities are all carried out at the survey rod through the use of a radio linked controller/data collector.

The robotic total station instrument is set up on a tripod just as a conventional survey instrument would be. The instrument and controller/data logger are turned on and a radio link is established between the units. The controller is used to direct the optical axis of the total station to the reflector prism. Once pointed, robotic servos automatically align the instrument axis with the prism. The instrument follows the prism as the surveyor moves about the site. When the surveyor reaches an object to be recorded, the instrument is instructed to record the current location and elevation and the surveyor then enters a discrete number and a description of the object. Data collection productivity achieved in the present study with this method was approximately one object per minute (Figure 5-3).

The robotic total station records locations relative to its position only. Orientation to state plane coordinates or latitude and longitude must be provided by separately calculated methods, either by reference to previously located monuments or by locating control points with a precision GPS system. Orientation of instrument azimuth and elevation must be similarly accomplished by reference to existing monuments. This orientation step adds a level of complexity to this method that is not required by the other methods studied. While the total station work has the disadvantage of requiring orientation into a reference system, it has the advantage of providing the highest level of precision of any method tested. Location and elevation accuracies of 0.5 cm are routine. This level of precision is necessary for some survey work, but it has not been shown to be necessary for highway safety inventory work.

The operating radius of the instrument is approximately 1,000 ft, allowing data collection along a maximum alignment length of 2,000 ft before the instrument must be relocated. The tracking mechanism operates by line of sight. Small obstructions such as tree trunks, utility poles, and signs do not usually cause the instrument to lose tracking lock on the prism. However, line of sight interruptions such as intervening hills, steep side slopes, and passing large trucks cause the instrument to lose tracking. When this occurs, the surveyor must stop moving and use the controller to reorient the optical axis until tracking is regained. This relocking procedure may require anywhere from a few seconds to a minute, depending on the length of time the line of sight was lost and the distance from the instrument. On busy highways, loss of tracking is a significant issue when working on the opposite side of the highway from the instrument because every passing vehicle potentially could cause at least a temporary loss of lock. It may well prove necessary on some alignments to set up the robotic total station on both sides of the alignment and collect data from one side of the road at a time. Table 5-2 shows the summary of collection times for this method.

As with the GPS data logger, crew exposure to traffic is an issue. Warning signs, traffic cones, high-visibility clothing, and site-specific safety analysis were all employed during the course of the present study. Setting up, moving, and taking down warning signs and traffic cones consumed a significant percentage of the time required to survey each segment. Collecting edge of pavement and centerline data is particularly hazardous as the surveyor must stand alongside of or within the traveled right-of-way.

Figure 5-3. Robotic total station method for data collection.

Table 5-2. Summary of the Robotic Total Station Method for Highway Inventory Data Collection

Satisfaction Factors	Number of Crew	Number of Objects	Data Collection Productivity Time (ft/hr)	Data Collection Productivity Time (objects/hr)	Length of Segment (ft)
Site1—Rural Multi-Lane Highway: South University Dr. from University Park Dr. to I-270	1	282	351	59	1680
Site 3—Rural Two-Lane Highway: IL-140 from IL-159 to IL-157	1	233	598	60	2000
Site 4—Urban and Suburban Arterials: Governor's Pkwy. from Esic Rd. to District Dr.	1	165	694	57	3450

5.3 GPS-ENABLED PHOTO/VIDEO LOG

The collection of geo-tagged digital videos and photos was carried out for the selected road segments using a video mapping system. Equipped with a Sony video camcorder and GPS antenna, the video mapping system collected geo-tagged digital video with essential locational information, which could be imported into ArcGIS 9.3. (with ArcView 9.3 or Arc Editor 9.3 license) using a Video for ArcGIS extension (or GeoVideo). Figure 5-4 shows the configuration of the video mapping system, which can be mounted a car dashboard.

Figure 5-4. Video logging system configuration.

The researchers collected video for a total of 28 mi on the four selected roadway segments (based on two directions): rural two-lane highway (12 mi, IL-140 from IL-159 to IL-157); urban and suburban arterials (4 mi, Governor's Parkway from Esic Road to District Drive); rural multi-lane highway (8 mi, South University Drive); and freeway (4 mi, I-270 from IL-157 to IL-159). Data recording took approximately 2 hr for a team of three researchers (only two were actually needed). The video files had a total data volume of slightly more than 5 gigabytes and were saved in four separate video files (one file for each roadway segment) in .mpg format. The video files contained both digital motion pictures and GPS locations for the roadways. The video files could be imported into ArcGIS to assist the extraction of roadside objects. Below are two examples (Figures 5-5 and Figure 5-6) that show the recorded roadway segments on the map and the video being played in ArcGIS.

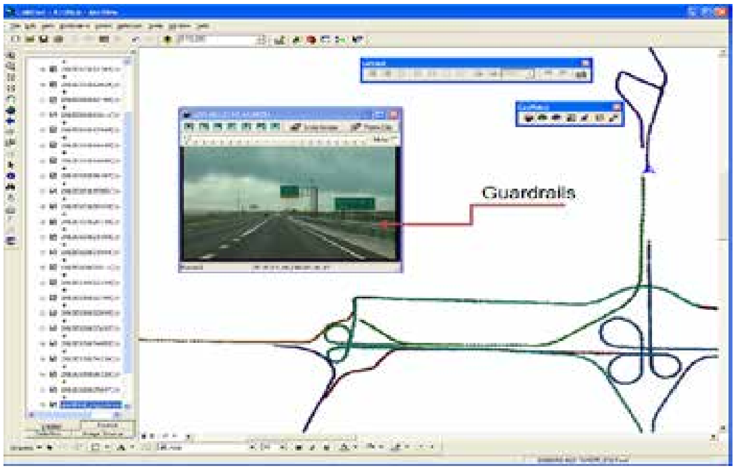


Figure 5-5. Video showing guardrail as roadside object.

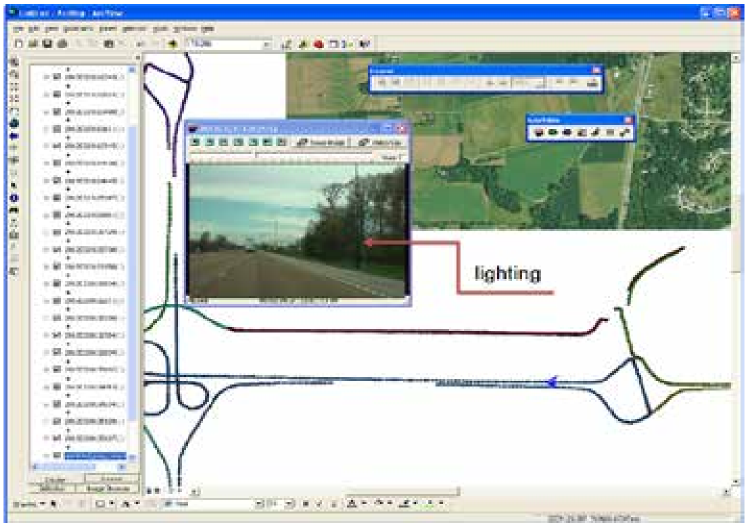


Figure 5-6. Video showing light poles as roadside objects.

5.4 SATELLITE/AERIAL IMAGERY

High-resolution images taken from satellite/aircraft can be used to identify and extract highway inventory information. In the present study, Google maps and Bing maps were used to extract as many objects as possible. Figure 5-7 shows some objects extracted from the Bing maps (based on aerial imagery), including signs, guardrails, and lighting poles. The average time for the extraction of each object using this method for selected road segments is shown in Table 5-3. Appendix F contains additional detailed information about the objects extracted from both Google maps and Bing maps.

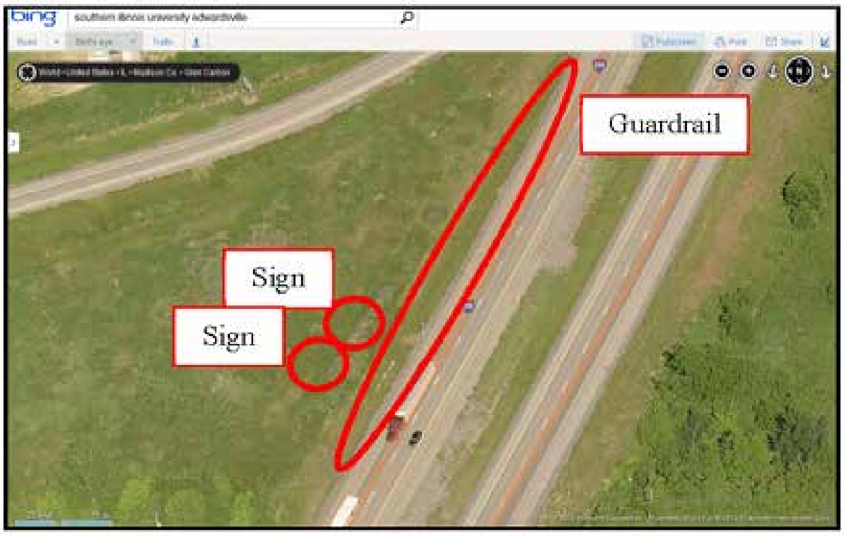


Figure 5-7. Data extracted by using satellite/aerial imagery method.

Table 5-3. Summary of Roadside Object Extraction Using a Satellite/Aerial Imagery Method

Segment	Time Reduction (Min)	Objects (Number)	Average Time for Each Object (Min)
Site1—Rural Multi-Lane Highway: South University Dr. from University Park Dr. to I-270	208	80	2
Site 2—Freeway Segment: I-270 from IL-157 to IL-159	170	79	2
Site 3—Rural Two-Lane Highway: IL-140 from IL-159 to IL-157	186	201	1
Site 4—Urban and Suburban Arterials: Governor's Pkwy. from Esic Rd. to District Dr.	60	58	1
Total	624	418	1.5

5.5 MOBILE LiDAR

The research team hired a consulting firm to conduct a mobile LiDAR field trial. On July 23, 2012, field data were collected on the following road segments. Point cloud and photo data were collected in both directions along the four selected segments. The segments along Site 4 (Governor's Parkway) were controlled for higher accuracy. Figure 5-8 shows the mobile LiDAR system used for data collection. Before data collection, control points were set up on Site 1 (South University Drive) (Figure 5-9).

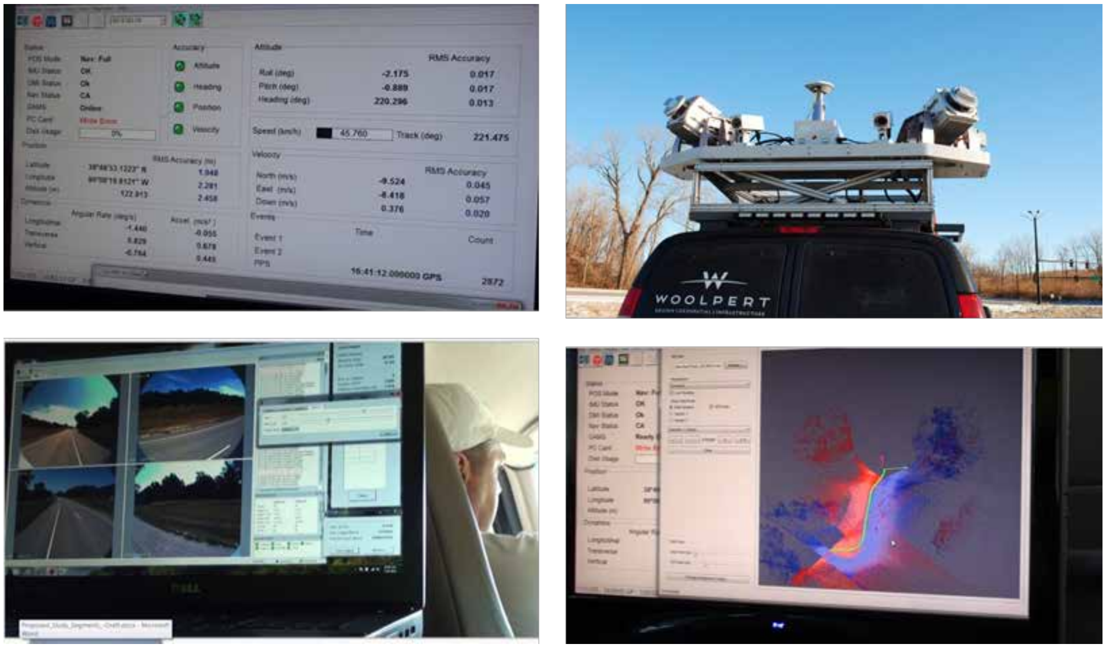


Figure 5-8. Mobile LiDAR system used for data collection.

Figure 5-9. Control point at Site 1.

During data collection, time was recorded for later comparison with other methods. Table 5-4 shows the summary of data collection times. Note that the time spent for field data collection using this method is much lower than for other field inventory data collection methods.

Table 5-4. Summary of Data Collection Times for Mobile LiDAR Data Collection Method

10:59AM - 1:42PM	**1**	**Test Strip #1**		**3:51PM - 5:05PM**	**1**	**Test Strip #1**
	2	**Test Strip #2**			**2**	**Test Strip #2**
	3	**Test Strip #3**			**3**	**Test Strip #3**
	4	**Test Strip #4**			**4**	**Test Strip #4**
	5	**Test Strip #5**			**5**	**Test Strip #5**
	6	**Strip #1**	**East University Drive**		**6**	**IL-140 East Bound**
	7	**Strip #2**			**7**	**IL-140 West Bound**
	8	**Strip #3**				
	9	**Strip #4**				
	10	**Strip #5**				
	11	**Strip #6**				
	12	**Strip #7**				
	13	**Strip #8**				
	14	**Strip #7 - redo**				
	15	**Strip #9**	**Governor's Parkway**			
	16	**Strip #10**				
	17	**Strip #11**	**Interstate**			
	18	**Strip #12**				

Once acquired, mobile LiDAR data were downloaded from the system and converted to .las files. Mobile LiDAR data were then post-processed using the following steps:

- Extract POS data
- Extract .las files
- Extract .jpg images

- Review .las files for completeness
- Boresight
- Apply boresight corrections to LiDAR and imagery
- Match strips
- Translate all data to the require coordinate system
- Verify point cloud to control

Table 5-5 shows features for different roadway types that were extracted with LiDAR data processing software.

Table 5-5. Features Extracted by LiDAR Data Processing Software

Site 1: Rural Multi-Lane Highway (South University Dr. from University Park Dr. to I-270) · Roadside slope (1:2, 1:3) at an interval of roughly 10 to 20 ft
Site 2: Freeway Segment (I-270 between IL-157 and IL-159) · Length of barrier (mi) (concrete barrier) · Distance from pavement edge to barrier face (ft) · Median barrier width (ft) · Nearest distance from edge of pavement to barrier face · Clear zone width (ft)
Site 3: Rural Two-Lane Highway (IL-140 between IL-159 and IL-157) · Superelevation rates · Roadside hazard rating (rating from 1 – 4 roughly, depending on density of roadside slope and roadside objects); SIUE to help populate · Roadside slope · Roadside objects · At least 4-in. in diameter, located on the roadside within 30 ft of the traveled way · Multiple roadside objects located within 70 ft of one another should be counted as a single object (70 ft beginning at the segment). Roadside objects located behind other objects should not be counted (perpendicular to travel direction)
Site 4: Urban and Suburban Arterials (Governor's Pkwy. between Esic Rd. and District Dr.) · Roadside fixed objects

CHAPTER 6 DATA REDUCTION AND PROCESSING

The data reduction effort required for each data collection technique has significant impact on the use of the technique. For example, one previous study showed that the manual highway inventory data collection technique was more cost effective than the automated methods such as mobile mapping systems because the latter incur high equipment costs and significantly greater data reduction effort (Khattak et al. 2000). However, recent developments in automated data reduction methods and declining hardware costs may reduce that disadvantage. To understand and measure the amount of data reduction effort required for each data collection technique, the research team used the software programs shown in Table 6-1.

Table 6-1. Proposed Data Reduction Methods

Data Collection Method	Data Reduction Methods (if required)
Field Inventory	N/A
Photo Log	Manual review, photogrammetry
Video Log	Manual review, photogrammetry
Integrated GPS/GIS Mapping Systems	N/A
Aerial Photography	GIS package (ArcGIS)
Satellite Imagery	GIS package (Google Earth Pro)
Mobile Mapping Systems	Point cloud post-processing software

The research team recorded the time spent conducting data reduction tasks such as extracting clear zone distance and side slope from data. Clear zone distance and side slope are the two most important roadside data elements required for RHR. In addition to data reduction time, the research team also evaluated the feasibility and training needs for IDOT personnel to use these programs. In general, the effort of data reduction was inversely proportional to the quantity and richness of data collected in the field. For data collection techniques that require extensive data reduction effort, the research team also investigated ways of automating the data reduction process, such as using a script programming language to automate repetitive data reduction steps. For example, to measure the clear zone distance from point clouds, a program was developed that allows users to specify the clearance distance along the center of roadway at one section and then a plan section that corresponds to a specific clear distance hazard rating that could be automatically swept along the roadway to classify the clear distance hazard rating for the entire road segment.

6.1 FIELD INVENTORY

Trimble equipment was used for both GPS data logger and robotic total station work. Both systems use a similar data collector running Microsoft-based data collection software. Collected data can be transferred from the data collector to a computer via a cable or wireless connection. Once the data transfer is complete, the data can be imported into a computer-aided design (CAD) software program for processing. AutoCAD Civil 3D was used as data processing software in the present study. The data reduction steps consisted of importing the data files into an AutoCAD-supported format, establishing a drawing file template, and importing the resulting data files into the drawing format. When these steps were completed, the drawing consisted of a series of discrete points with associated elevation and description attributes. The points were located to scale within the drawing in relation to their location in the field. The CAD operator then edited the drawing to create centerlines, edge of pavement, edge of shoulder, and objects of interest. At that point, the drawing resembled a highway alignment drawing.

Additional processing used the discrete point elevations to define a surface representing the topography. A process called slope banding can be employed to identify right-of-way side slope by percentage of slope. In the present case, we were interested in assigning one of two values, either greater than or less than 33% slope for the 30 ft of right-of-way adjacent to the edge of shoulder.

Dealing with ever-changing drawing software programs can be challenging. Problems with file incompatibility, revised software routines, planned obsolescence of software, and lack of up-to-date operator training will severely impact productivity and drawing quality. A skilled CAD operator, using up-to-date software, should be able to process survey crew–derived data at rates in excess of 2,000 ft per hr. In the present case, some of the factors listed previously extended the drawing production times such that several days were consumed for accurate creation of even small sections of alignment. Figure 6-1 shows the slope banding in the segment.

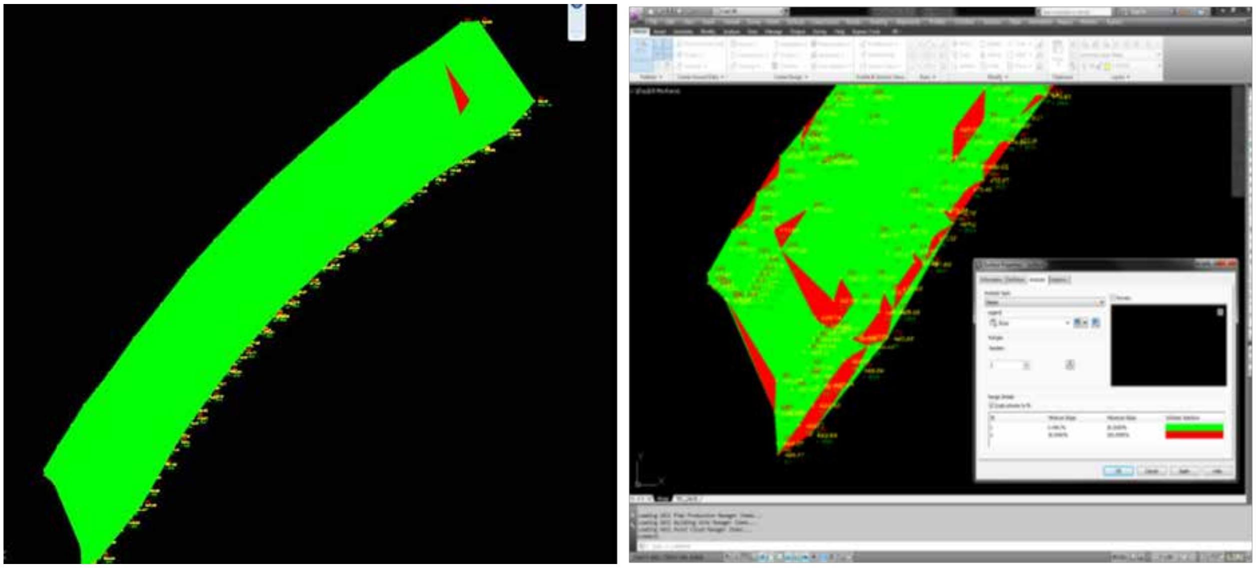


Figure 6-1. Sample of slope banding in the segment.

6.2 PHOTO LOG/VIDEO LOG/AERIAL PHOTO/SATELLITE IMAGE

Video files collected in the field in .mpg format can be imported into ArcGIS to allow the extraction of roadside objects. A specialized ArcGIS extension called Video for ArcGIS or GeoVideo is required to import the original video files. This GeoVideo program creates a point feature class that correlates with the GPS locations where the video was taken. GeoVideo allows the user to click on any point to start the play of the video file so that roadside objects can be easily identified by the system operator (Figure 6-2).

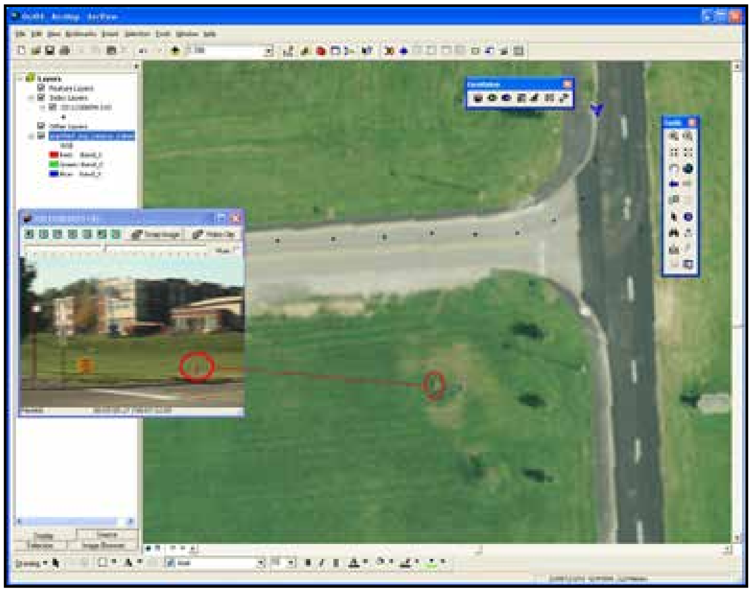


Figure 6-2. Video being played in ArcGIS.

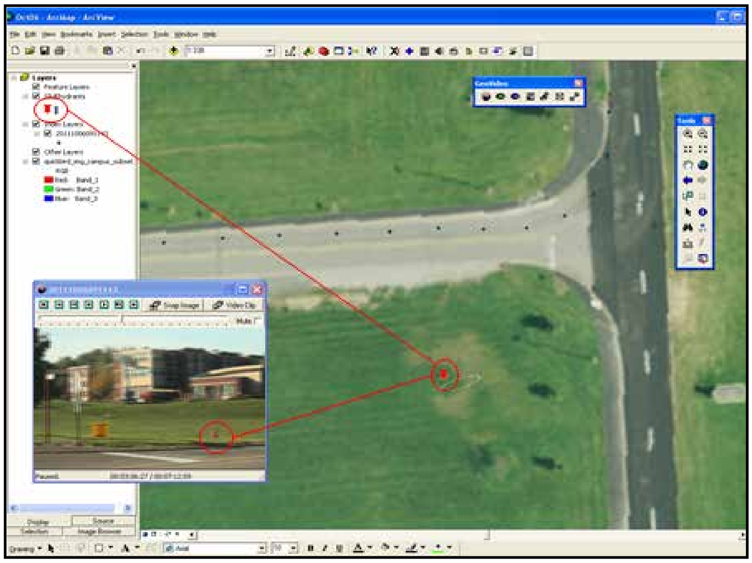
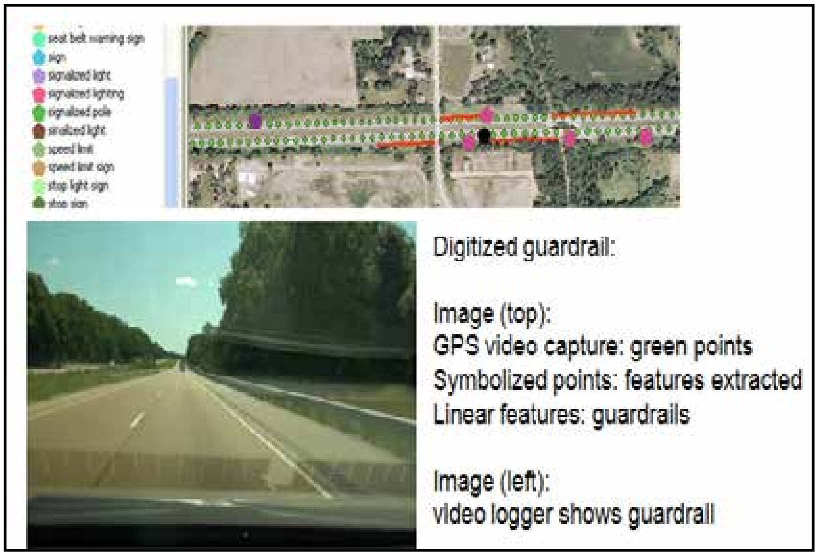


Figure 6-3. Roadside objects extracted in ArcGIS.

With the help of high-resolution imagery (e.g., 1-ft digital orthophotos or satellite imagery) as a background, extraction of roadside objects is possible. Working with both video and high-resolution aerial/satellite imagery, features in the form of points, lines, and polygons can be traced through on-screen digitizing and saved as feature classes in ArcGIS. Figure 6-3 shows the creation of a point feature class in ArcView shapefile format and how roadside objects could be extracted from high-resolution imagery through on-screen digitizing in the ArcGIS.

Figure 6-4 shows the creation of a polyline feature class for guardrails in ArcView shapefile format and how guardrails could be extracted from high-resolution imagery through on-screen digitizing in the ArcGIS.



Digitized guardrail:

Image (top):
GPS video capture: green points
Symbolized points: features extracted
Linear features: guardrails

Image (left):
video logger shows guardrail

Figure 6-4. Examples of object extraction using both video log and high-resolution imagery.

Table 6-2 summarizes the number of objects per mile extracted using the video logging method for selected roadway segments. An average of 41 objects per mi was extracted.

Table 6-2. Summary of Roadside Object Extraction—Objects per Mile

Selected Roadway Segments	Number of Objects	Mi	Objects/Mi
Site1—Rural Multi-Lane Highway: South University Dr. from University Park Dr. to I-270	347 (Points)	8	43
Site 2—Freeway Segment: I-270 from IL-157 to IL-159	87 (Points) and 18 (Linear)	4	26
Site 3—Rural Two-Lane Highway: IL-140 from IL-159 to IL-157	571 (Points)	12	47
Site 4—Urban and Suburban Arterials: Governor's Pkwy. from Esic Rd. to District Dr.	108 (Points) and 11 (Linear)	4	30
Total	1141	28	41

Table 6-3 shows the time spent to extract roadside objects per mile using the video logging method for the selected roadway segments. An average of 50 min was required to extract all roadside objects along each mile of roadway.

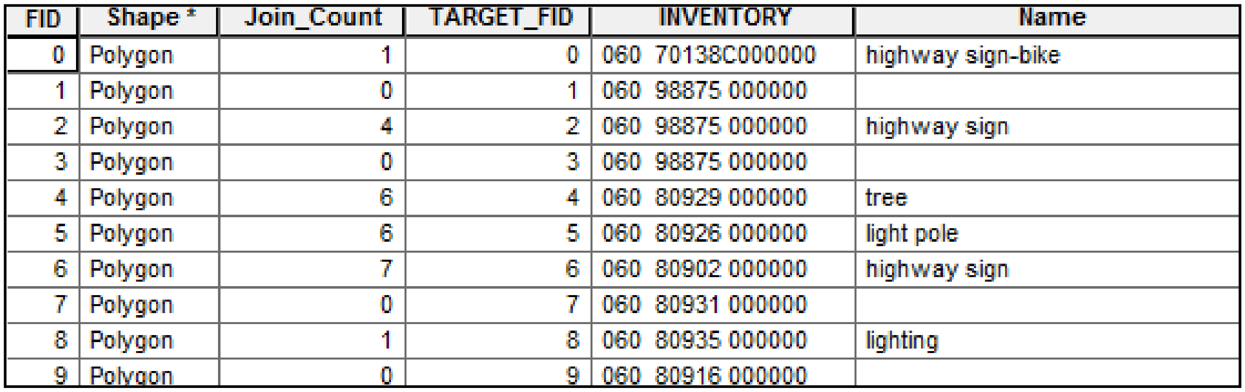
Table 6-3. Summary of Roadside Object Extraction—Minutes per Mile

Selected Roadway Segments	Number of Objects	Number of Min	Mi	Min/Mi
Site1—Rural Multi-Lane Highway: South University Dr. from University Park Dr. to I-270	347 (Points)	285	8	36
Site 2—Freeway Segment: I-270 from IL-157 to IL-159	87 (Points) and 18 (Linear)	300	4	75
Site 3—Rural Two-Lane Highway: IL-140 from IL-159 to IL-157	571 (Points)	565	12	47
Site 4—Urban and Suburban Arterials: Governor's Pkwy. from Esic Rd. to District Dr.	108 (Points) and 11 (Linear)	240	4	60
Total	1141	1390	28	50

In summary, a total of 1,141 objects were collected along a total of 28 mi of roadway segments, averaging 41 objects per mi. Similarly, it took 1,390 min to extract those roadside objects, equivalent to about 1 min per object or 50 min per mi.

The extracted roadside objects can then be assigned to each road segment based on the inventory number in the existing IDOT GIS database. This was accomplished through a spatial join process in ArcGIS. A Snap tool was first used to assign each extracted object to the nearest road segment. Then a buffer of 30 ft was used to tally the number of objects for each segment, which could be merged into the existing IDOT GIS database. Table 6-4 shows the total count of the number of objects (see the Joint_Count attribute field in the table) assigned to each roadway segment according to the road inventory number.

Table 6-4. Total Count of the Number of Objects Assigned to Each Roadway Segment



FID	Shape *	Join_Count	TARGET_FID	INVENTORY	Name
0	Polygon	1	0	060 70138C000000	highway sign-bike
1	Polygon	0	1	060 98875 000000	
2	Polygon	4	2	060 98875 000000	highway sign
3	Polygon	0	3	060 98875 000000	
4	Polygon	6	4	060 80929 000000	tree
5	Polygon	6	5	060 80926 000000	light pole
6	Polygon	7	6	060 80902 000000	highway sign
7	Polygon	0	7	060 80931 000000	
8	Polygon	1	8	060 80935 000000	lighting
9	Polygon	0	9	060 80916 000000	

6.3 MOBILE LiDAR

The mobile LiDAR data can be processed according to steps shown in the Table 6-5. The time associated with these steps is also listed in the table. Note that the processing involves fairly intensive computational effort. The data processed during these steps consist of point clouds in .las format, geo-referenced imagery, data collection path, and a CAD file. The total size of the collected dataset is 132 gigabytes, and the total length of data collection is 14.2 mi. This leads to the estimate of 9.3 Gb/mi. These processed data are the starting point for highway feature extraction.

Table 6-5. Summary of Data Reduction Time for Post-Process Steps

Data Process	Data Reduction Time
Extract POS data	30 min
Extract .las files	1 man-hr 6 computer-hr
Extract .jpg images	20 min 6 computer-hr
Review .las files for completeness	2.5 man-hr
Boresight	2 man-hr
Match Strips	2 hr/mi
Verify Point Cloud to Control	30 min/mi

Because of their large volume, mobile scanning data are typically divided into manageable blocks, with each block containing approximately 2 gigabytes of data. The schema of blocks is then displayed in a CAD file. A part of the colorized point cloud data for South University Drive is shown in Figure 6-5.

Figure 6-5. Example of colorized point clouds.

Processing of and feature extraction from mobile LiDAR point clouds require fairly specialized software. Widely used commercial LiDAR processing software packages include Terrasolid Suite, Virtual Geomatics, and QTModeler. Terrasolid is essentially a collection of Microstation add-ons; therefore, it requires Microstation to be functional. Virtual Geomatics is a stand-alone program integrated with GIS systems. QTModeler has been widely used for airborne LiDAR processing, but it lacks tools to support feature extraction and asset management functionalities. In the present research, Terrasolid was tested to extract features needed for the HSM.

Specifically, mobile LiDAR data were collected on four different types of roadway segments. Each type of roadway segment had different safety feature needs. Extraction of safety features for each type of roadway segment was performed to determine the complexity and time involved for feature extraction. Because each type of highway segment was broken into equal-sized blocks, data extraction was performed on representative blocks. The results were used to infer the data reduction time for the whole highway segment. Note that mobile LiDAR processing software packages are designed for the purpose of extracting low-level features, such as positions of poles or widths of shoulders, instead of extracting aggregate features such as roadside hazard rating or roadside object density. These aggregate features are best derived by extracting the low-level features first in the LiDAR processing software then computing the aggregate features using the spatial analysis functionalities available in most GIS systems. The following section details this data extraction process and the results.

6.3.1 Rural Multi-Lane Highway

Location: Site 1 (South University Drive from University Park Drive to I-270)

Data Extracted:

a. Roadside slope at an interval of roughly 10-20 ft

   Data Extraction Time: 5 min for each block (400 ft)

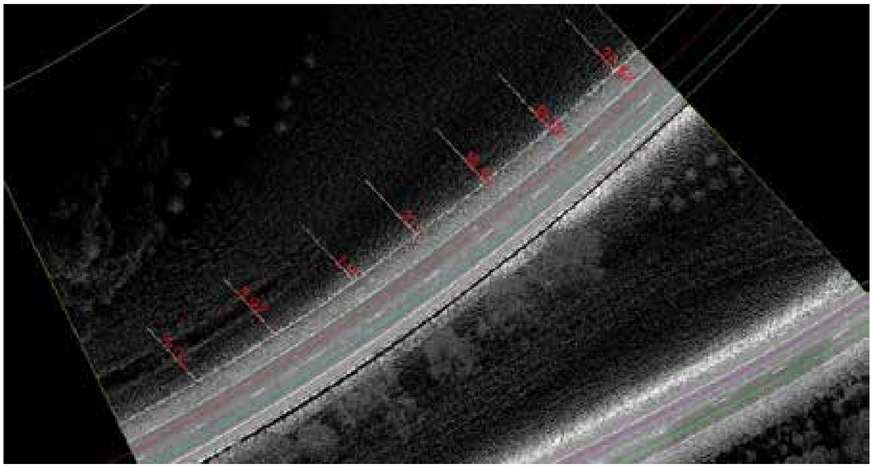


Figure 6-6. Extracted roadside slope at Site 1.

6.3.2 Freeway Segment

Location: Site 2 (I-270 between IL-157 and IL-159)

Data Extracted:

1. Length of barrier (mi) (Concrete Barrier)
2. Distance from pavement edge to barrier face (ft)
3. Median barrier width (ft)
4. Nearest distance from edge of pavement to barrier face
5. Clear zone width (ft)

Data Extraction Time: 10 min for each block (400 ft)

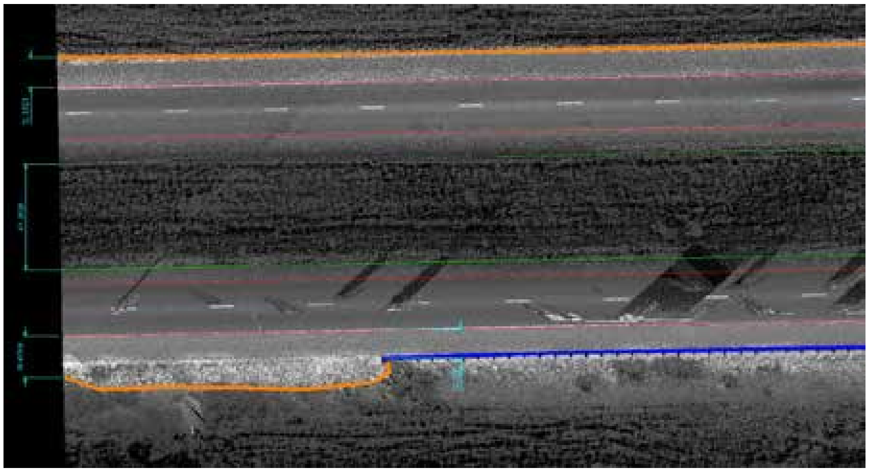


Figure 6-7. Extraction data requirements at Site 2.

6.3.3 Rural Two-Lane Highway

Location: Site 3 (IL-140 between IL-159 and IL157)

Data Extracted:

1. Superelevation rates

Data Extraction Time: 15 min for each block (400 ft)

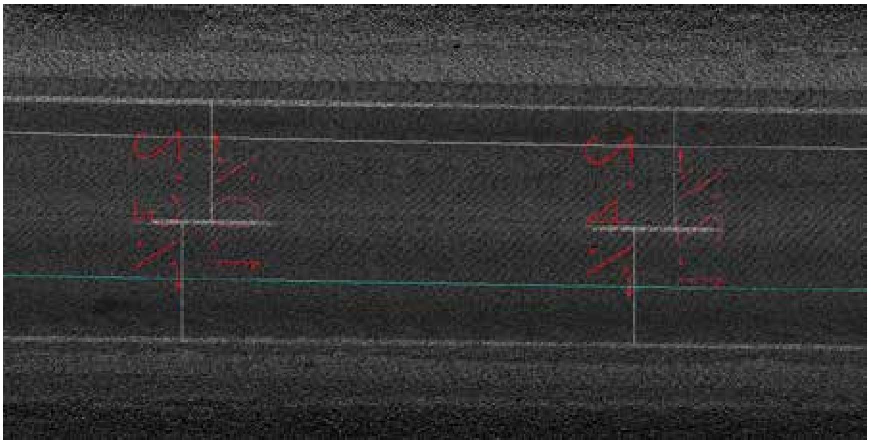


Figure 6-8. Extracted superelevation at Site 3.

b. Roadside hazard rating (Rating from 1-4 roughly, depending on density of roadside slope, and roadside objects)

   1. Roadside slope
   2. Roadside objects (detailed explanations of roadside objects can be found in Table 5-6)

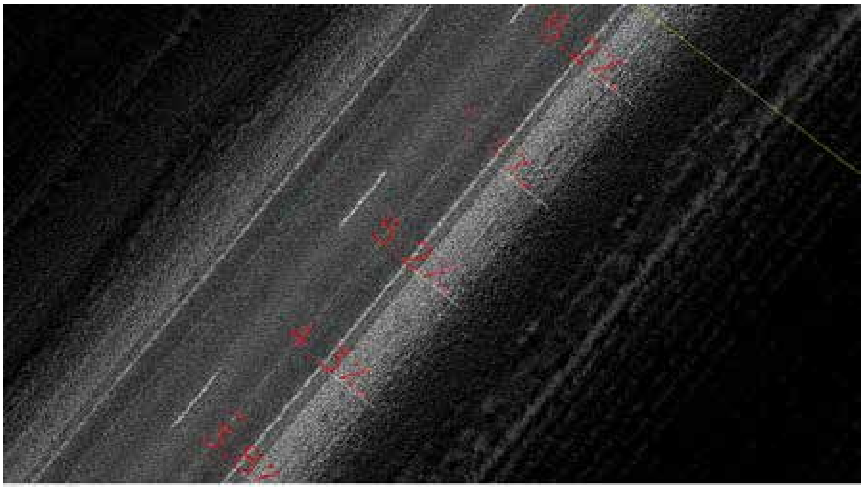


Figure 6-9. Extracted roadside slope at Site 3.

Figure 6-10. Extracted roadside objects at Site 3.

6.3.4 Urban and Suburban Arterials

Location: Site 4 (Governor’s Parkway between Esic Road and District Drive)

Data Extracted:

a. Roadside fixed objects (detailed explanations of roadside objects can be found in Table 5-6)

Data Extraction Time: 10 min for each block (400 ft)

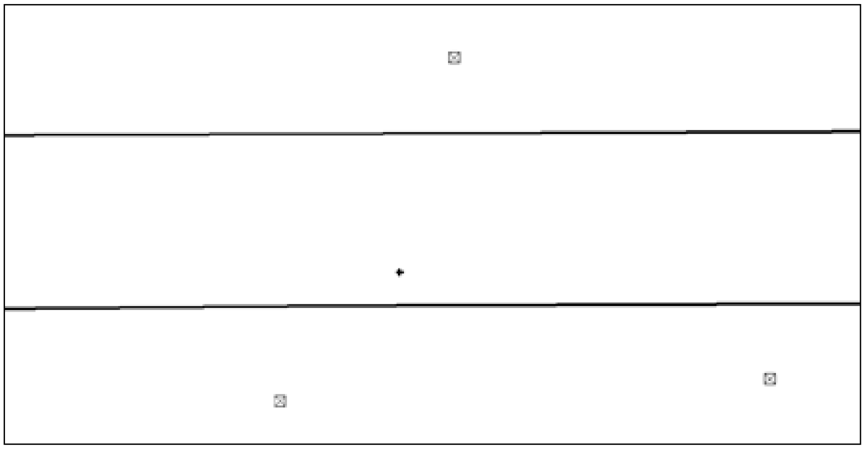


Figure 6-11. Extracted roadside objects at Site 4.

6.3.5 Summary of Results

Table 6-6 provides a summary of the time required for data collection and data reduction using the mobile LiDAR method.

Table 6-6.Summary of Data Collection and Data Reduction Time with the Mobile LiDAR Field Test

Data Collection		30 mi/day	
Data Pre-Processing		6.5 man-hr 12 computer-hr	
Feature Extraction (Block size = 400 ft)	Site 1 (Rural Multi-Lane Highway)	Roadside Slope	5 min/block
	Site 2 (Freeway Segment)	Length of Barrier	10 min/block
		Distance from Pavement Edge to Barrier Face	
		Median Barrier Width	
		Nearest Distance from Edge of Pavement to Barrier Face	
		Clear Zone Width	
	Site 3 (Rural Two-Lane Highway)	Roadside Slope	15 min/block
		Roadside Fixed Objects	
		Superelevation Rates	
	Site 4 (Urban and Suburban Arterials)	Roadside Fixed Objects	10 min/block

CHAPTER 7 EVALUATION OF DIFFERENT METHODS

Five field-tested methods—GPS data logger, robotic total station, GPS-enabled photo/video log, satellite/aerial imagery, and mobile LiDAR—were evaluated to determine the most advantageous technique, or combination of techniques, for collecting safety-related features on IDOT roads. This chapter provides a brief discussion of the strengths and shortcomings of each technique, followed by ranking based on costs, time requirements, data completeness and accuracy, disruption to traffic, and safety.

7.1 FIELD TESTING RESULTS

7.1.1 GPS Data Logger

Field tests demonstrated that a GPS data logger can meet the accuracy required by the HSM models. In general, the GPS data logger device is very user friendly, reducing the need for extensive training. It can be operated by one surveyor, possibly with the need for another person to watch traffic. The average times for setting up the device, entering a description, and collecting data per object were 5 min, 10 to 20 sec, and 0.75 min, respectively. Note that all the highway inventory data to be used in the HSM can be collected with this method. One of the method’s shortcomings is the likelihood of GPS outage in areas with tall buildings and significant tree cover. Crew exposure to traffic is another issue that requires mitigation strategies such as setting up warning signs and traffic cones.

7.1.2 Robotic Total Station

As with the GPS data logger method, the robotic total station system collected data with adequate accuracy for implementing HSM and was capable of collecting all the required road inventory data. The initial system setup time and data collection time per object were higher than for the GPS data logger method. Specifically, an average of 1 min was required to collect information for each object. One major shortcoming with this method was that once the robotic total station was set up at one spot, it had a limited operating radius. Collection of information on objects along a long segment of roadway required a new setup of the robotic total station at least once every 1,000 ft of segment. Another issue was the significant influence of area topography on the line of sight of the system. For example, hills caused line of sight problems in the tracking process. In addition, robotic total stations exposed crews to road traffic.

7.1.3 Photo/Video Log

The photo/video log method requires a relatively short field data collection time but an extensive feature extraction effort in the office. The photo/video log is conducted on a vehicular platform, which eliminates the risk of exposing the data collection crew to road traffic. In the present research, extraction of HSM-related information using photo/video log required an average of 50 min per mi or 1 min per object. If used with high-resolution aerial photographs or satellite imagery, the photo/video logging method can provide all roadside inventory data except roadside slope with the accuracy needed for HSM. A locational accuracy of 6 in. for all roadside objects is achievable with 1-ft spatial resolution images.

7.1.4 Satellite/Aerial Imagery

The increasing availability of high-resolution images offers the possibility of leveraging the images to extract some HSM-related safety features. Compared to other methods, this method is the most economical method becausee it has no field data collection needs.

However, similar to the photo/video log method, satellite/aerial imagery is not capable of collecting some HSM-related road inventory data. For example, extraction of roadside slope information is very difficult from satellite/aerial imagery. In addition, small vertical objects are not very visible in satellite/aerial imagery.

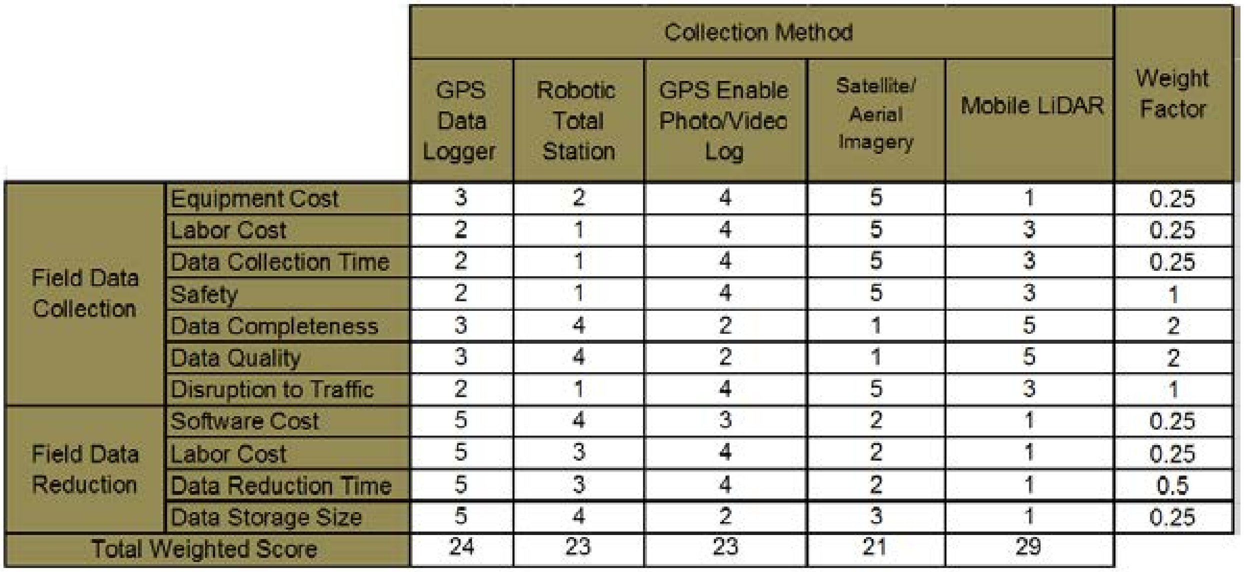
7.1.5 Mobile LiDAR

Mobile LiDAR has the capability of collecting all categories of HSM road inventory data. Processing of and feature extraction from mobile LiDAR data require fairly specialized software and technical expertise. The cost of field data collection by this method is higher than with the other methods, although its data collection time is short. For example, in the present study, all the features for the road segments, totaling 14.2 mi, were collected in 4 hr. Data reduction was a major undertaking with mobile LiDAR. Approximately 5.5 man-hr and 12 computer-hr time were required for data pre-processing. Another concern with this method is the need for a large amount of space for data storage. This study estimated that 9.3 gigabytes of data were generated per mile of roadway. However, these shortcomings cannot overshadow the potential of this method. Mobile LiDAR collects survey-grade data, which can be matched only by the robotic total station method but with no traffic exposure or need for road closures. The main strength of this method also lies in its ability to collect data that are valuable for multiple DOT programs. The rapid development of computing hardware and LiDAR data processing methods indicate that the mobile LiDAR method will soon be comparable with other methods in terms of data reduction time.

7.2 COMPARISON OF DATA COLLECTION TECHNOLOGIES

An evaluation matrix was developed to compare different data collection methods, as shown in Table 7-1. Eleven criteria were used to assess the performance of the different technologies, based on field data collection and data reduction factors. Each criterion was assigned a score of 1 to 5 to rank it (5 being the best and 1 the worst) to indicate the relative performance of one method compared to the others. For example, the equipment cost for the satellite/aerial imagery method had a score of 5 because it did not incur any field data collection cost (satellite/aerial imagery is already available for most state roads). Feedback from this project’s Technical Review Panel (TRP) members was also used to determine proper weight factors for different criteria to measure the importance for each item. A total weighted score was calculated for each method to give the final ranking. The mobile LiDAR method had the highest overall score because it provides the highest data completeness and data accuracy, which were the two criteria weighted very highly by TRP members.

Table 7-1. Highway Inventory Data Collection Technique Evaluation Matrix



		Collection Method					Weight Factor
		GPS Data Logger	Robotic Total Station	GPS Enable Photo/Video Log	Satellite/ Aerial Imagery	Mobile LiDAR	
Field Data Collection	Equipment Cost	3	2	4	5	1	0.25
	Labor Cost	2	1	4	5	3	0.25
	Data Collection Time	2	1	4	5	3	0.25
	Safety	2	1	4	5	3	1
	Data Completeness	3	4	2	1	5	2
	Data Quality	3	4	2	1	5	2
	Disruption to Traffic	2	1	4	5	3	1
Field Data Reduction	Software Cost	5	4	3	2	1	0.25
	Labor Cost	5	3	4	2	1	0.25
	Data Reduction Time	5	3	4	2	1	0.5
	Data Storage Size	5	4	2	3	1	0.25
Total Weighted Score		24	23	23	21	29	

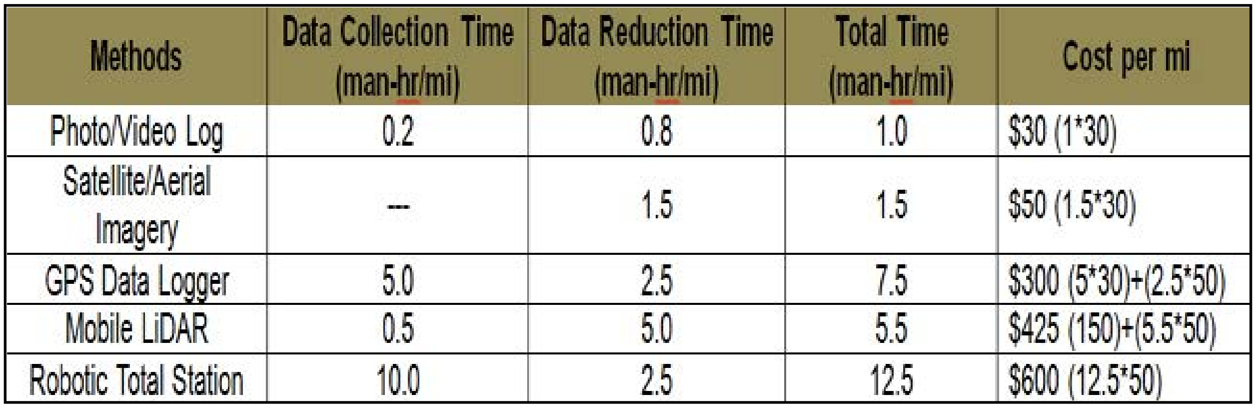
The total data collection time and cost per mile for each method were also computed based on the field data collection and data reduction for the four selected roadway segments. Table 7-2 shows a summary of total length, total data collection time, total data reduction time, and total time for the different data collection methods used in the present research. The photo/video log method required the least total time (man-hr/mi), and the robotic total station method required the most. The mobile LiDAR technology ranked at the median level, with 5.5 man-hr/mi.

Table 7-2. Comparison of Different Methods in Terms of Total Time

Methods	Total Length (mi)	Data Collection Time (man-hr)	Data Reduction Time (man-hr)	Total Time (man-hr/mi)
Photo/Video Log	28.0	4.0	23.0	1.0
Satellite/Aerial Imagery	7.0	—	10.0	1.5
Mobile LiDAR	14.2	8.0	70.0	5.5
GPS Data Logger	1.3	6.0	3.5	7.5
Robotic Total Station	1.3	13.0	3.5	12.5

A cost analysis was also conducted to rank each method based only on labor costs for field data collection and data reduction times. For this analysis, two unit labor costs were assumed: $30 for a person trained at an introductory level and $50 for an expert-level person. Table 7-3 shows that the cost per mile for data collection for the photo/video log, satellite/aerial imagery, GPS data logger, mobile LiDAR, and robotic total station were $30, $50, $300, $425, and $600, respectively. The photo/video log method had the lowest cost, and the robotic total station had the highest cost.

Table 7-3. Cost Analysis of Different Data Collection Methods



Methods	Data Collection Time (man-hr/mi)	Data Reduction Time (man-hr/mi)	Total Time (man-hr/mi)	Cost per mi
Photo/Video Log	0.2	0.8	1.0	$30 (1*30)
Satellite/Aerial Imagery	---	1.5	1.5	$50 (1.5*30)
GPS Data Logger	5.0	2.5	7.5	$300 (5*30)+(2.5*50)
Mobile LiDAR	0.5	5.0	5.5	$425 (150)+(5.5*50)
Robotic Total Station	10.0	2.5	12.5	$600 (12.5*50)

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

The purpose of this research project was to identify cost-effective methods for collecting highway inventory data not currently stored in IDOT databases. A literature review was conducted to compare common road inventory data collection methods in order to determine their capabilities and limitations. The review results suggested that (1) field inventory and integrated GPS/GIS mapping methods can collect all required feature data, but they impose long data collection times and expose data collection crews to dangerous road traffic; (2) photo/video log and aerial imagery, when used together, can collect nearly all required feature data, but they cannot collect roadside slope; and (3) mobile LiDAR can collect all required features data in a short amount of time, but the data require extensive reduction efforts.

Data needs and importance were identified by conducting sensitivity analyses of HSM variables for all modules. The sensitivity analysis results showed that the predicted average crash frequency has a varied sensitivity to each HSM input variable. In particular, driveway density, fixed-object density, roadside hazard rating (slope and object density), lighting, and skew angle for intersections have greater impacts on average crash frequency predictions than do the other variables.

A web-based survey of state departments of transportation was conducted to evaluate the strengths and weaknesses of various highway inventory data collection methods. No single technology stood out as the obvious choice of method for roadside-feature data collection. Several promising methods were identified through a literature review and the survey. Field experiments were performed to evaluate and compare the utility of five data collection methods (GPS data logger, robotic total station, GPS-enabled photo/video log, satellite/aerial imagery, and mobile LiDAR) by collecting HSM-related road inventory data along four road segments. The findings of this research indicate that the GPS data logger, robotic total station, mobile LiDAR, and the combination of video/photo log method with aerial imagery are all capable of collecting HSM-related roadside information.

Based on the perceived advantages and disadvantages of each data collection method, the following recommendations are made for consideration by IDOT and other state departments of transportation:

- The GPS data logger method can be used for short distances and low speed roadways with low to medium traffic volume as long as there are no large obstructions by buildings or trees.
- The robotic total station technology can be used for points of specific interest, such as intersections.
- The photo/video log method, together with high-resolution aerial imagery, can be used to collect roadside inventory data for large-scale statewide data collection.
- Mobile LiDAR technology can be used to collect highway inventory data for implementing HSM and other functions within the Bureau of Safety Engineering, other IDOT offices, and local agencies. Identifying multiple clients within IDOT is important in order to share the costs of mobile LiDAR data collection and processing.

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APPENDIX A GENERAL INFORMATION ON INPUT DATA FOR HSM MODULES

A.1 URBAN AND SUBURBAN ARTERIALS

A.1.1 Two-Lane Undivided Arterials (2U)

Parameter	Range	Information
Length of segment (mi)	0–∞	Nearest hundredth of a mile
AADT (veh/day)	0–32,600	
Type of on-street parking	None Parallel (Residential) Parallel (Commercial) Angle (Residential) Angle (Commercial)	
Proportion of curb length with on-street parking	0–1	
Lighting	Present Not Present	
Auto speed enforcement	Present Not Present	
Major commercial driveways (number)	0–∞	More than 50 parking spaces
Minor commercial driveways (number)	0–∞	Fewer than 50 parking spaces
Major industrial/institutional driveways (number)	0–∞	More than 50 parking spaces
Minor industrial/institutional driveways (number)	0–∞	Fewer than 50 parking spaces
Major residential driveways (number)	0–∞	More than 50 parking spaces
Minor residential driveways (number)	0–∞	Fewer than 50 parking spaces
Other driveways (number)	0–∞	
Speed category	Greater than 30 mph Lower than 30 mph	
Roadside fixed object density (fixed objects/mi)	0–∞	At least 4 in. diameter and not of breakaway design that is located on the roadside within 30 ft of the traveled way. Multiple roadside objects located within 70 ft of one another should be counted as a single object; roadside objects located behind other objects should not be counted.
Offset to roadside fixed objects (ft) [If greater than 30 or not present, input 30]	2–30	2, 5, 10, 15, 20, 25, 30
Calibration factor, Cr	1.00	

A.1.2 Four-Lane Undivided Arterials (4U)

Parameter	Range	Information
Length of segment (mi)	0–∞	Nearest hundredth of a mile
AADT (veh/day)	0–40,100	
Type of on-street parking	None Parallel (Residential) Parallel (Commercial) Angle (Residential) Angle (Commercial)	
Proportion of curb length with on-street parking	0–1	
Lighting	Present Not Present	
Auto speed enforcement	Present Not Present	
Major commercial driveways (number)	0–∞	More than 50 parking spaces
Minor commercial driveways (number)	0–∞	Fewer than 50 parking spaces
Major industrial/institutional driveways (number)	0–∞	More than 50 parking spaces
Minor industrial/institutional driveways (number)	0–∞	Fewer than 50 parking spaces
Major residential driveways (number)	0–∞	More than 50 parking spaces
Minor residential driveways (number)	0–∞	Fewer than 50 parking spaces
Other driveways (number)	0–∞	
Speed category	Greater than 30 mph Lower than 30 mph	
Roadside fixed object density (fixed objects/mi)	0–∞	At least 4 in. diameter and not of breakaway design that is located on the roadside within 30 ft of the traveled way. Multiple roadside objects located within 70 ft of one another should be counted as a single object; roadside objects located behind other objects should not be counted.
Offset to roadside fixed objects (ft) [If greater than 30 or not present, input 30]	2–30	2, 5, 10, 15, 20, 25, 30
Calibration factor, Cr	1.00	

A.1.3 Four-Lane Divided Arterials (4D)

Parameter	Range	Information
Length of segment (mi)	0–∞	Nearest hundredth of a mile
AADT (veh/day)	0–66,000	
Type of on-street parking	None Parallel (Residential) Parallel (Commercial) Angle (Residential) Angle (Commercial)	
Proportion of curb length with on-street parking	0–1	
Median width (ft)	10	1–14
	20	15–24
	30	25–34
	40	35–44
	50	45–54
	60	55–64
	70	65–74
	80	75–84
	90	85–94
	100	95–∞
Lighting	Present Not Present	
Auto speed enforcement	Present Not Present	
Major commercial driveways (number)	0–∞	More than 50 parking spaces
Minor commercial driveways (number)	0–∞	Fewer than 50 parking spaces
Major industrial/institutional driveways (number)	0–∞	More than 50 parking spaces
Minor industrial/institutional driveways (number)	0–∞	Fewer than 50 parking spaces
Major residential driveways (number)	0–∞	More than 50 parking spaces
Minor residential driveways (number)	0–∞	Fewer than 50 parking spaces
Other driveways (number)	0–∞	
Speed category	Greater than 30 mph Lower than 30 mph	
Roadside fixed object density (fixed objects mi)	0–∞	At least 4 in. diameter and not of breakaway design that is located on the roadside within 30 ft of the traveled way. Multiple roadside objects located within 70 ft of one another should be counted as a single object; roadside objects located behind other objects should not be counted.
Offset to roadside fixed objects (ft) [If greater than 30 or not present, input 30]	2–30	2, 5, 10, 15, 20, 25, 30
Calibration factor, Cr	1.00	

A.1.4 Three-Leg Arterials with TWLTL (3T)

Parameter	Range	Information
Length of segment (mi)	0–∞	Nearest hundredth of a mile
AADT (veh/day)	0–32,900	
Type of on-street parking	None Parallel (Residential) Parallel (Commercial) Angle (Residential) Angle (Commercial)	
Proportion of curb length with on-street parking	0–1	
Lighting	Present Not Present	
Auto speed enforcement	Present Not Present	
Major commercial driveways (number)	0–∞	More than 50 parking spaces
Minor commercial driveways (number)	0–∞	Fewer than 50 parking spaces
Major industrial/institutional driveways (number)	0–∞	More than 50 parking spaces
Minor industrial/institutional driveways (number)	0–∞	Fewer than 50 parking spaces
Major residential driveways (number)	0–∞	More than 50 parking spaces
Minor residential driveways (number)	0–∞	Fewer than 50 parking spaces
Other driveways (number)	0–∞	
Speed category	Greater than 30 mph Lower than 30 mph	
Roadside fixed object density (fixed objects/mi)	0–∞	At least 4 in. diameter and not of breakaway design that is located on the roadside within 30 ft of the traveled way. Multiple roadside objects located within 70 ft of one another should be counted as a single object; roadside objects located behind other objects should not be counted.
Offset to roadside fixed objects (ft) [If greater than 30 or not present, input 30]	2–30	2, 5, 10, 15, 20, 25, 30
Calibration factor, Cr	1.00	

A.1.5 Five-Leg Arterials with TWLTL (5T)

Parameter	Range	Information
Length of segment (mi)	0–∞	Nearest hundredth of a mile
AADT (veh/day)	0–53,800	
Type of on-street parking	None Parallel (Residential) Parallel (Commercial) Angle (Residential) Angle (Commercial)	
Proportion of curb length with on-street parking	0–1	
Lighting	Present Not Present	
Auto speed enforcement	Present Not Present	
Major commercial driveways (number)	0–∞	More than 50 parking spaces
Minor commercial driveways (number)	0–∞	Fewer than 50 parking spaces
Major industrial/institutional driveways (number)	0–∞	More than 50 parking spaces
Minor industrial/institutional driveways (number)	0–∞	Fewer than 50 parking spaces
Major residential driveways (number)	0–∞	More than 50 parking spaces
Minor residential driveways (number)	0–∞	Fewer than 50 parking spaces
Other driveways (number)	0–∞	
Speed category	Greater than 30 mph Lower than 30 mph	
Roadside fixed object density (fixed objects/mi)	0–∞	At least 4 in. diameter and not of breakaway design that is located on the roadside within 30 ft of the traveled way. Multiple roadside objects located within 70 ft of one another should be counted as a single object; roadside objects located behind other objects should not be counted.
Offset to roadside fixed objects (ft) [If greater than 30 or not present, input 30]	2–30	2, 5, 10, 15, 20, 25, 30
Calibration factor, Cr	1.00	

A.1.6 Three-Leg Signalized Intersection (3SG)

Parameter	Range	Information
AADT major (veh/day)	0–58,100	
AADT minor (veh/day)	0–16,400	
Intersection lighting	Present Not Present	
Calibration factor, Ci	1.00	
Number of approaches with left-turn lanes	0–3	0, 1, 2, 3
Number of approaches with right-turn lanes	0–3	0, 1, 2, 3
Number of approaches with left-turn signal phasing	0–3	0, 1, 2, 3
Type of left-turn signal phasing for Leg #1	Permissive Protected Protected/Permissive Permissive/Protected	
Type of left-turn signal phasing for Leg #2	Permissive Protected Protected/Permissive Permissive/Protected	
Type of left-turn signal phasing for Leg #3	Permissive Protected Protected/Permissive Permissive/Protected	
Number of approaches with right turn on red prohibited	0–3	0, 1, 2, 3
Intersection red light cameras	Present Not Present	
Sum of all pedestrian crossing volumes (PedVol)	0–∞	
Maximum number of lanes crossed by a pedestrian (nlanesx)	0–∞	
Number of bus stops within 300 m (1,000 ft) of the intersection	0–∞	
Schools within 300 m (1,000 ft) of the intersection	Present Not Present	
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0–∞	

A.1.7 Four-Leg Signalized Intersection (4SG)

Parameter	Range	Information
AADT major (veh/day)	0–67,700	
AADT minor (veh/day)	0–33,400	
Intersection lighting	Present Not Present	
Calibration factor, Ci	1.00	
Number of approaches with left-turn lanes	0–4	0, 1, 2, 3, 4
Number of approaches with right-turn	0–4	0, 1, 2, 3, 4
Number of approaches with left-turn signal phasing	0–4	0, 1, 2, 3, 4
Type of left-turn signal phasing for Leg #1	Permissive Protected Protected/Permissive Permissive/Protected	
Type of left-turn signal phasing for Leg #2	Permissive Protected Protected/Permissive Permissive/Protected	
Type of left-turn signal phasing for Leg #3	Permissive Protected Protected/Permissive Permissive/Protected	
Type of left-turn signal phasing for Leg #4 (if applicable)	Permissive Protected Protected/Permissive Permissive/Protected	
Number of approaches with right turn on red	0–4	0, 1, 2, 3, 4
Intersection red light cameras	Present Not Present	
Sum of all pedestrian crossing volumes (PedVol)	0–∞	
Maximum number of lanes crossed by a pedestrian (nlanesx)	0–∞	
Number of bus stops within 300 m (1,000 ft) of the intersection	0–∞	
Schools within 300 m (1,000 ft) of the intersection	Present Not Present	
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0–∞	

A.1.8 Three-Leg Unsignalized Intersection (3ST)

Parameter	Range	Information
AADT major (veh/day)	0–45,700	
AADT minor (veh/day)	0–9,300	
Intersection lighting	Present Not Present	
Calibration factor, Ci	1.00	
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	

A.1.9 Four-Leg Unsignalized Intersection (4ST)

Parameter	Range	Information
AADT major (veh/day)	0-46,800	
AADT minor (veh/day)	0-5,900	
Intersection lighting	Present Not Present	
Calibration factor, Ci	1.00	
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	

A.2 RURAL TWO-LANE ROADWAYS

A.2.1 Rural Two-Lane Intersection

Input	Range	Information
Intersection type	3ST, 4ST, 4SG	
AADT major (veh/day)	0–25,200	3ST; 0–19,500 4ST; 0–14,700 4SG; 0–25,200
AADT minor (veh/day)	0–12,500	3ST; 0–4,300 4ST; 0–3,500 4SG; 0–12,500
Intersection skew angle (degrees)	0–∞	
Number of signalized or uncontrolled approaches with a left-turn lane	0–4	0, 1, 2, 3, 4
Number of signalized or uncontrolled approaches with a right-turn lane	0–4	0, 1, 2, 3, 4
Intersection lighting	Present Not Present	
Calibration factor	1.00 to 1.20	

A.2.2 Rural Two-Lane Segment

Input	Range	Information
Length of segment (mi)	0 to ∞	
AADT (veh/day)	0–17,800	
Lane width (ft)	9 to 12	If 9.2 ft or less, round to 9 ft If 9.3 to 9.7 ft, round to 9.5 ft If 9.8 to 10.2 ft, round to 10 ft If 10.3 to 10.7 ft, round to 10.5 ft If 10.8 to 11.2 ft, round to 11 ft If 11.3 to 11.7 ft, round to 11.5 ft If 11.8 ft or more, round to 12 ft
Shoulder width (ft)	0 to 8	If 0.5 or less, ft, round to 0 ft If 0.6 to 1.5 ft, round to 1 ft If 1.6 to 2.5 ft, round to 2 ft If 2.6 to 3.5 ft, round to 3 ft If 3.6 to 4.5 ft, round to 4 ft If 4.6 to 5.5 ft, round to 5 ft If 5.6 to 6.5 ft, round to 6 ft If 6.6 to 7.5 ft, round to 7 ft If 7.6 ft or more, round to 8 ft
Shoulder type	Paved Gravel Composite Turf	
Length of horizontal curve (mi)	0 to ∞	
Radius of curvature (ft)	0 to ∞	
Spiral transition curve	Present Not Present One End Only	
Superelevation variance (ft/ft)	—	
Grade (%)	0% to 6%	
Driveway density (driveways/mi)	0 to ∞	
Centerline rumble strips	Present Not Present	
Passing lanes	Not Present Present (1 lane) Present (2 lanes)	
Two-way left-turn lane	Present Not Present	

A.2.2 Rural Two-Lane Segment (continued)

Roadside hazard rating	1 to 7	RHR 1 = Clear zone greater than or equal 30 ft; side slope flatter than 1V:4H RHR 2 = Clear zone between 20 and 25 ft; side slope about 1V:4H RHR 3 = Clear Zone about 10 ft: side slope about 1V;3H RHR 4 = Clear zone between 5 and 10 ft; side slope about 1V:3H; marginally forgiving RHR 5 = Clear zone between 5 and 10 ft; side slope about 1V:3H; virtually non-recoverable RHR 6 = Clear zone less than or equal to 5 ft; side slope about 1V:2H; non-recoverable RHR 7 = Clear zone less than 5 ft; side slope of 1V:2H or steeper; non-recoverable
Segment lighting	Present Not Present	
Auto speed enforcement	Present Not Present	
Calibration factor	1.00 to 1.20	

A.3 RURAL MULTI-LANE ROADWAYS

A.3.1 Rural Multi-Lane Intersection

Input	Range	Information
Intersection type	3ST, 4ST, 4SG	
AADTmajor (veh/day)	0–78,300	3ST: 0–78,300 4ST: 0–78,300 4SG: 0–43,500
AADTmajor (veh/day)	0–23,000	3ST: 0–23,000 4ST: 0–7,400 4SG: 0–18,500
Intersection skew angle (degrees)	0–∞	
Number of non-STOP-controlled approaches with left-turn lanes	0–2	
Number of non-STOP-controlled approaches with right-turn lanes	0–4	
Intersection lighting	Present Not Present	
Calibration factor	1.00–1.30	

A.3.2 Rural Multi-Lane Segment

Input	Range	Information
Roadway type	Divided Undivided	
Length of segment (mi)	> 0	
AADT (veh/day)	0–89,300	
Lane width (ft)	9–12	If 9.2 ft or less, round to 9 ft If 9.3 to 9.7 ft, round to 9.5 ft If 9.8 to 10.2 ft, round to 10 ft If 10.3 to 10.7 ft, round to 10.5 ft If 10.8 to 11.2 ft, round to 11 ft If 11.3 to 11.7 ft, round to 11.5 ft If 11.8 ft or more, round to 12 ft
Shoulder width (ft)	0–10	If 0.5 or less, ft, round to 0 ft If 0.6 to 1.5 ft, round to 1 ft If 1.6 to 2.5 ft, round to 2 ft If 2.6 to 3.5 ft, round to 3 ft If 3.6 to 4.5 ft, round to 4 ft If 4.6 to 5.5 ft, round to 5 ft If 5.6 to 6.5 ft, round to 6 ft If 6.6 to 7.5 ft, round to 7 ft If 7.6 ft or more, round to 8 ft
Shoulder type	Paved Gravel Composite Turf	
Median width (ft)	10–100	If between 1 to 14 ft, round to 10 ft If between 15 to 24 ft, round to 20 ft If between 25 to 34 ft, round to 30 ft If between 35 to 44 ft, round to 40 ft If between 45 to 54 ft, round to 50 ft If between 55 to 64 ft, round to 60 ft If between 65 to 74 ft, round to 70 ft If between 75 to 84 ft, round to 80 ft If between 85 to 94 ft, round to 90 ft If 95 ft or more, round to 1,000 ft
Slide slopes	1:2 -1:7	
Lighting	Present Not Present	
Auto speed enforcement	Present Not Present	
Calibration factor	1.00–1.20	

A.4 FREEWAY SEGMENTS

Parameter	Range	Information
Length of segment (L),(mi)	0.01–∞	
Number of through lanes (n)	4–10	Rural: 4–8 Urban: 4–10
Horizontal curve in segment	No One direction Both direction	
Curve radius (R_1),(ft)	1000–∞	
Length of curve (L_{c1}),(mi)	$<0.00119 \times R$	
Length of curve in segment ($L_{c1,seg}$),(mi)	$\leq L$ $\leq L_{c1}$	
Lane width (W_l),(ft)	10.5–14	
Outside shoulder width (W_s),(ft)	4–14	
Inside shoulder width (W_{is}), (ft)	2–12	
Median width (W_m),(ft)	2 W_{is}–90	$W_{is:}$ Inside shoulder width
Rumble strips on outside shoulders	Yes No	
Length of rumble strips for travel in increasing milepost direction (mi)	0–L	L: Length of segment
Length of rumble strips for travel in decreasing milepost direction (mi)	0–L	L: Length of segment
Rumble strips on outside shoulders	Yes No	
Length of rumble strips for travel in increasing milepost direction (mi)	0–L	L: Length of segment
Length of rumble strips for travel in decreasing milepost direction (mi)	0–L	L: Length of segment
Presence of barrier in median:	None Some Center Offset	
Length of barrier ($L_{ib,1}$),(mi)	0–∞	
Distance from edge of traveled way to barrier face ($W_{off,in,1}$),(ft)	$\geq W_{is}$ $\leq W_m - W_{is}$	$W_{is:}$ Inside shoulder width W_m: Median width
Median barrier width (W_{ib}),(ft)	$\leq W_m - (2W_{is})$	$W_{is:}$ Inside shoulder width W_m: Median width

A.4 FREEWAY SEGMENTS (CONTINUED)

Nearest distance from edge of traveled way to barrier face (W_{near}),(ft)	$\geq W_{is}$ $\leq W_m/2$	$W_{is:}$ Inside shoulder width W_m: Median width
Clear zone width (W_{hc}),(ft)	W_s –30	W_s: Outside shoulder width
Presence of barrier on roadside	None Some Full	
Length of barrier ($L_{ob,1}$),(mi)	0–∞	
Distance from edge of traveled way to barrier face ($W_{off,o}$),(ft)	$\geq W_s$	W_s: Outside shoulder width
Distance from edge of traveled way to barrier face, increasing milepost ($W_{off,inc}$),(ft)	$\geq W_s$	W_s: Outside shoulder width
Distance from edge of traveled way to barrier face, decreasing milepost ($W_{off,inc}$),(ft)	$\geq W_s$	W_s: Outside shoulder width
Ramp entrance in segment	No Lane add S-C Lane	
Distance from begin milepost to upstream entrance ramp gore ($X_{b,ent}$),(mi)	0–∞	
Length of ramp entrance ($L_{en,inc}$), (mi)	0.04–0.30	
Length of ramp entrance in segment ($L_{en,seg,inc}$),(mi)	≥0.01 mi ≤0.30 ≤L $\leq L_{en,inc}$	$L_{en,inc}$: Length of ramp entrance L: Length of segment
Entrance side	Right Left	
Ramp exit in segment	No Lane drop S-C Lane	
Distance from end milepost to downstream exit ramp gore ($X_{e,ext}$),(mi)	0–∞	
Length of ramp exit ($L_{ex,inc}$),(mi)	0.02–0.30	
Length of ramp exit in segment ($L_{ex,seg,inc}$),(mi)	≥0.01 mi ≤0.30 ≤L $\leq L_{ex,inc}$	$L_{ex,inc}$: Length of ramp exit L: Length of segment

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A.4 FREEWAY SEGMENTS (CONTINUED)

Exit side	Right Left	
Type B weave in segment	Yes No	
Length of weaving section ($L_{wev,inc}$), (mi)	0.01–0.85	
Length of weaving section in segment ($L_{wev,seg,inc}$),(mi)	≥0.01 mi ≤0.85 ≤L ≤$L_{wev,inc}$	$L_{wev,inc}$: Length of weaving section L: Length of segment
Ramp entrance in segment	No Lane add S-C Lane	
Distance from begin milepost to upstream entrance ramp gore ($X_{b,ent}$),(mi)	0–∞	
Length of ramp entrance ($L_{en,dec}$), (mi)	0.04–0.30	
Length of ramp entrance in segment ($L_{en,seg,dec}$),(mi)	≥0.01 mi ≤0.30 ≤L ≤$L_{en,dec}$	$L_{en,dec}$: Length of ramp entrance L: Length of segment
Entrance side	Right Left	
Ramp exit in segment	No Lane drop S-C Lane	
Distance from end milepost to downstream exit ramp gore ($X_{e,ext}$),(mi)	0–∞	
Length of ramp exit ($L_{ex,dec}$),(mi)	0.02–0.30	
Length of ramp exit in segment ($L_{ex,seg,dec}$),(mi)	≥0.01 mi ≤0.30 ≤L ≤$L_{ex,inc}$	$L_{ex,inc}$: Length of ramp exit L: Length of segment
Exit side	Right Left	
Type B weave in segment	Yes No	
Length of weaving section ($L_{wev,dec}$), (mi)	0.01–.85	

A.4 FREEWAY SEGMENTS (CONTINUED)

Length of weaving section in segment ($L_{wev,seg,dec}$),(mi)	≥0.01 mi ≤0.85 ≤L ≤$L_{wev,dec}$	$L_{wev,dec}$: Length of weaving section L: Length of segment
Proportion of AADT during high-volume hours (P_{hv})	0–1	
$AADT_{fs}$ by year (veh/hr)	0–∞	
Entrance Ramp Data for Travel in Increasing Milepost Direction		
$AADT_{b,ent}$ by year (veh/hr)	0–∞	
Exit Ramp Data for Travel in Increasing Milepost Direction		
$AADT_{b,ext}$ by year (veh/hr)	0–∞	
Entrance Ramp Data for Travel in Decreasing Milepost Direction		
$AADT_{e,int}$ by year (veh/hr)	0–∞	
Exit Ramp Data for Travel in Decreasing Milepost Direction		
$AADT_{b,ext}$ by year (veh/hr)	0–∞	
Crash Data		
Count of Fatal and Injury (FI) Crashes by Year		
Multiple-vehicle crashes (not ramp related) ($N_{o,fs,n,mv,fi}$)	0–∞	
Single-vehicle crashes (not ramp related) ($N_{o,fs,n,sv,fi}$)	0–∞	
Ramp-entrance-related crashes ($N_{o,sc,EN,at,fi}$)	0–∞	
Ramp-exit-related crashes ($N_{o,sc,EX,at,fi}$)	0–∞	
Count of Property-Damage-Only (PDO) Crashes by Year		
Multiple-vehicle crashes (not ramp related) ($N_{o,fs,n,mv,pdo}$)	0–∞	
Single-vehicle crashes (not ramp related) ($N_{o,fs,n,sv,pdo}$)	0–∞	
Ramp-entrance-related crashes ($N_{o,sc,EN,at,pdo}$)	0–∞	
Ramp-exit-related crashes ($N_{o,sc,EX,at,pdo}$)	0–∞	

A.5 RAMP SEGMENTS

Parameter	Range	Information
Length of segment (L),(mi)	0.01–∞	
Number of through lanes (n)	1–2	Rural: 1 Urban: 1, 2
Average traffic speed on the freeway (V_{frwy}),(mi/h)	50–75	
Segment type (ramp or collector-distributor road)	Entrance Exit C-D Road Connector	
Type of control at crossroad ramp terminal	None Stop Yield Signal	
Horizontal curve	No In Segment Off Segment	
Curve radius (R_1),(ft)	100–∞	
Length of curve (L_{c1}),(mi)	<0.00119×R	
Length of curve in segment ($L_{c1,seg}$),(mi)	≤L ≤L_{c1}	
Milepost of beginning of curve in direction of travel (X_1),(mi)	0–∞	
Cross Section Data		
Lane width (W_l),(ft)	10–20	
Right shoulder width (W_{rs}),(ft)	2–12	
Left shoulder width (W_{Ls}), (ft)	2–10	
Presence of lane add or drop	No Lane add Lane drop	
Length of taper in segment ($L_{add,seg}$ or $L_{drop,seg}$), mi	≥0.01 ≤0.30 ≤L	L: Length of segment
Roadside Data		
Presence of barrier on <u>right</u> side of roadway	Yes No	
Presence of barrier on <u>left</u> side of roadway	Yes No	
Length of barrier ($L_{rb,1}$),(mi)	0–∞	
Distance from edge of traveled way to barrier face ($W_{off,r,1}$),(ft)	≥ W_{rs}	W_{rs}: Right shoulder width

A.5 RAMP SEGMENTS (CONTINUED)

Ramp entrance in segment	No Lane add S-C Lane	
Length of entrance S-C lane in segment ($L_{en,seg}$),(mi)	≥0.01 ≤0.19 ≤L	L: Length of segment
Ramp exit in segment	No Lane add S-C Lane	
Length of exit S-C lane in segment ($L_{ex,seg}$),(mi)	≥0.01 ≤0.19 ≤L	L: Length of segment
Weave section in collector-distributor road segment	Yes No	
Length of weaving section (L_{wev}),(mi)	0.05–0.30	
Length of weaving section in segment ($L_{wev,seg}$),(mi)	≥0.01 ≤0.30 ≤ L_{wev} ≤L	L_{wev}: Length of weaving section L: Length of segment
AADT $_r$ or AADT $_c$ (veh/hr)	0–∞	
Count of Fatal and Injury (FI) Crashes by Year		
Multiple-vehicle crashes (not ramp related) ($N_{o,w,n,mv,fi}$)	0–∞	
Single-vehicle crashes (not ramp related) ($N_{o,w,n,sv,fi}$)	0–∞	
Count of Property-Damage-Only (PDO) Crashes by Year		
Multiple-vehicle crashes (not ramp related) ($N_{o,w,n,mv,pdo}$)	0–∞	
Single-vehicle crashes (not ramp related) ($N_{o,w,n,sv,pdo}$)	0–∞	

A.6 RAMP TERMINALS

Parameter	Range	Information
Ramp terminal configuration	D 3ex D 3en D4 A4 B4 A2 B2	
Ramp terminal traffic control mode	Signal One Stop All Stop	
Is a non-ramp public street leg present at the terminal (I_{ps})	Yes No	
Alignment Data		
Exit ramp skew angle (I_{sk}),(degrees)	0–70	
Distance to the next public street intersection on the outside crossroad leg (L_{str}), (mi)	≥0.02	
Distance to the adjacent ramp terminal (L_{rmp}),(mi)	≥0.02	
Left-Turn Operational Mode		
Inside approach: Protected-only mode ($I_{p,lt,in}$)	Yes No	
Outside approach: Protected-only mode ($I_{p,lt,in}$)	Yes No	
Right-Turn Operational Mode		
Exit ramp approach: Right-turn control mode	Signal Stop Yield Merge Free	
Crossroad median width (W_m), (mi)	0–50	
Crossroad–Both approaches: Lanes serving through-vehicles (n_{th})	2–6	Stop: 2, 3, 4 Rural signal: 2, 3, 4 Urban signal: 2–6
Crossroad–Inside approach: Lanes serving through-vehicles ($n_{th,in}$)	$\leq n_{th}$	
Crossroad–Outside approach: Lanes serving through-vehicles ($n_{th,out}$)	0–∞	
Ramp–Exit ramp approach: All lanes (n_{ex})	1–4	Stop: 1, 2 Signal: 1–4
Right-Turn Channelization		
Crossroad–Inside approach: Channelization present ($I_{ch,in}$)	Yes No	
Crossroad–Outside approach: Channelization present ($I_{ch,out}$)	Yes No	
Ramp–Exit ramp approach: Channelization present ($I_{ch,ext}$)	Yes No	

A.6 RAMP TERMINALS (CONTINUED)

Left-Turn Lane or Bay		
Crossroad–Inside approach: Lane or bay present ($I_{bay,it,in}$)	Yes No	
Crossroad–Inside approach: Width of lane or bay ($W_{b,in}$),(ft)	0–26	
Crossroad–Outside approach: Lane or bay present ($I_{bay,it,out}$)	Yes No	
Crossroad–Outside approach: Width of lane or bay ($W_{b,out}$),(ft)	0–26	
Right-Turn Lane or Bay		
Crossroad–Inside approach: Lane or bay present ($I_{bay,rt,in}$)	Yes No	
Crossroad–Outside approach: Lane or bay present ($I_{bay,rt,out}$)	Yes No	
Access Data		
Number of driveways on the outside crossroad leg (n_{dw})	0–4	
Number of public street approaches on the outside crossroad leg (n_{ps}):	0–2	
$AADT_{in}$ (veh/hr)	0–∞	
Outside Crossroad Leg Data		
$AADT_{out}$ (veh/hr)	0–∞	
Exit Ramp Data		
$AADT_{ex}$ (veh/hr)	0–∞	
Entrance Ramp Data		
$AADT_{en}$ (veh/hr)	0–∞	
Count of Fatal and Injury (FI) Crashes by Year		
($N_{o,w,ac,at,fi}$)	0–∞	
Count of Property-Damage-Only (PDO) Crashes by Year		
($N_{o,w,ac,at,pdo}$)	0–∞	

APPENDIX B NEVTEQ GIS DATABASE

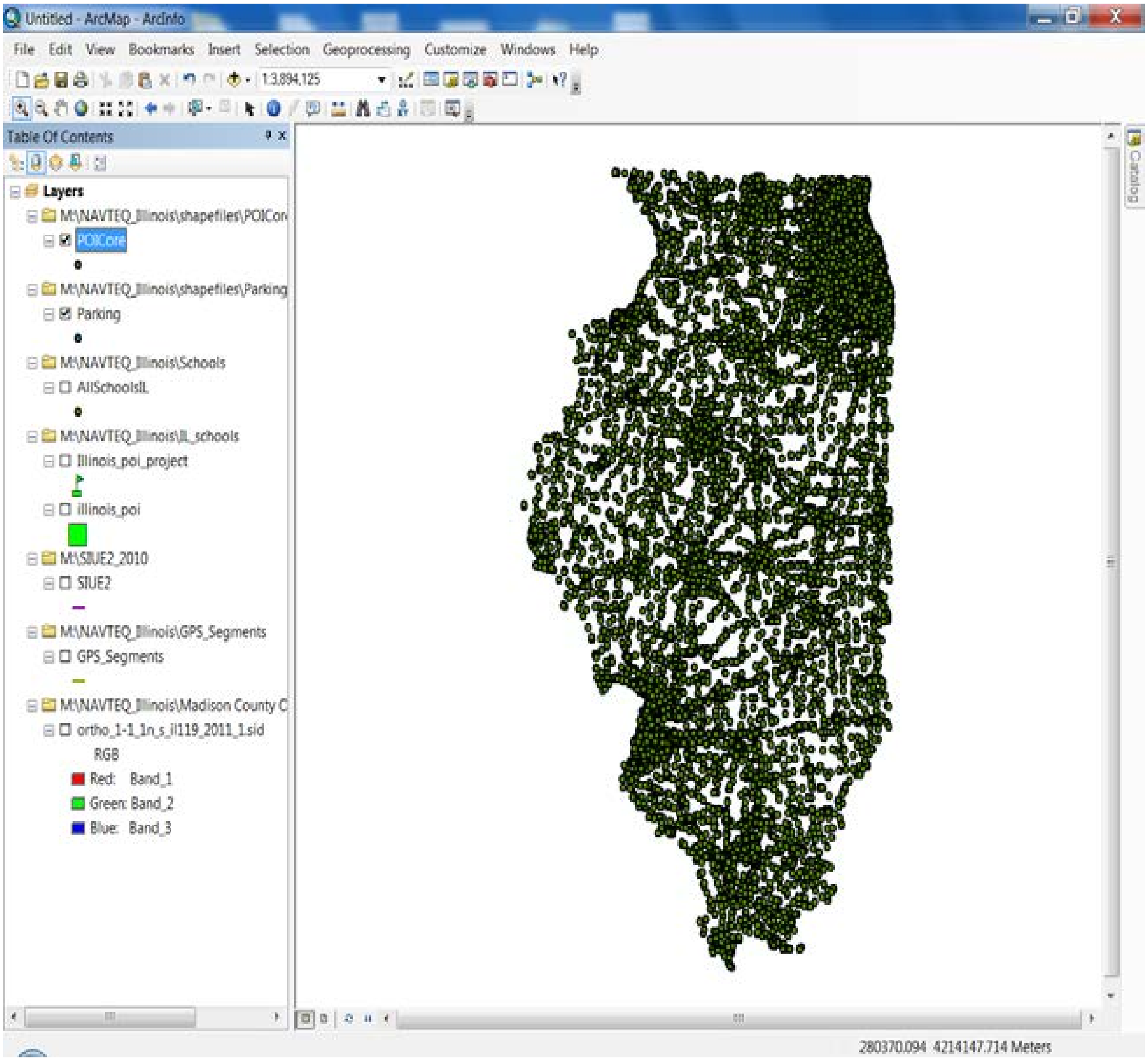


Figure B1. NAVTEQ GIS data provide Core points of interest or POICore (POICore.shp) offers 92,164 business locations such as banks, ATMs, restaurants, schools, libraries, and so on.

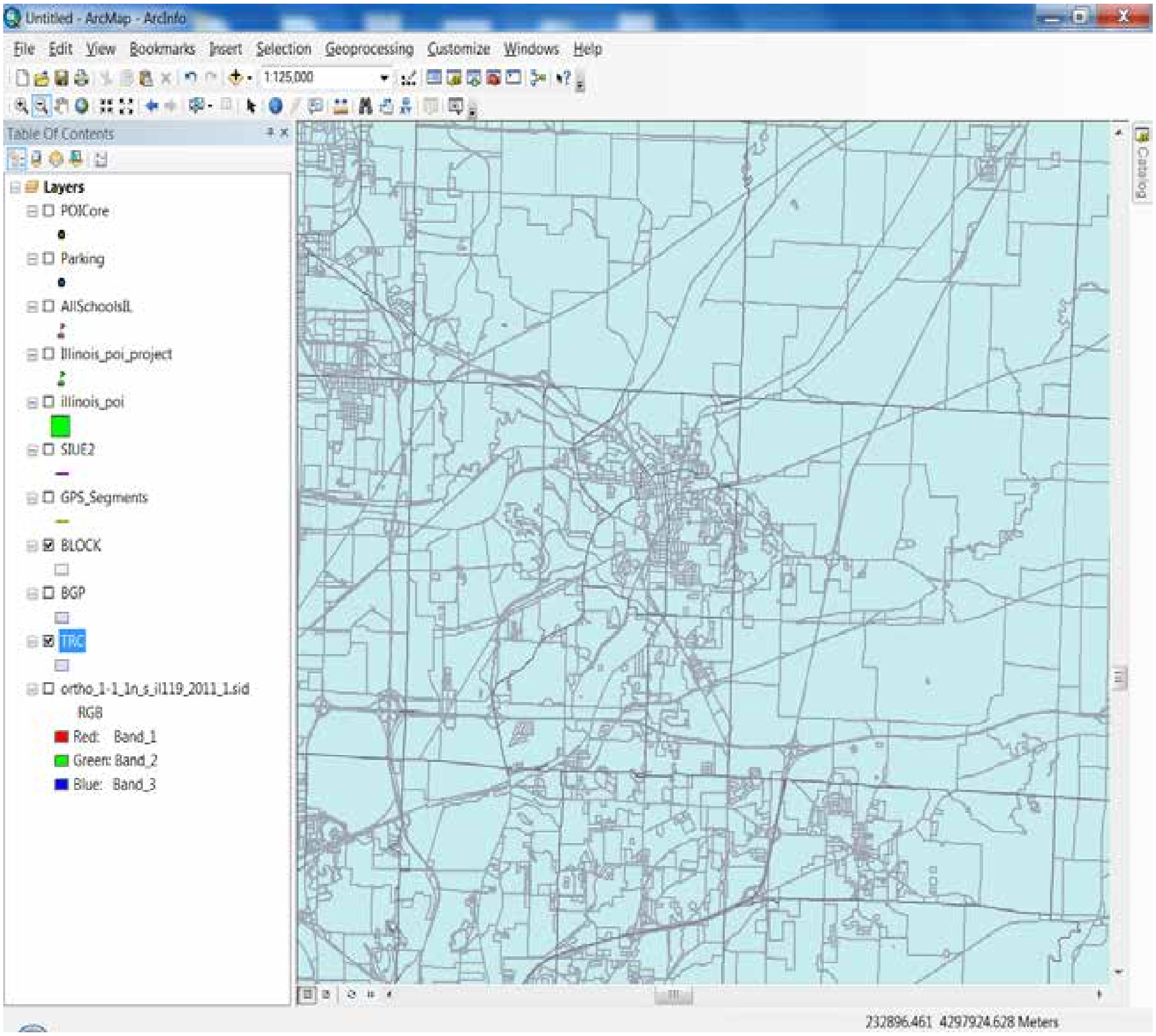


Figure B2. NAVTEQ GIS data provide census boundaries at the census block, census block group and census tract levels.

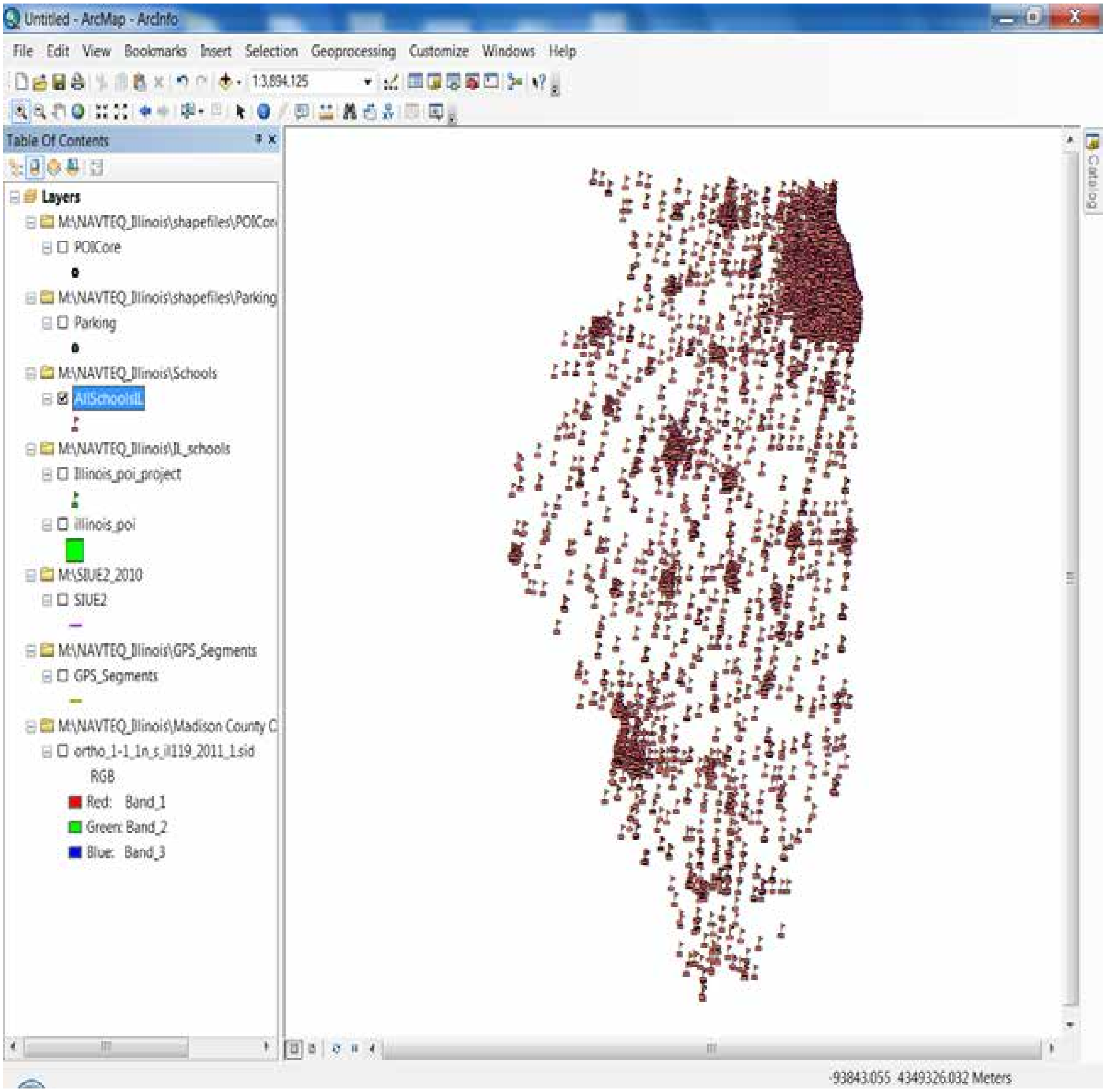
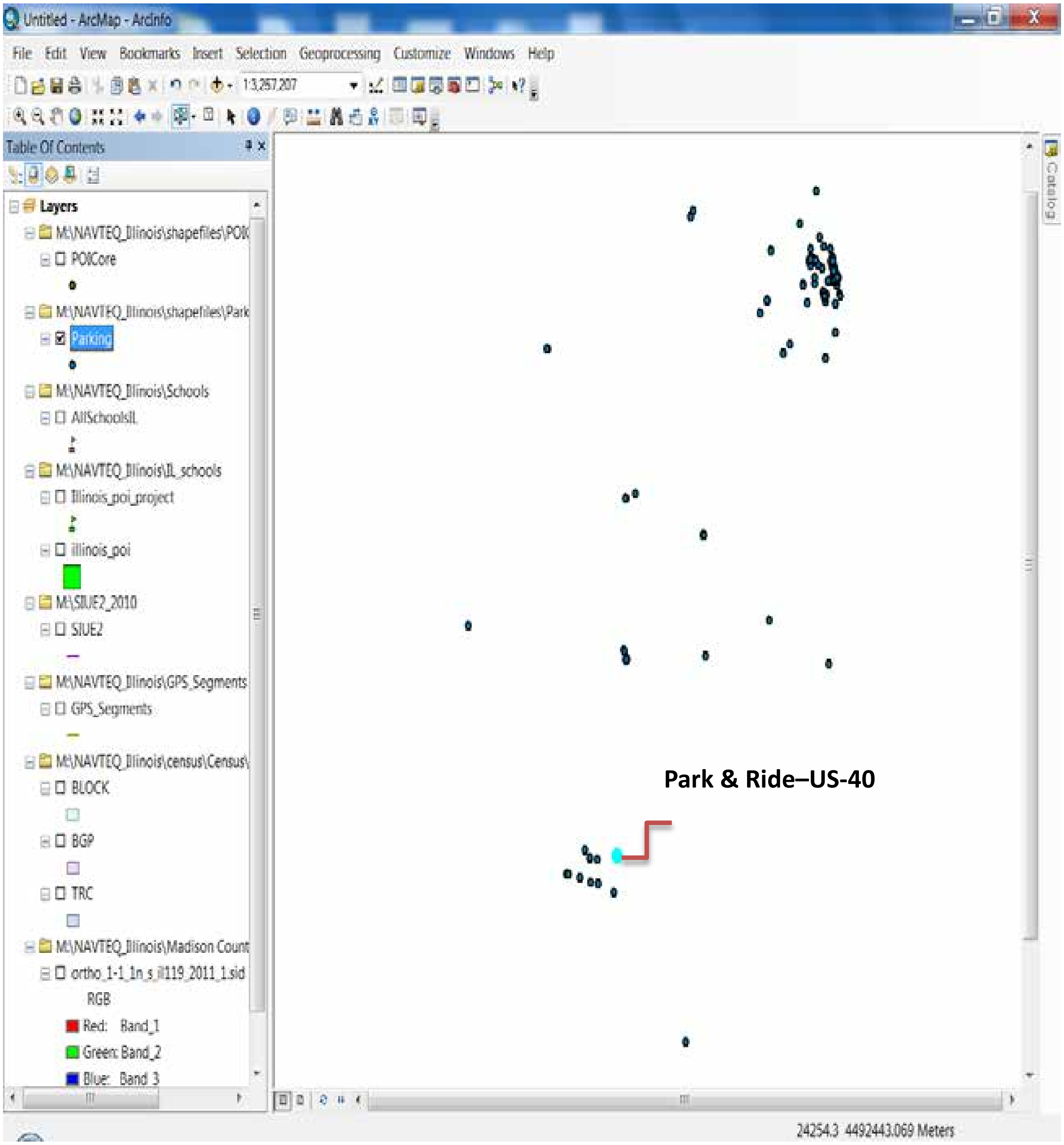


Figure B3. NAVTEQ GIS data provide school locations (Schools.shp): a total of 6,195 schools in the state of Illinois.



Park & Ride–US-40

Figure B4. NAVTEQ GIS data provide parking (Parking.shp): a total of 361parking facilities in the state of Illinois.

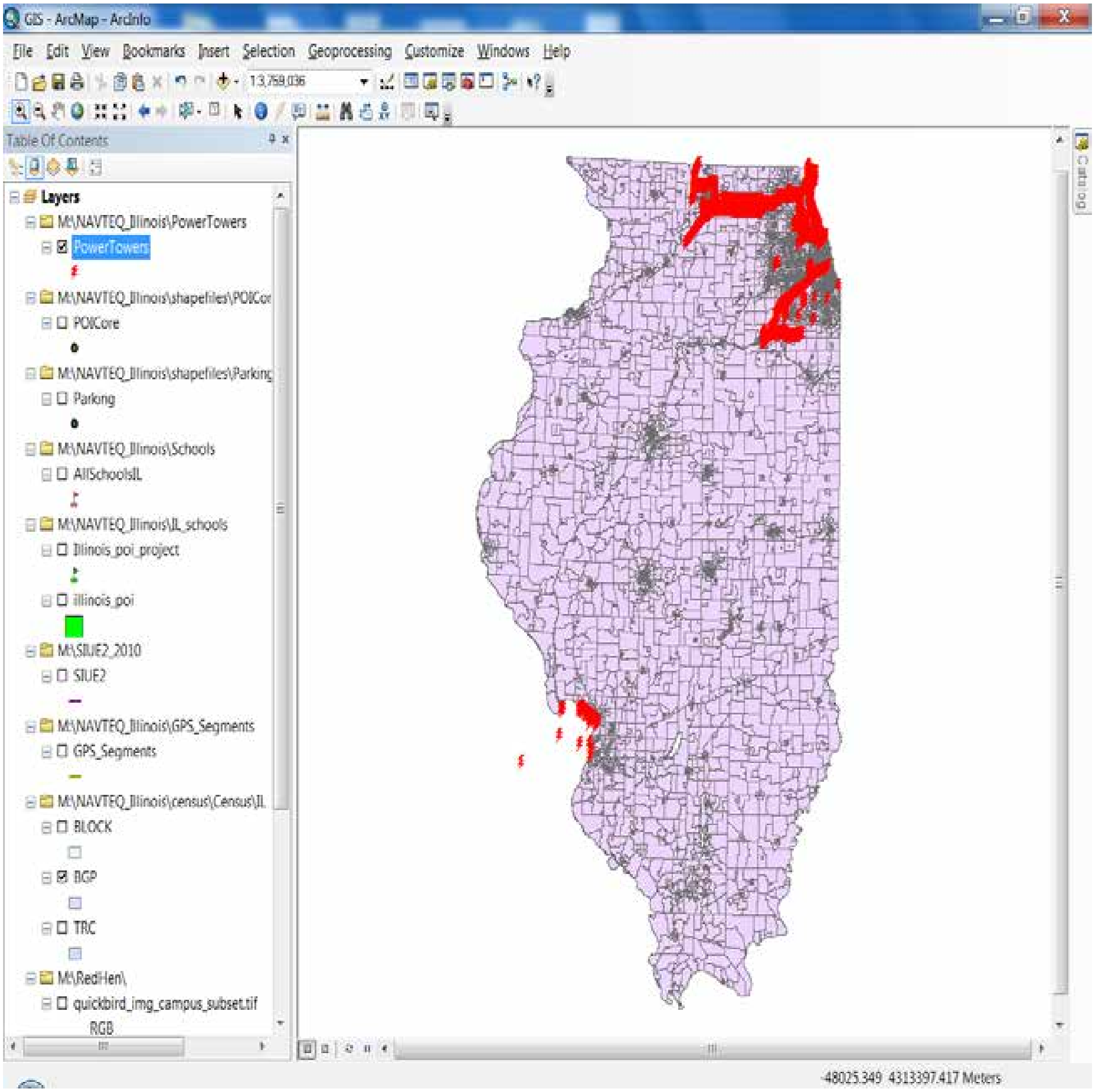


Figure B5. NAVTEQ GIS data provide lighting (PowerTowers.shp): a total of 4,991 lighting facilities in the state of Illinois.

APPENDIX C LIST OF DATA AVAILABLE, DATE TO BE ESTIMATED, AND DATA TO BE COLLECTED FOR DIFFERENT TYPES OF FACILITY

Note: Data to be collected is indicated with bold text.

C.1 DATA NEEDED FOR RURAL TWO-LANE INTERSECTIONS

Data Available	Data to be Estimated or Calculated
AADT for major approach	Intersection type
AADT for minor approach	Intersection skew angle
—	Right-turn lane
—	Left-turn lane
—	Lighting

C.2 DATA NEEDED FOR URBAN/SUBURBAN ARTERIALS

Data Available	Data to be Estimated or Calculated
AADT	Proportion of curb length with on-street parking
Roadway type	Driveway type and number
Length of segment	Lighting
Speed category	**Roadside fixed object density**
Type of on-street parking	**Offset to roadside fixed objects**
Median width	—

C.3 DATA NEEDED FOR URBAN AND SUBURBAN ARTERIALS INTERSECTION

Data Available	Data to be Estimated or Calculated
AADT for major approach	Lighting
AADT for minor approach	Turn lane
—	Signal phasing
—	Number of bus stops within 300 m (1,000 ft) of the intersection
—	Schools within 300 m (1,000 ft) of the intersection
—	Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection

C.4 DATA NEEDED FOR RURAL MULTI-LANE SEGMENTS

Data Available	Data to be Estimated or Calculated
Roadway type	Lighting
AADT	**Roadside slope**
Length of segment	—
Lane width	—
Shoulder width	—
Shoulder type	—
Median width	—

C.5 DATA NEEDED FOR RURAL MULTI-LANE INTERSECTIONS

Data Available	**Data to be Estimated or Calculated**
AADT for major approach	Intersection type
AADT for minor approach	Intersection skew angle
—	Lighting
—	Left-turn lane
—	Right-turn lane

C.6 DATA NEEDED FOR INTERSTATE FREEWAY SEGMENT

Data Available	**Data to be Estimated or Calculated**
Length of segment	Ramp entrance in segment
AADT	Horizontal curve in segment
Number of through lanes	Curve radius
Lane width	Length of curve in segment
Shoulder width	Length of rumble strips
Median width	**Length of barrier**
Presence of barrier in median	**Distance from edge to barrier face**
Rumble strips on outside shoulder	**Median barrier width**
Passing lanes	**Nearest distance from edge to barrier face**
Two-way left-turn lane	**Clear zone width**
—	Entrance/exit side
—	Ramp entrance/exit
—	Length of ramp entrance /exit
—	Distance Beg. milepost to upstream entrance ramp gore
—	Distance End mi. post to downstream exit ramp gore
—	Length of weaving section

C.7 DATA NEEDED FOR INTERSTATE RAMP SEGMENTS

Data Available	**Data to be Estimated or Calculated**
AADT	Horizontal curve in segment
Number of through lane	Curve radius
Speed	Length of curve in segment
Lane width	Presence of lane add/drop
Segment type	Length of taper
—	Ramp entrance
—	Length of exit S-C lane
—	Weaving section in collector-distributor
—	Length of weaving section

C.8 DATA NEEDED FOR INTERSTATE RAMP TERMINAL

Data Available	Data to be Estimated or Calculated
AADT	Exit ramp skew angle
Median width	Ramp terminal configuration
—	Distance to next public street Intersection on the outside crossroad leg
—	Distance to the adjacent ramp terminal
—	Present of right-turn channelization
—	Left-turn lane or bay
—	Right-turn lane or bay

APPENDIX D THE SENSITIVITY ANALYSES FOR ALL TYPES OF HSM MODELS

D.1 SENSITIVITY RANKING FOR FOUR-LANE UNDIVIDED URBAN/SUBURBAN SEGMENT

Parameter	Elasticity	Rank
Major industrial driveway	0.1205	1
Major commercial driveway	0.1149	2
AADT	0.0995	3
Lighting	0.0862	4
Major residential driveway	0.0774	5
Minor commercial driveway	0.0541	6
Auto speed enforcement	0.0517	7
Minor industrial driveway	0.0269	8
Minor residential driveway	0.0198	9
Roadside fixed object density (Offset 5)	0.0182	10
Roadside fixed object density (Offset 10)	0.0110	11
Roadside fixed object density (Offset 20)	0.0049	12
Type of on-street parking	—	13
Proportion of curb length with on-street parking	—	14

D.2 SENSITIVITY RANKING FOR FOUR-LANE DIVIDED URBAN/SUBURBAN SEGMENT

Parameter	Elasticity	Rank
AADT	0.0764	1
Lighting	0.0890	2
Auto speed enforcement	0.0479	3
Major industrial driveway	0.0464	4
Major commercial driveway	0.0426	5
Major residential driveway	0.0258	6
Roadside fixed object density (Offset 5)	0.0183	7
Minor commercial driveway	0.0160	8
Roadside fixed object density (Offset 10)	0.0104	9
Median width	0.0093	10
Minor industrial driveway	0.0086	11
Roadside fixed object density (Offset 20)	0.0049	12
Minor residential driveway	0.0047	13
Type of on-street parking	—	14
Proportion of curb length with on-street parking	—	15

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D.3 SENSITIVITY RANKING FOR THREE-LEG WITH TWLTL URBAN/SUBURBAN SEGMENT

Parameter	Elasticity	Rank
AADT	0.1484	1
Major industrial driveway	0.0838	2
Major commercial driveway	0.0800	3
Lighting	0.0641	4
Major residential driveway	0.0495	5
Auto speed enforcement	0.0385	6
Minor commercial driveway	0.0333	7
Roadside fixed object density (Offset 5)	0.0176	8
Minor industrial driveway	0.0167	9
Minor residential driveway	0.0122	10
Roadside fixed object density (Offset 10)	0.0113	11
Median width	0.0089	12
Roadside fixed object density (Offset 20)	0.0056	13
Type of on-street parking	—	14
Proportion of curb length with on-street parking	—	15

D.4 SENSITIVITY RANKING FOR FIVE-LEG WITH TWLTL URBAN/SUBURBAN SEGMENT

Parameter	Elasticity	Rank
Major industrial driveway	0.0997	1
Major commercial driveway	0.0944	2
AADT	0.0912	3
Major residential driveway	0.0602	4
Lighting	0.0582	5
Auto speed enforcement	0.0529	6
Minor commercial driveway	0.0407	7
Minor residential driveway	0.0153	8
Median width	0.0089	9
Minor industrial driveway	0.0086	10
Roadside fixed object density (Offset 5)	0.0085	11
Roadside fixed object density (Offset 10)	0.0047	12
Roadside fixed object density (Offset 20)	0.0021	13
Type of on-street parking	—	14
Proportion of curb length with on-street parking	—	15

D.5 SENSITIVITY RANKING FOR THREE-LEG SIGNALIZED INTERSECTION

Parameter	Elasticity	Rank
AADT(major)	0.9845	1
AADT(minor)	0.5240	2
Intersection lighting	0.0818	3
Number of approaches with left-turn lanes	0.0673	4
Intersection red light cameras	0.0435	5
Number of approaches with right-turn lanes	0.0360	6
Number of approaches with right turn on red prohibited	0.0182	7
Number of approaches with left-turn signal phasing	0.0064	8
Type of left-turn signal phasing for Legs	—	9
Sum of all pedestrian crossing volumes	—	10
Maximum number of lanes crossed by a pedestrian	—	11
Number of bus stops within 1,000 ft of the intersection	—	12
Schools within 300 m of the intersection	—	13
Number of alcohol sales within 1,000 ft of the intersection	—	14

D.6 SENSITIVITY RANKING FOR FOUR-LEG SIGNALIZED INTERSECTION

Parameter	Elasticity	Rank
AADT(major)	1.0040	1
AADT(minor)	0.5083	2
Intersection lighting	0.0875	3
Number of approaches with left-turn lanes	0.0854	4
Number of approaches with right-turn lanes	0.0375	5
Number of approaches with right turn on red prohibited	0.0196	6
Intersection red light cameras	0.0123	7
Number of approaches with left-turn signal phasing	0.0063	8
Type of left-turn signal phasing for legs	—	9
Sum of all pedestrian crossing volumes	—	10
Maximum number of lanes crossed by a pedestrian	—	11
Number of bus stops within 1,000 ft of the intersection	—	12
Schools within 300 m of the intersection	—	13
Number of alcohol sales within 1,000 ft of the intersection	—	14

D.7 SENSITIVITY RANKING FOR THREE-LEG UNSIGNALIZED INTERSECTION

Parameter	Elasticity	Rank
AADT(major)	0.9766	1
AADT(minor)	0.6646	2
Number of major-road approaches with left-turn lanes	0.2733	3
Number of major-road approaches with right-turn lanes	0.1267	4

D.8 SENSITIVITY RANKING FOR FOUR-LEG UNSIGNALIZED INTERSECTION

Parameter	Elasticity	Rank
AADT(major)	0.9264	1
AADT(minor)	0.3993	2
Number of major-road approaches with left-turn lanes	0.2378	3
Number of major-road approaches with right-turn lanes	0.1280	4

D.9 SENSITIVITY RANKING FOR RURAL TWO-LANE SEGMENT

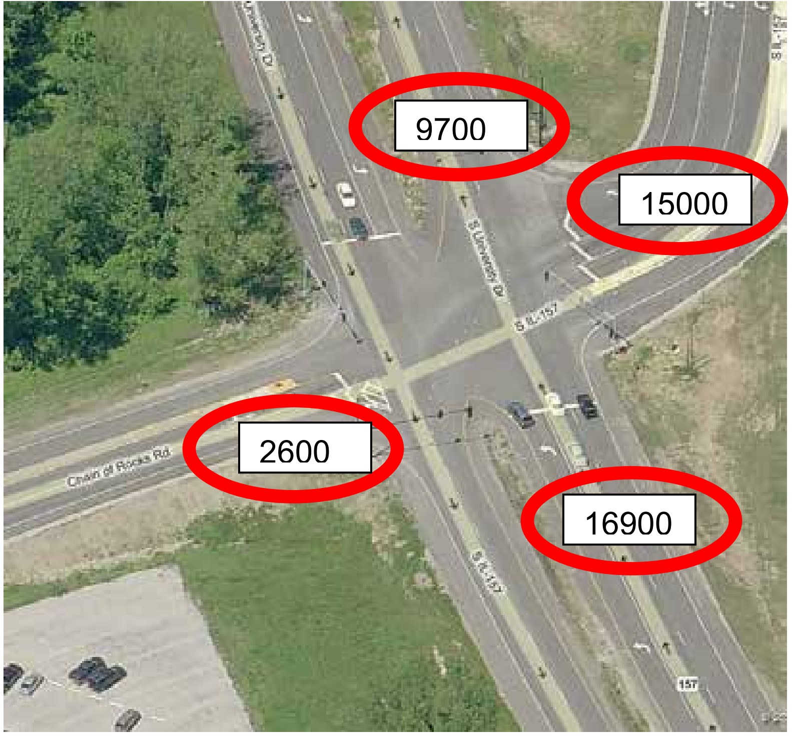
Parameter	Elasticity	Rank
AADT	1.004	1
Lane width	0.971	2
Roadside hazard rating	0.401	3
Passing lane	0.360	4
Shoulder width	0.293	5
Length of curve	0.169	5
Grade	0.119	7
Driveway density	0.114	8
Centerline rumble strip	0.083	9
Lighting	0.081	10
Auto speed enforcement	0.081	11
Super elevation	—	12
Spiral transition curve	—	13

D.10 SENSITIVITY RANKING FOR RURAL THREE-LEG SIGNALIZED INTERSECTION

Parameter	Elasticity	Rank
AADT $_{\text{Major}}$	0.939	1
Number of approaches with left-turn lane	0.694	2
AADT $_{\text{Minor}}$	0.642	3
Skew angle	0.306	4
Number of approaches with left-turn lane	0.262	5
Intersection lighting	0.111	6

APPENDIX E RESULTS OF HSM MODELS FOR INTERSECTIONS

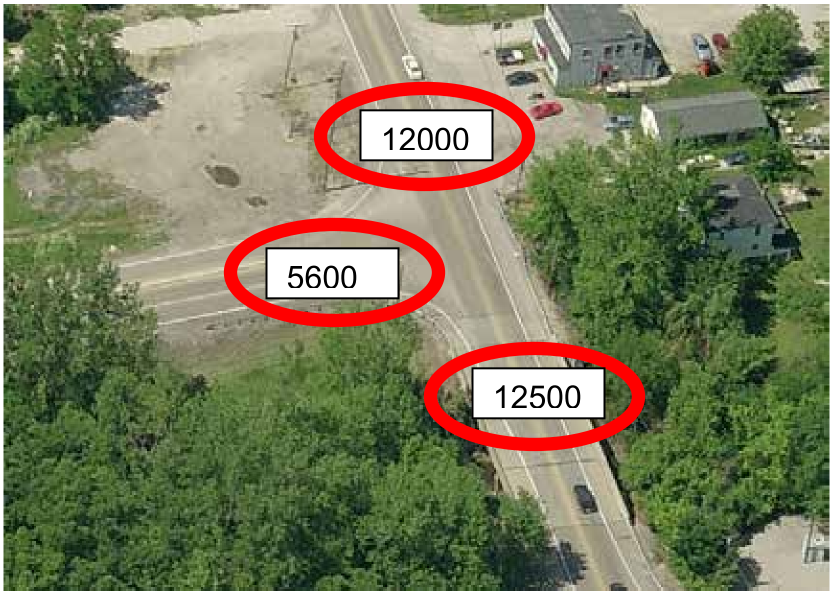
Rural Multi-Lane Intersection (South University Drive)
4SG (Four-Leg Signalized Intersection)
(South University Drive–Chain of Rocks Road)



Input	Range	Information
Intersection Type	4SG, 4ST, 3ST	4SG
AADTmajor (veh/day)	0–43,500	16,900
AADTmajor (veh/day)	0–18,500	9,700
Intersection skew angle (degrees)	0–∞	45
Number of non-STOP-controlled approaches with left-turn lanes	0–2	0
Number of non-STOP-controlled approaches with right-turn lanes	0–4	0
Intersection lighting	Present Not Present	Not Present
Calibration factor	1.00–1.30	1:00 to 1:30

Crash Rate (crash/year)		
Total Crash	Fatal and Injury (FI)	Property Damage (PDO)
18.9	7	11.9

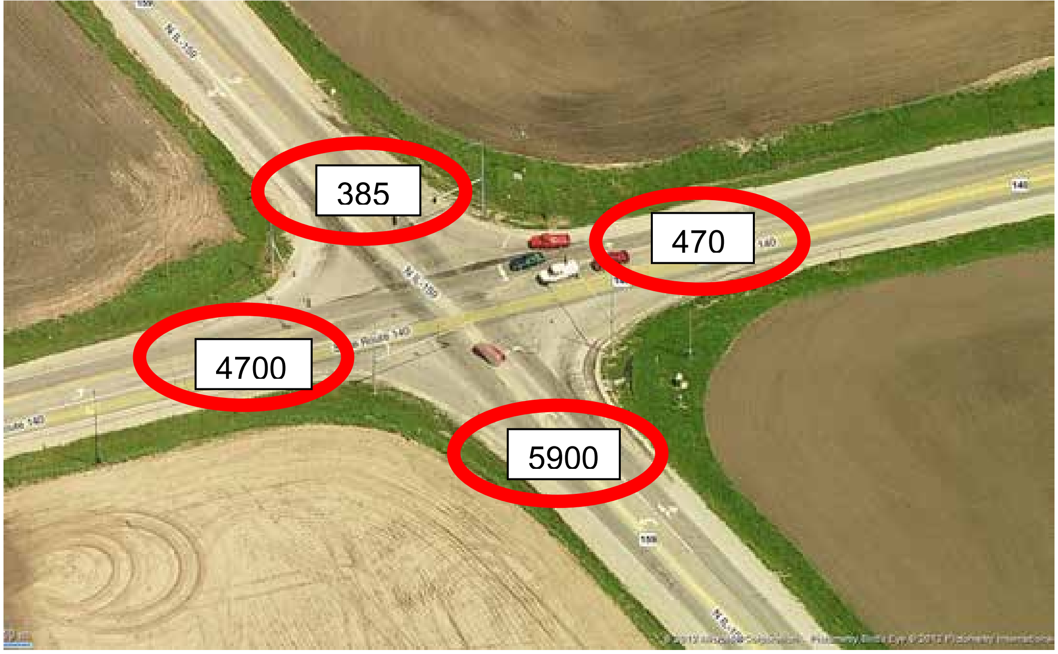
Rural Multi-Lane Intersection (South University Drive)
3ST (Three-Leg Unsignalized Intersection)
State Route 162–S IL 157



Input	Range	Information
Intersection type	4SG, 4ST, 3ST	3ST
AADT major (veh/day)	0–78,300	12,500
AADT major (veh/day)	0–23,000	5,600
Intersection skew angle (degrees)	0–∞	90
Number of non-STOP-controlled approaches with left-turn lanes	0–2	0
Number of non-STOP-controlled approaches with right-turn lanes	0–4	0
Intersection lighting	Present Not Present	Not Present
Calibration factor	1.00–1.30	1:00 to 1:30

Crash Rate (crashes/year)		
Total Crash	Fatal and Injury (FI)	Property Damage (PDO)
2.6	1.2	1.4

Rural Two-Lane Intersection (IL 140 from IL 159 to IL 157)
4SG (Four-Leg Signalized Intersection)
(140-159 Junction)



Input	Range	Information
Intersection type	4SG, 4ST, 3ST	4SG
AADT major (veh/day)	0–25,200	5,900
AADT major (veh/day)	0–12,500	4,700
Intersection skew angle (degrees)	0–∞	70
Number of signalized or uncontrolled approaches with left-turn lanes	0–4	4
Number of signalized or uncontrolled approaches with right-turn lanes	0–4	0
Intersection lighting	Present Not Present	Present
Calibration factor	1.00–1.30	1:00 to 1:30

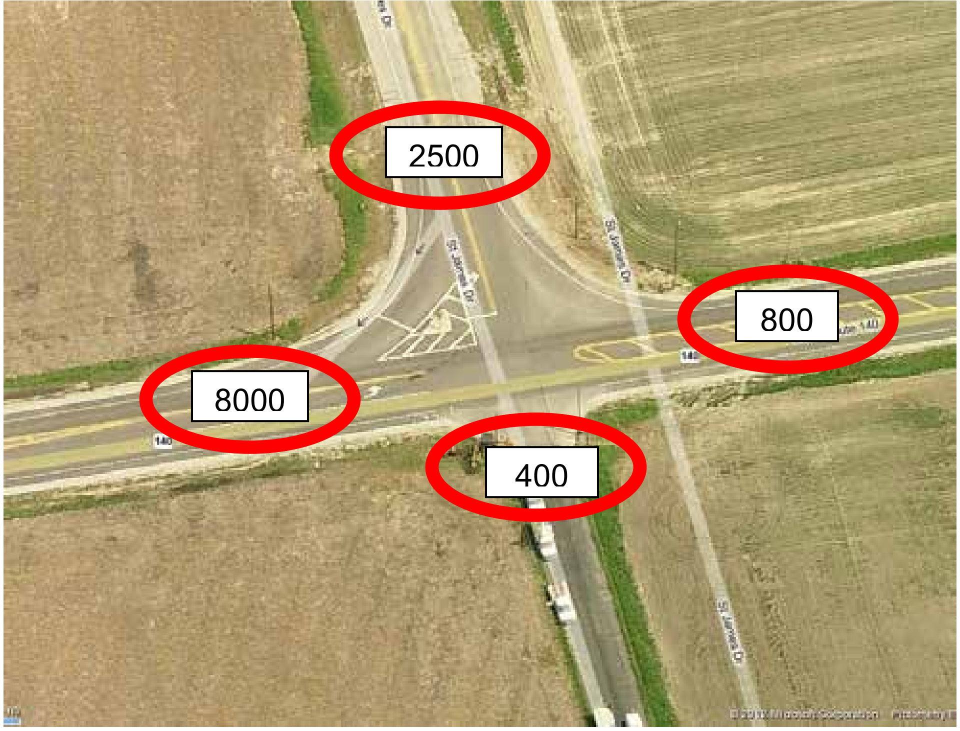
Crash Rate (crashes/year)		
Total Crash	Fatal and Injury (FI)	Property Damage (PDO)
2.4	0.8	1.6

Rural Two-Lane Intersection (IL 140 from IL 159 to IL 157)
3ST (Three-Leg Unsignalized Intersection)

Input	Range	Information
Intersection type	4SG, 4ST, 3ST	3ST
AADT major (veh/day)	0–19,500	8,000
AADT major (veh/day)	0–4,300	4,300
Intersection skew angle (degrees)	0–∞	90
Number of signalized or uncontrolled approaches with left-turn lanes	0–4	0
Number of signalized or uncontrolled approaches with right-turn lanes	0–4	0
Intersection lighting	Present Not Present	Present
Calibration factor	1.00–1.30	1:00 to 1:30

Crash Rate (crashes/year)		
Total Crash	Fatal and Injury (FI)	Property Damage (PDO)
4.9	2.0	2.9

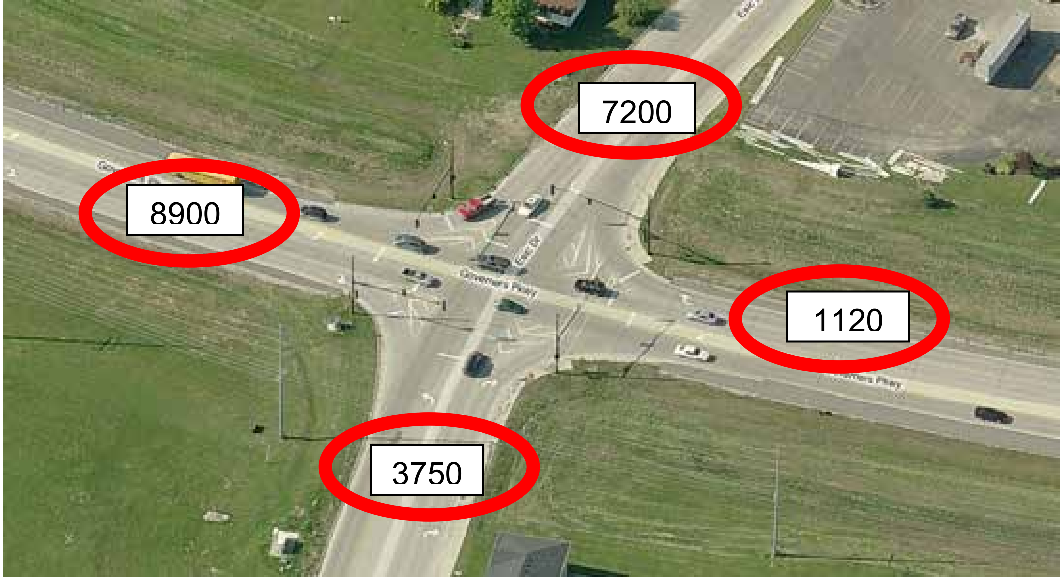
Rural Two-Lane Intersection (IL 140 from IL 159 to IL 157)
4ST (Four-Leg Unsignalized Intersection)
(St. James Drive–IL 140)



Input	Range	Information
Intersection type	4SG, 4ST, 3ST	4ST
AADT major (veh/day)	0–14,700	8,000
AADT major (veh/day)	0–3,500	400
Intersection skew angle (degrees)	0–∞	90
Number of signalized or uncontrolled approaches with left-turn lanes	0–4	1
Number of signalized or uncontrolled approaches with right-turn lanes	0–4	0
Intersection lighting	Present Not Present	Present
Calibration factor	1.00–1.30	1:00 to 1:30

Crash Rate (crashes/year)		
Total Crash	Fatal and Injury (FI)	Property Damage (PDO)
1.7	0.7	1.0

Urban and Suburban Intersection (Governor's Parkway from Esic Road to District Drive)
4SG (Four-Leg Signalized Intersection)
(Esic Drive–Governor's Parkway)



Parameter	Range	Information
AADT major (veh/day)	0–67,700	11,200
AADT minor (veh/day)	0–33,400	7,200
Intersection lighting	Present Not Present	Present
Calibration factor, Ci	1.00	1.00
Number of approaches with left-turn lanes	0–4	4
Number of approaches with right-turn	0–4	4
Number of approaches with left-turn signal phasing	0–4	0
Type of left-turn signal phasing for Leg #1	Permissive Protected Protected/Permissive Permissive/Protected	
Type of left-turn signal phasing for Leg #2	Permissive Protected Protected/Permissive Permissive/Protected	Permissive
Type of left-turn signal phasing for Leg #3	Permissive Protected Protected/Permissive Permissive/Protected	Permissive
Type of left-turn signal phasing for Leg #4 (if applicable)	Permissive Protected Protected/Permissive Permissive/Protected	Permissive
Number of approaches with right turn on red	0–4	0
Intersection red light cameras	Present Not Present	Present
Sum of all pedestrian crossing volumes (PedVol)	0–∞	50

(continued)

Urban and Suburban Intersection (Governor's Parkway from Esic Road to District Drive)
4SG (Four-Leg Signalized Intersection)
(Esic Drive–Governor's Parkway)
(Continued)

Maximum number of lanes crossed by a pedestrian (nlanesx)	0–∞	4
Number of bus stops within 300 m (1,000 ft) of the intersection	0–∞	0
Schools within 300 m (1,000 ft) of the intersection	Present Not Present	Not Present
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0–∞	0

Crash Rate (crashes/year)		
Total Crash	**Fatal and Injury (FI)**	**Property Damage (PDO)**
1.6	0.5	1.1

APPENDIX F EXTRACTION DATA NEEDED FROM GOOGLE AND BING MAPS

F.1: SOUTH UNIVERSITY DRIVE

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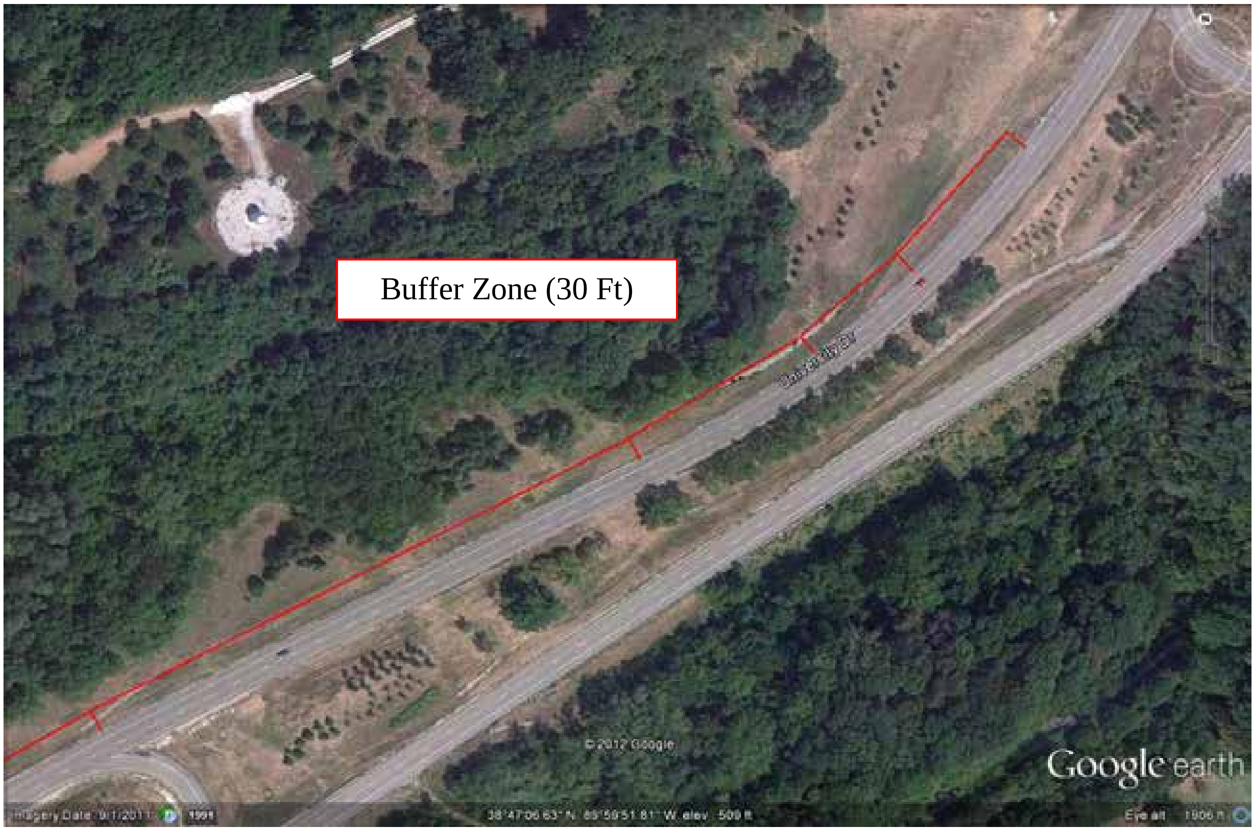


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© 2012 Google
Google earth
Imagery Date: 9/1/2011
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38°47'00.66" N 90°00'10.47" W elev 523 ft
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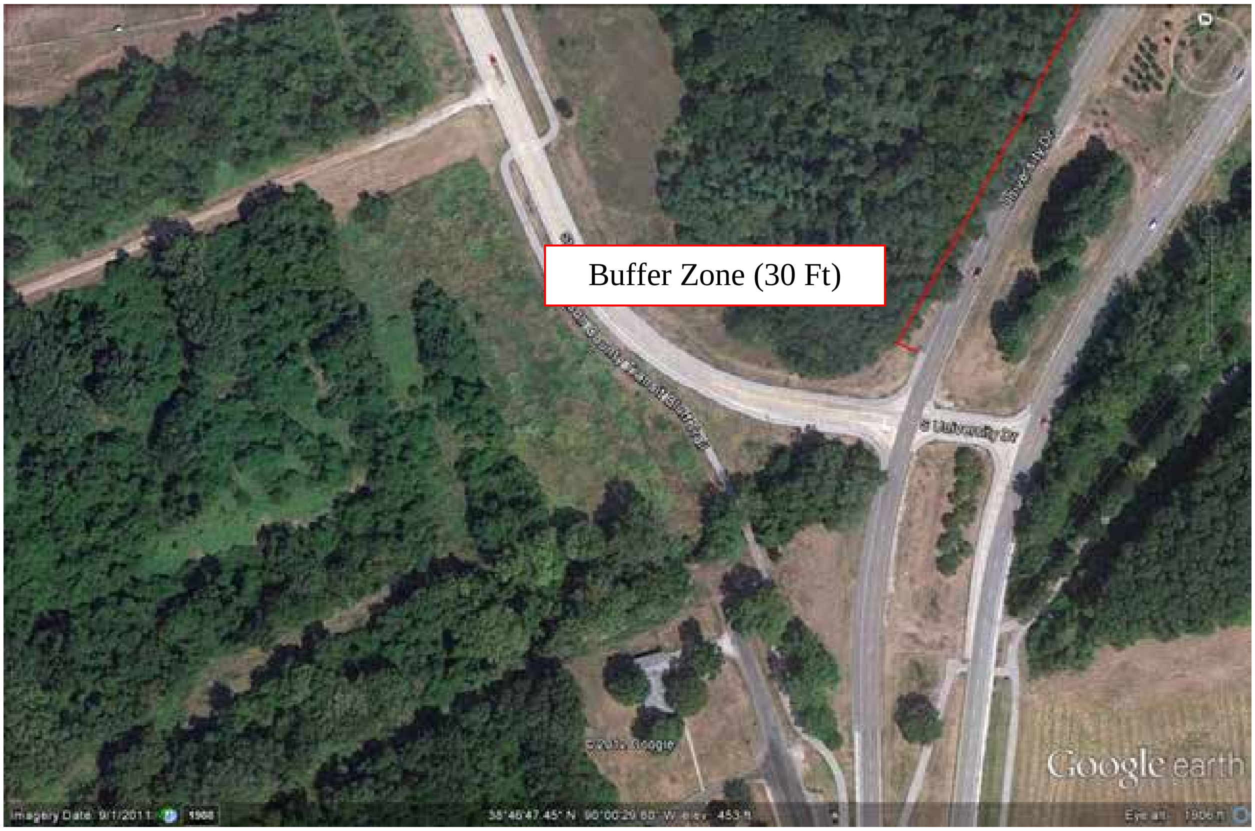
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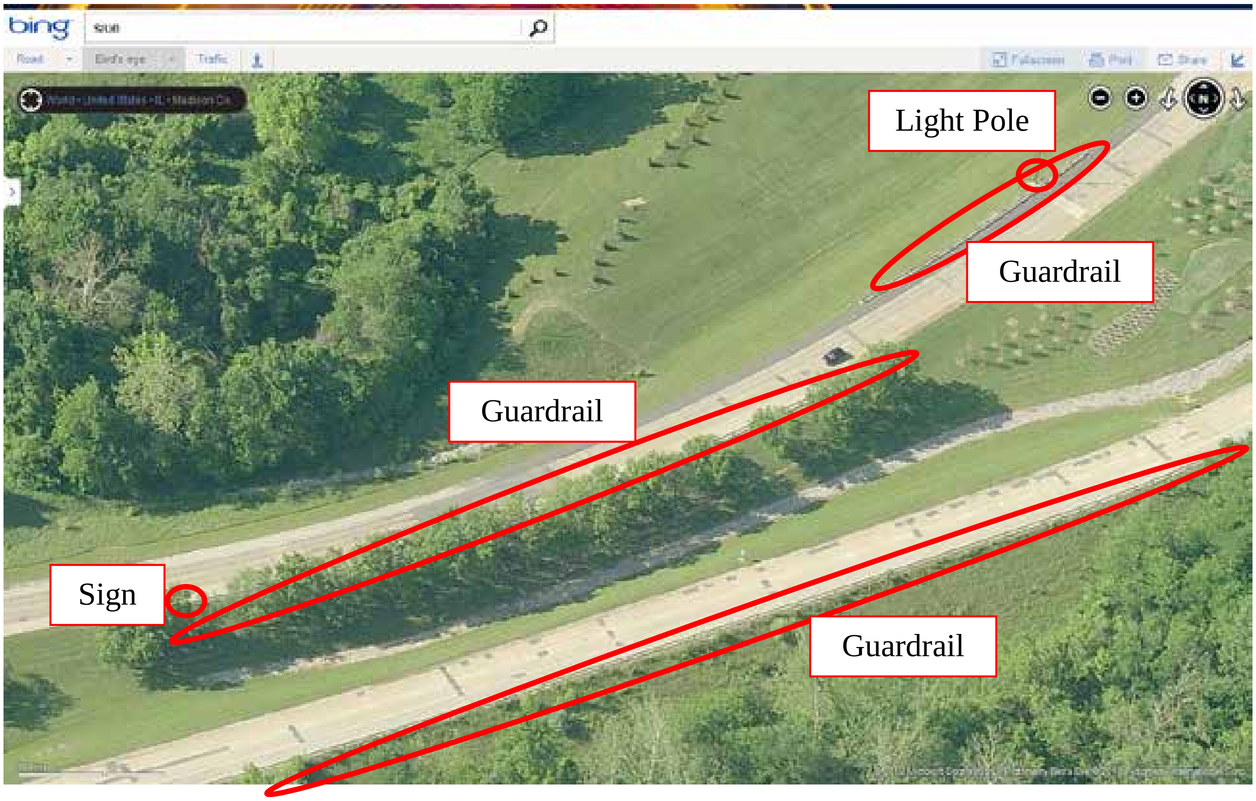
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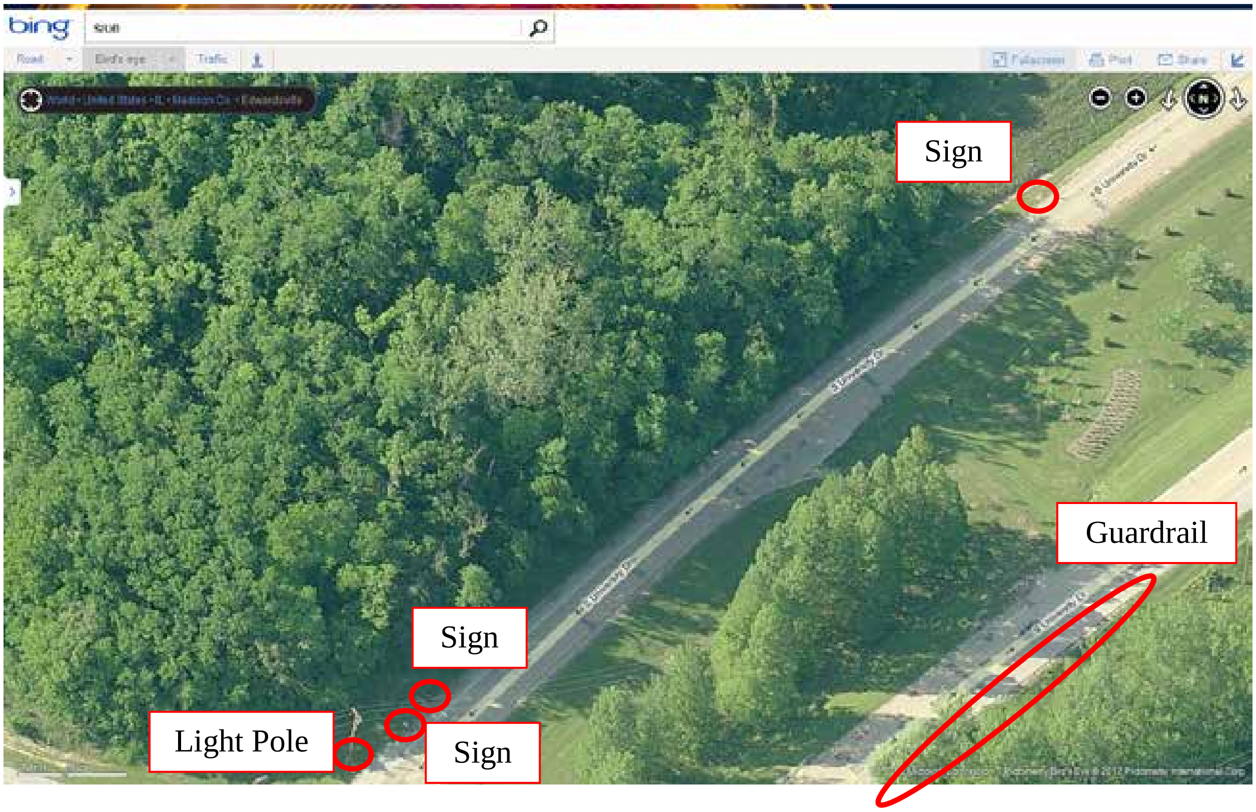
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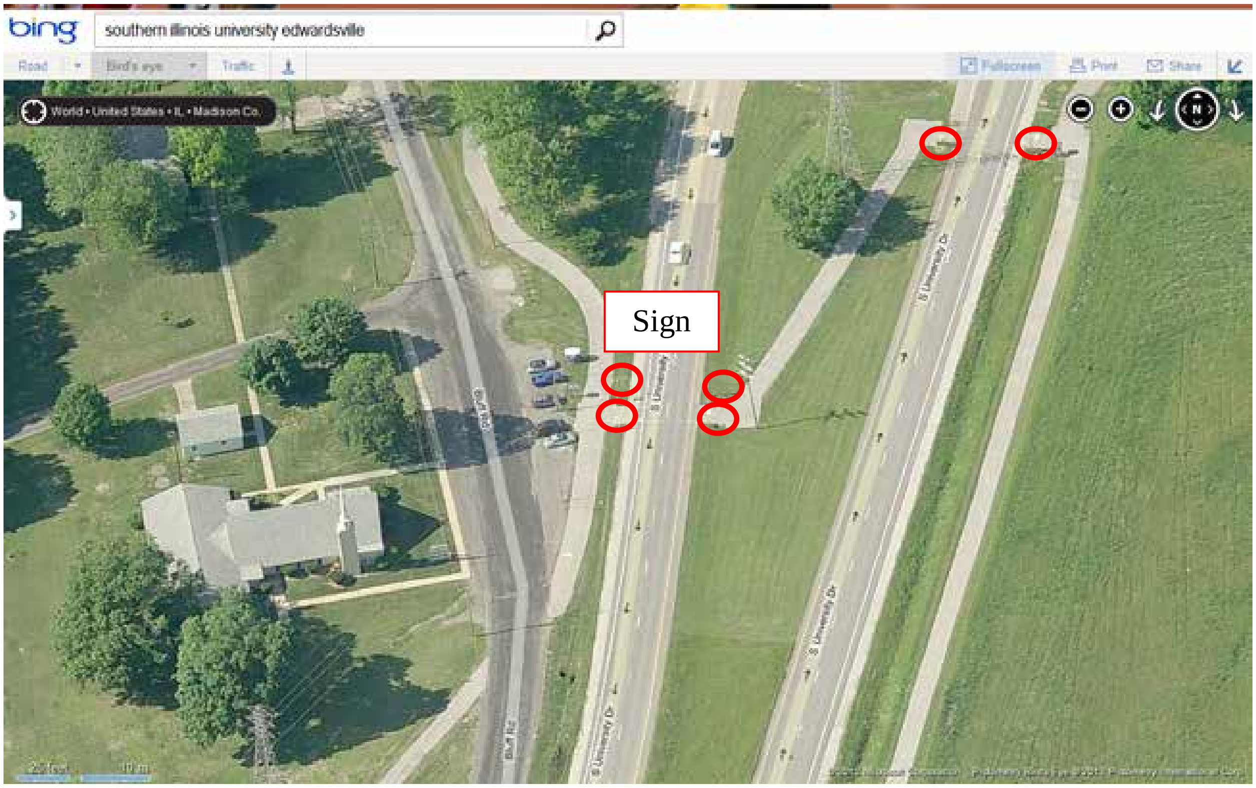

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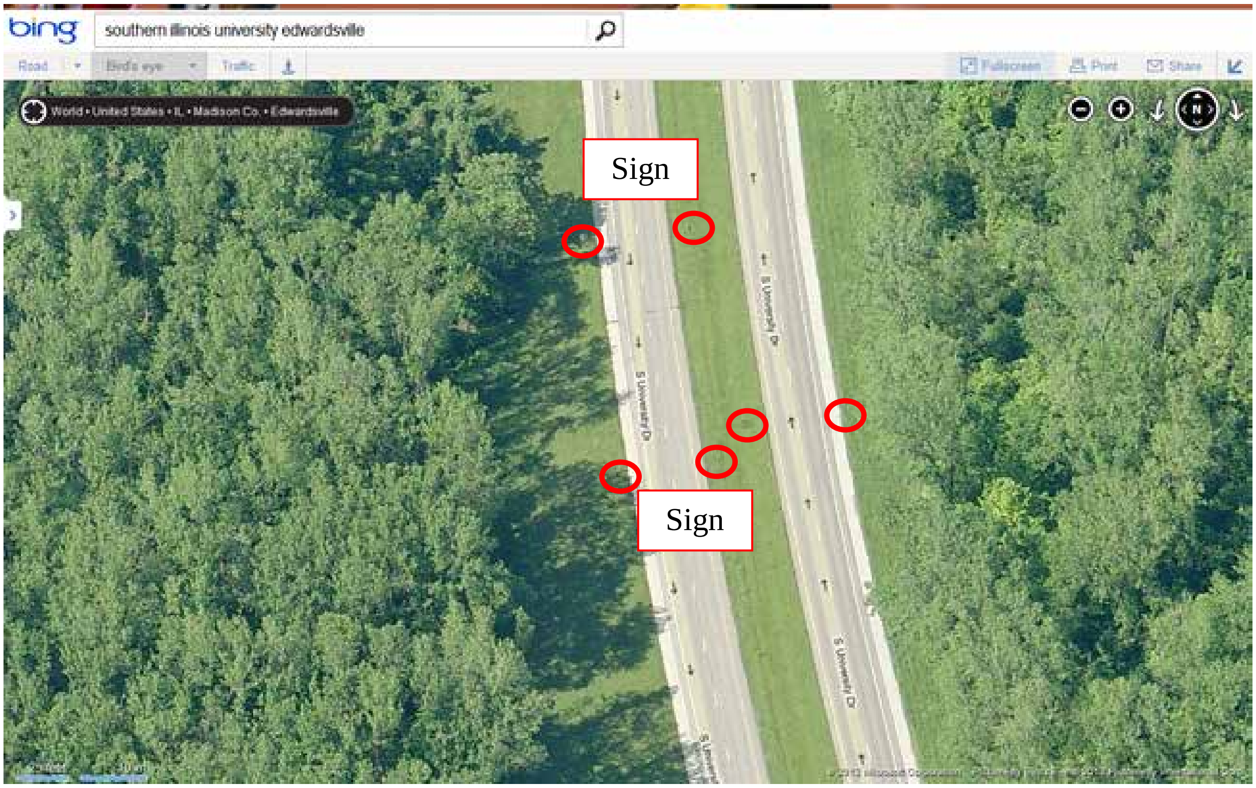
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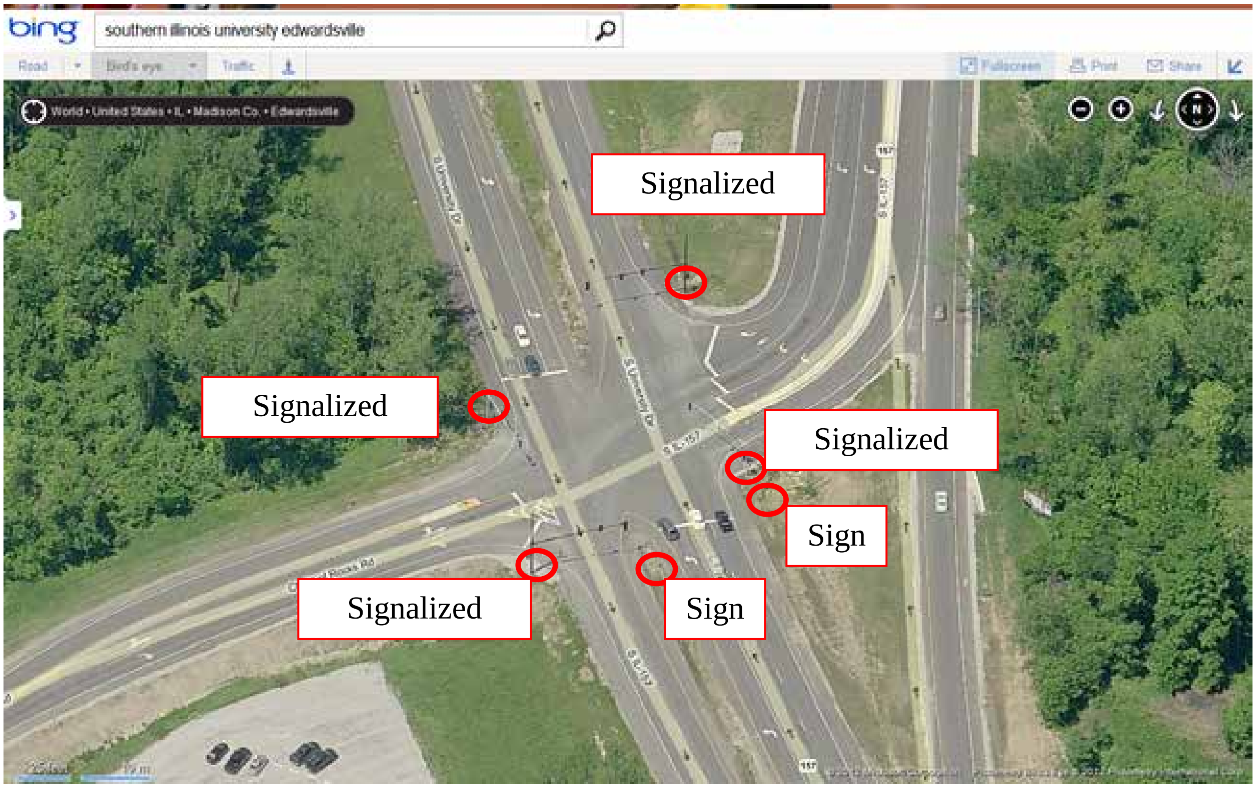
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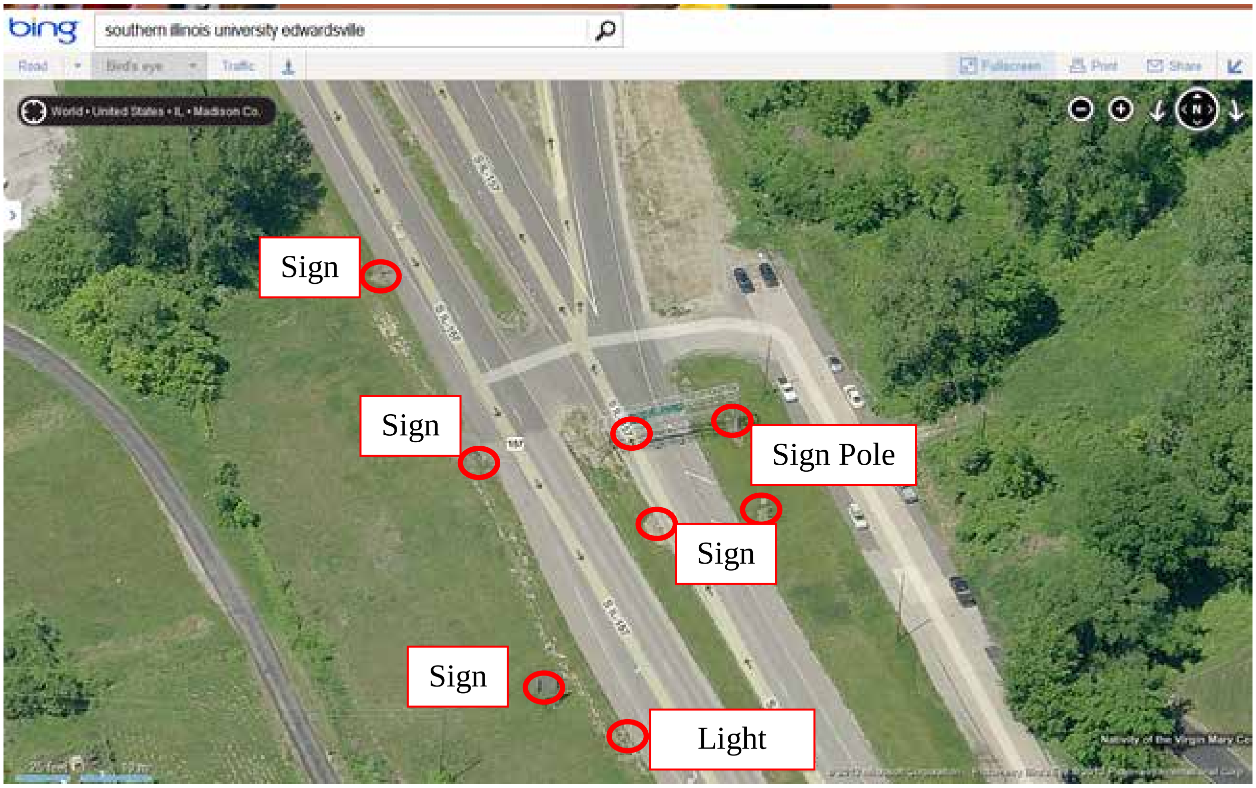

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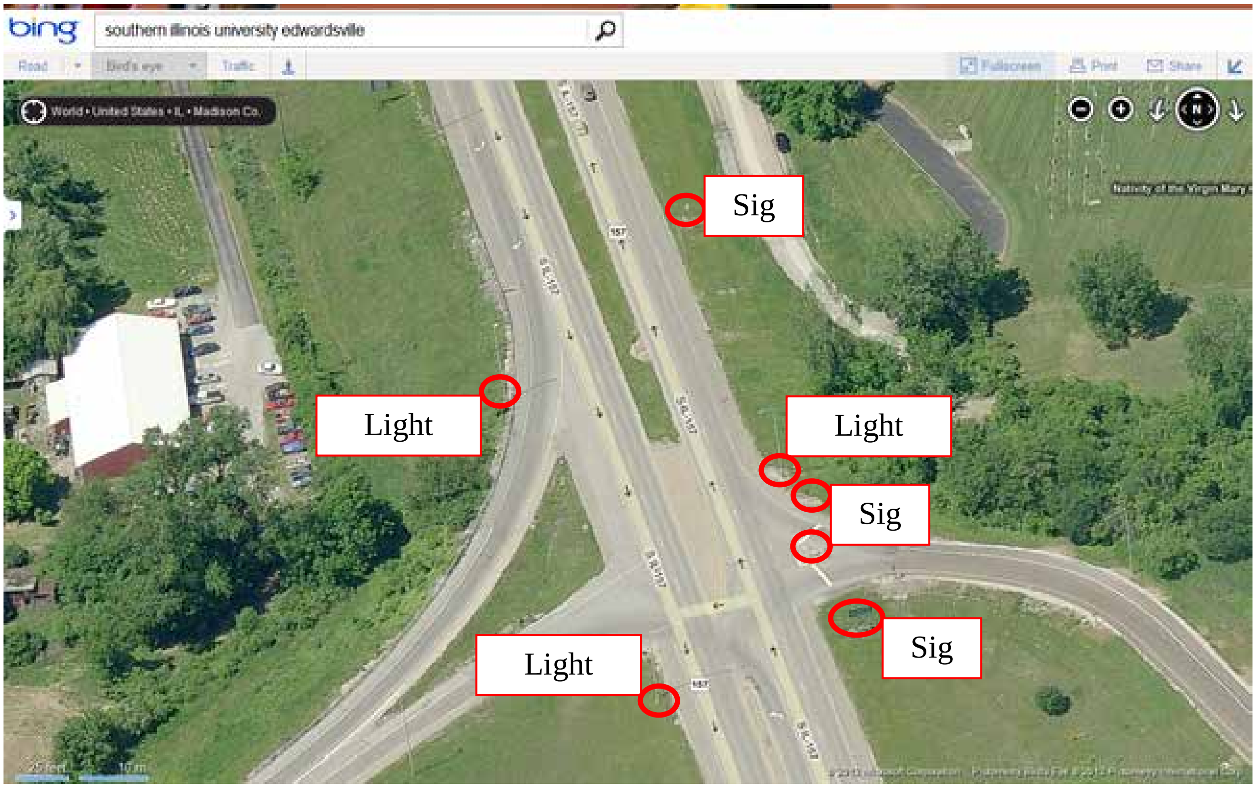

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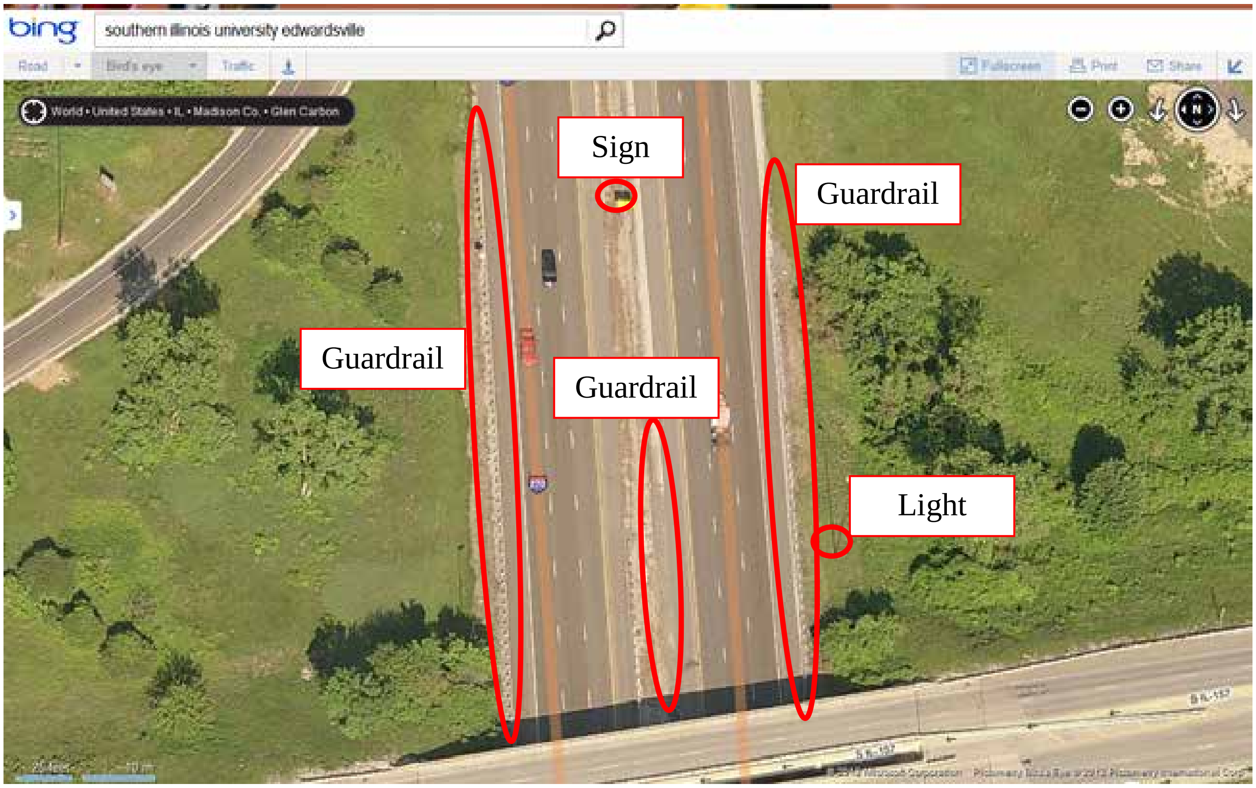
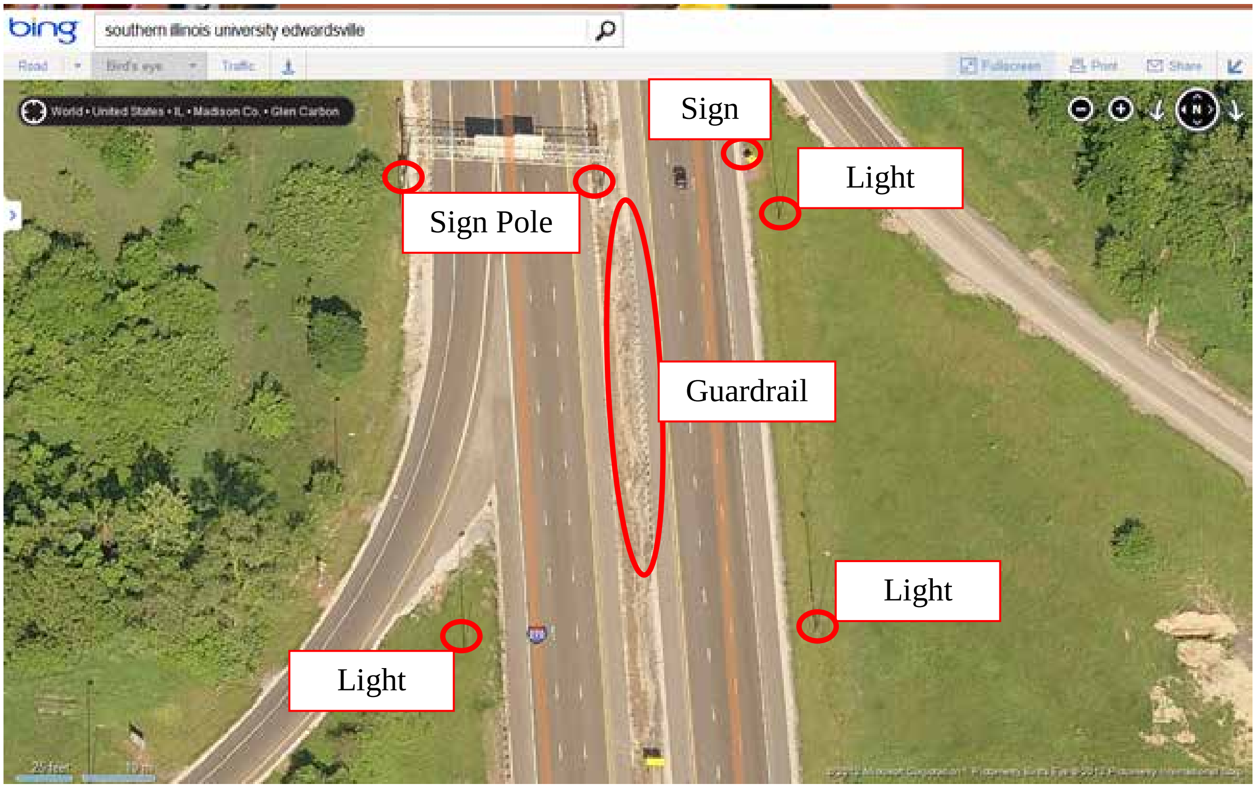
F.2: I-270 BETWEEN IL-157 AND IL-159

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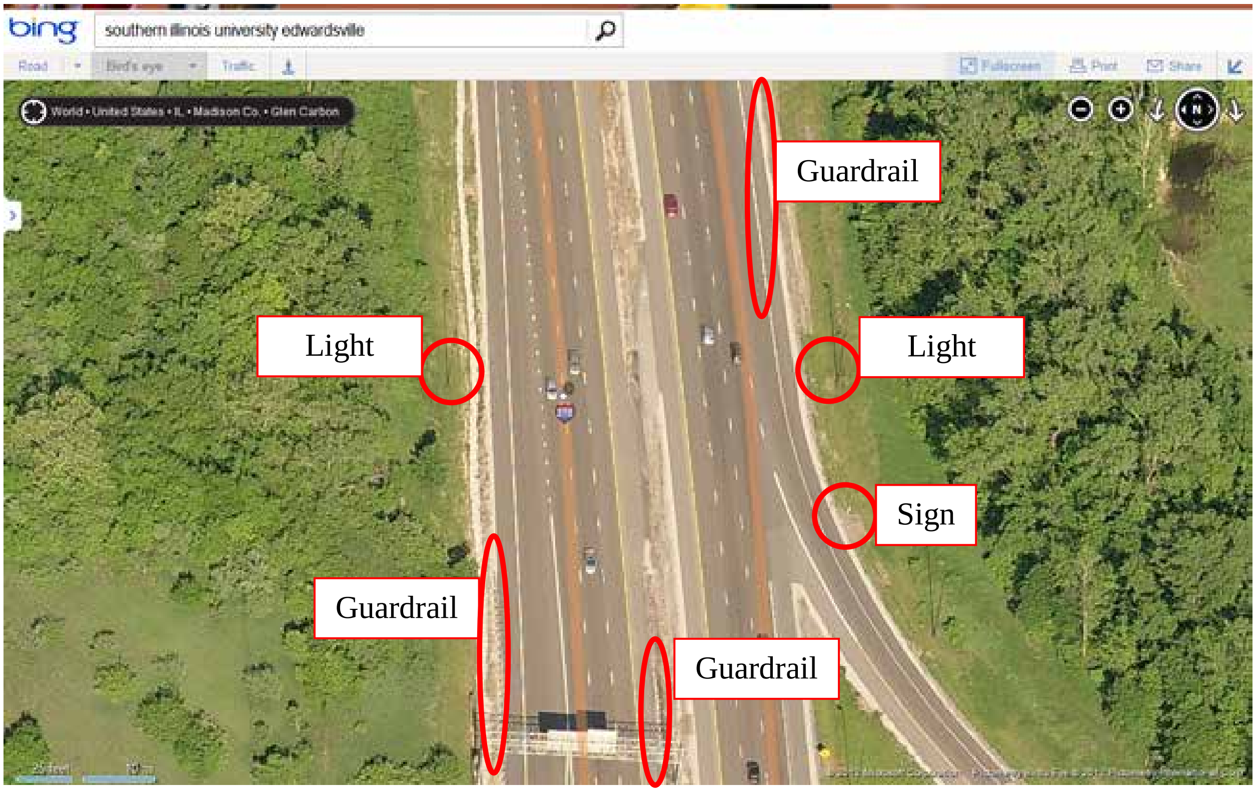
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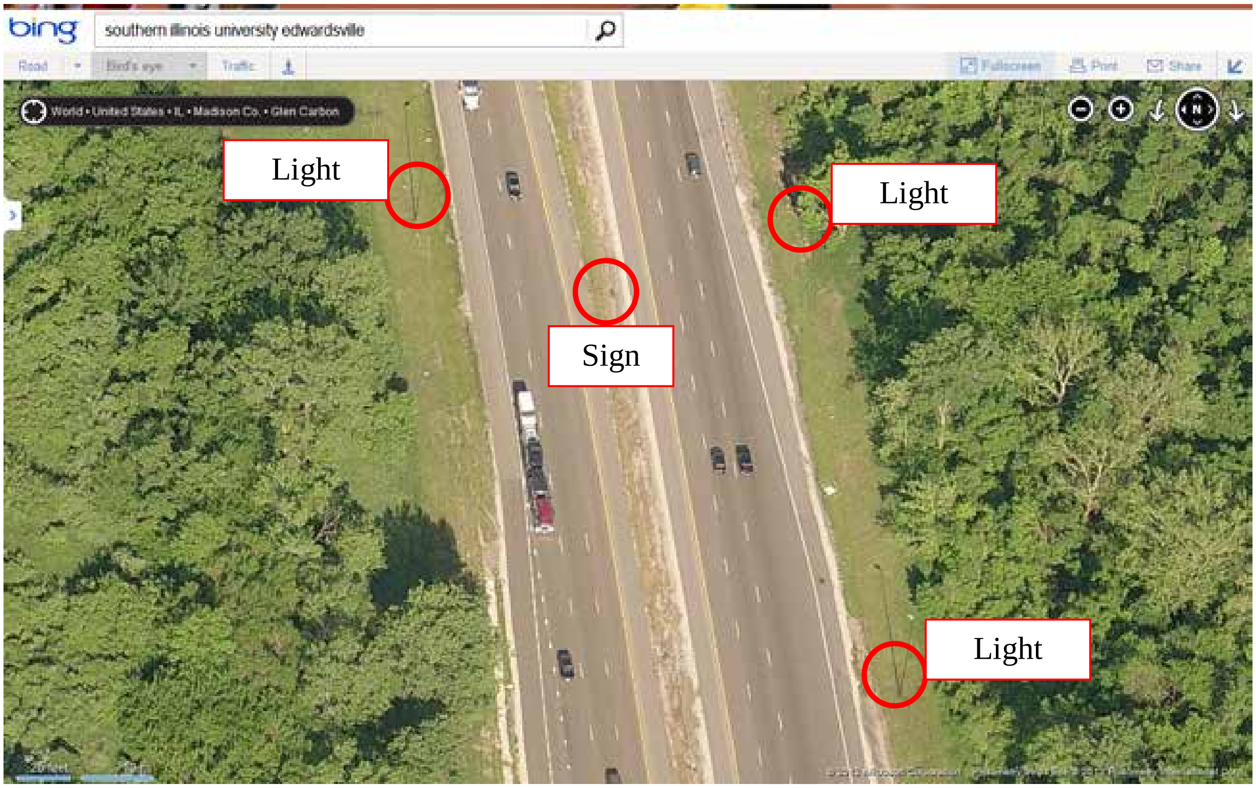

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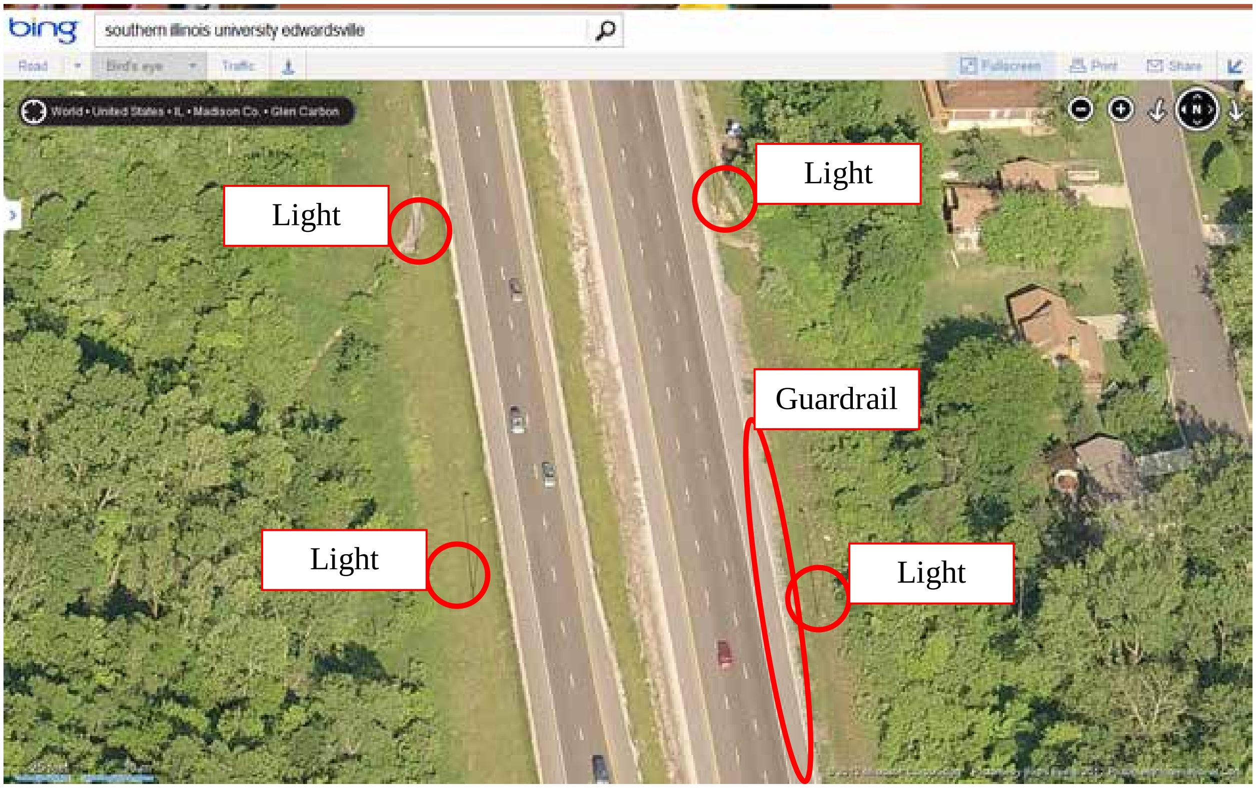

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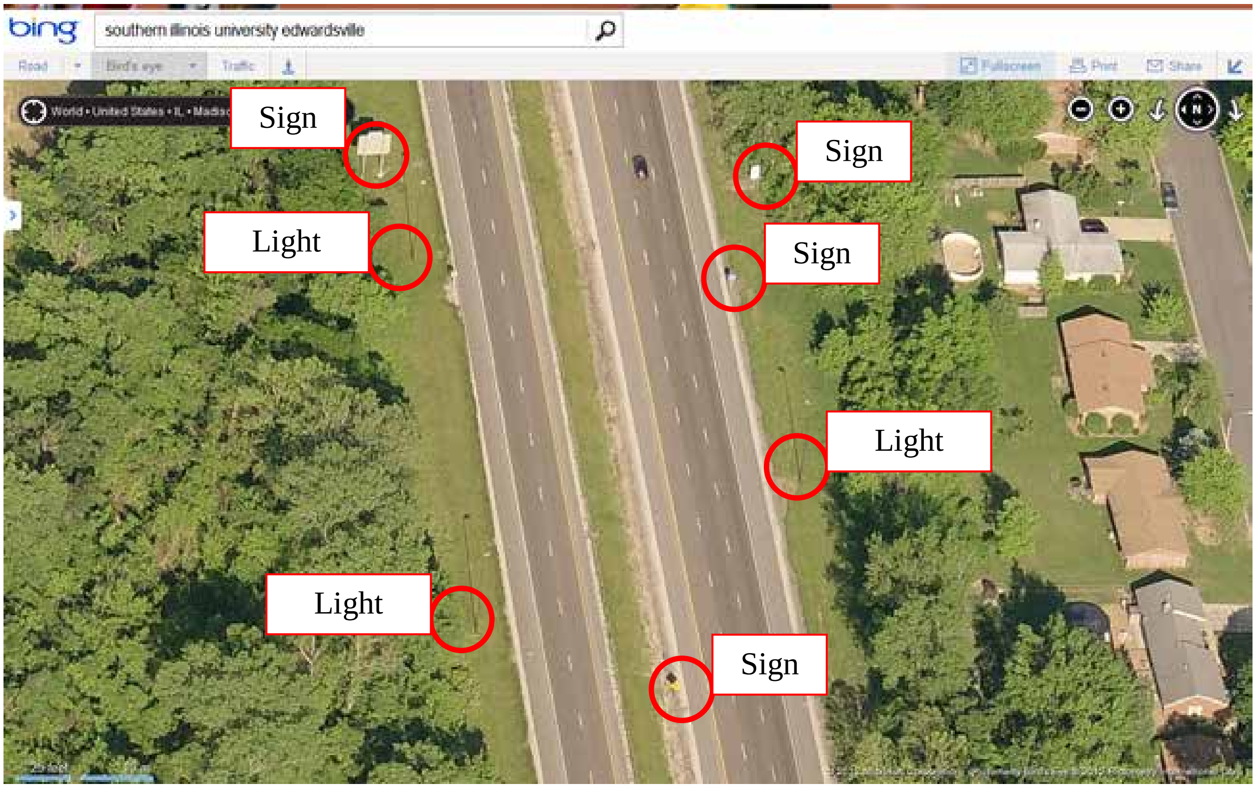

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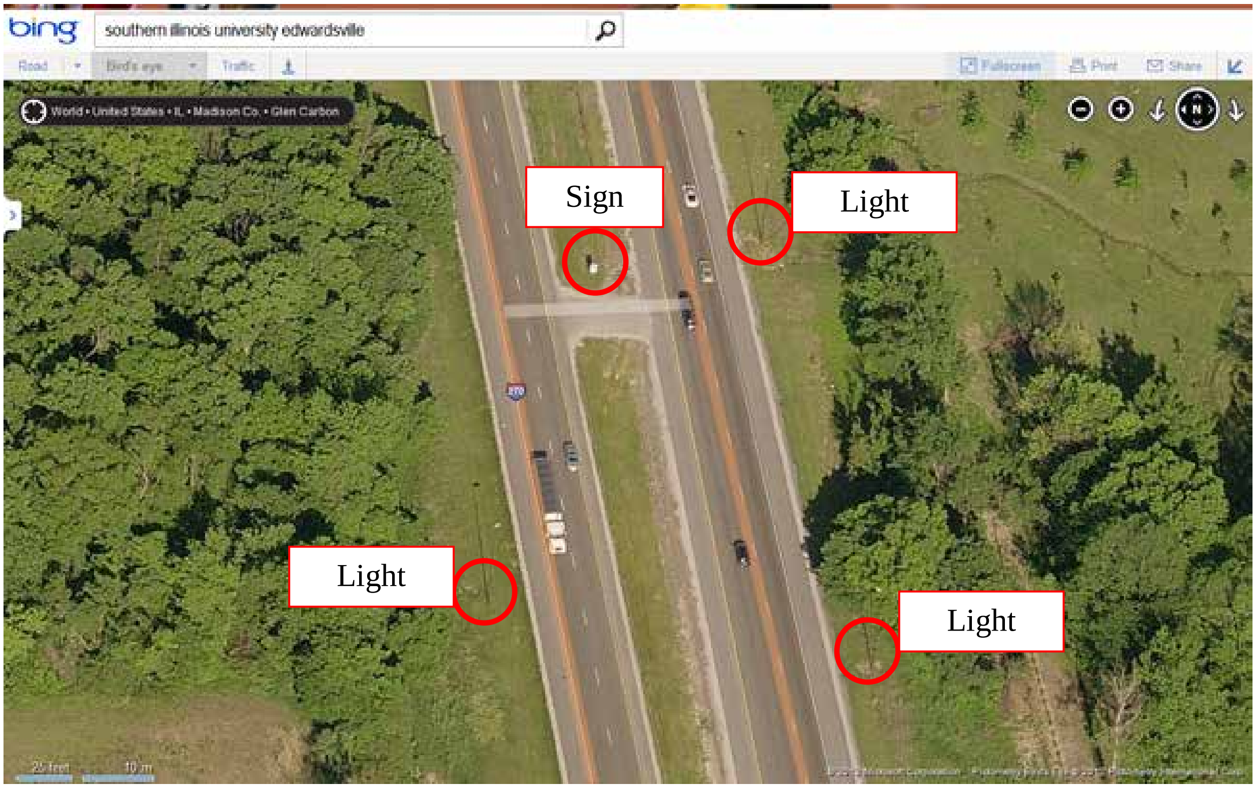

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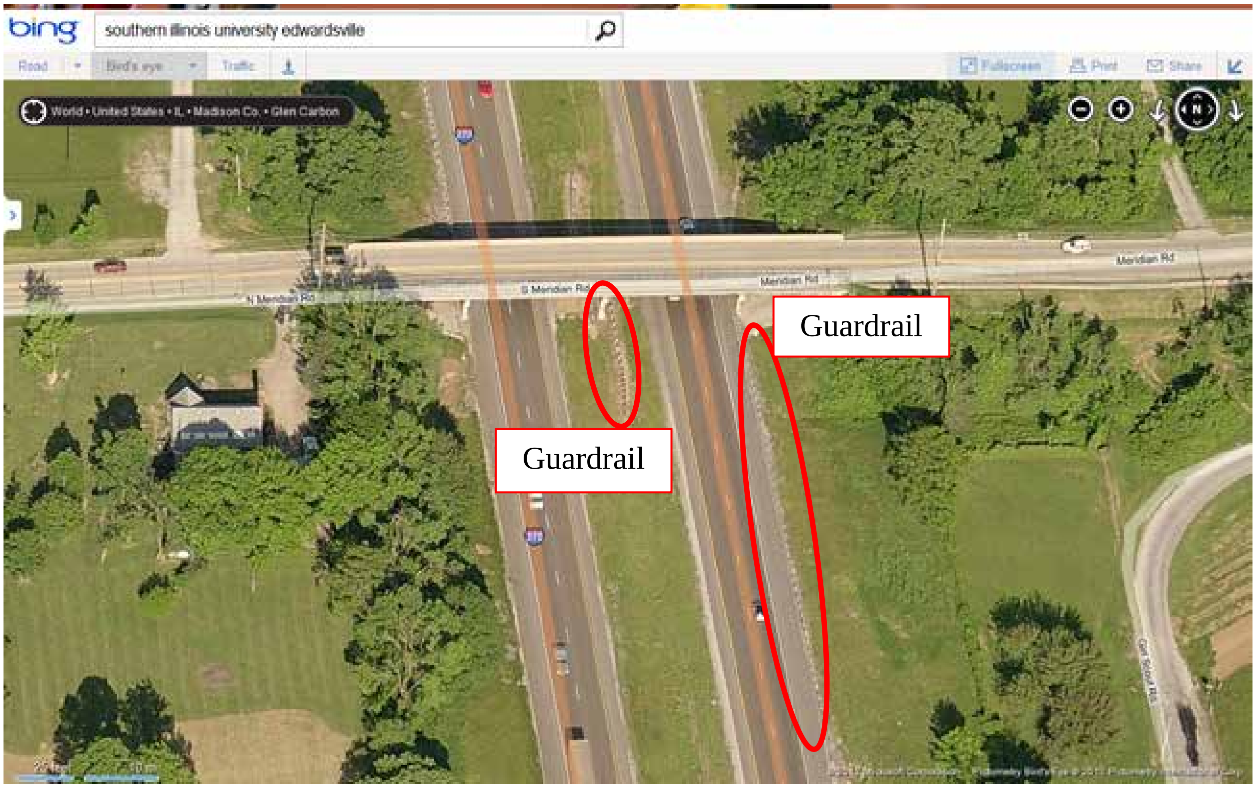
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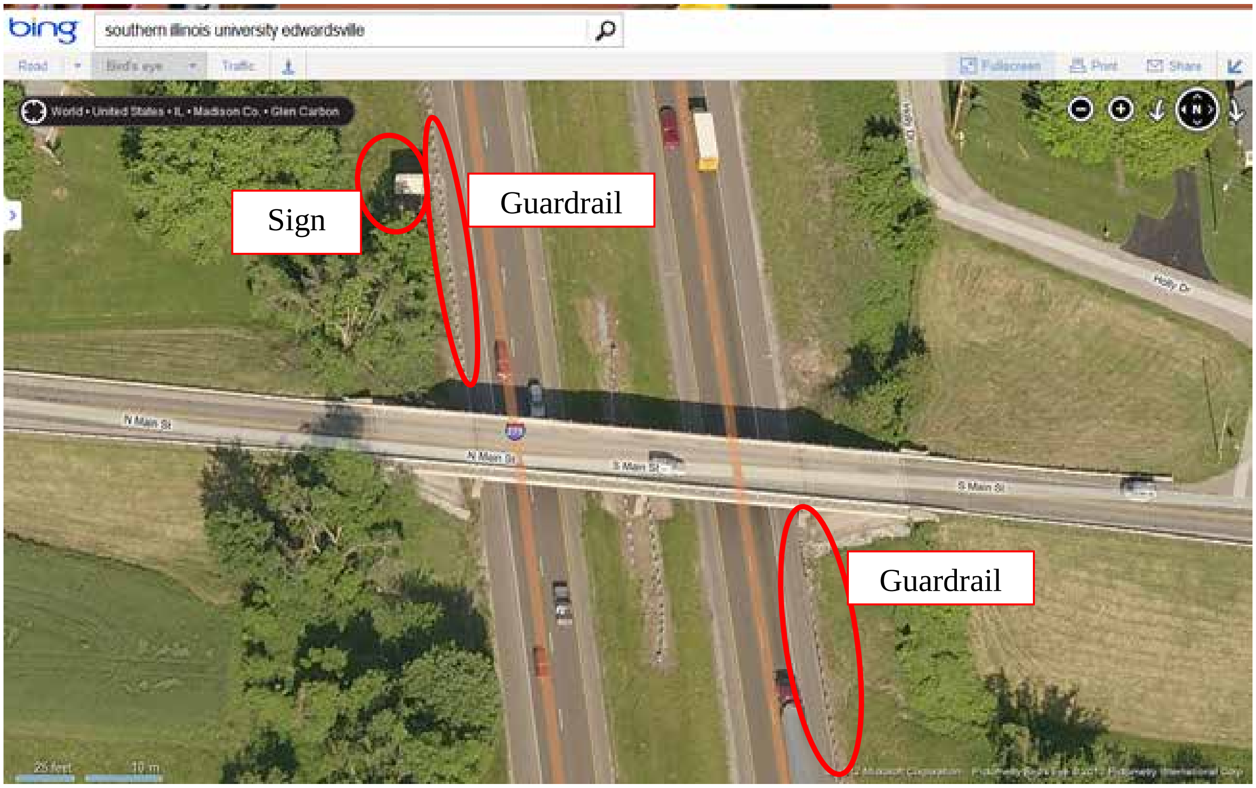
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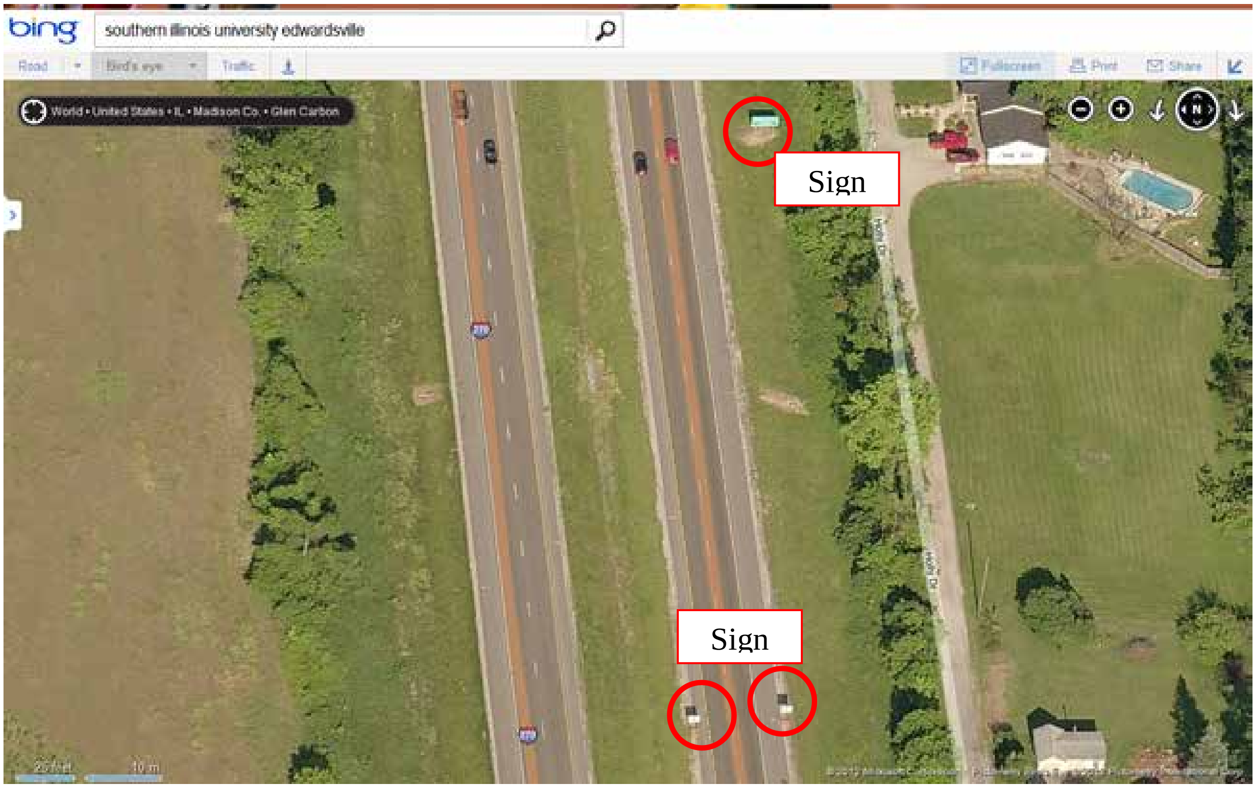
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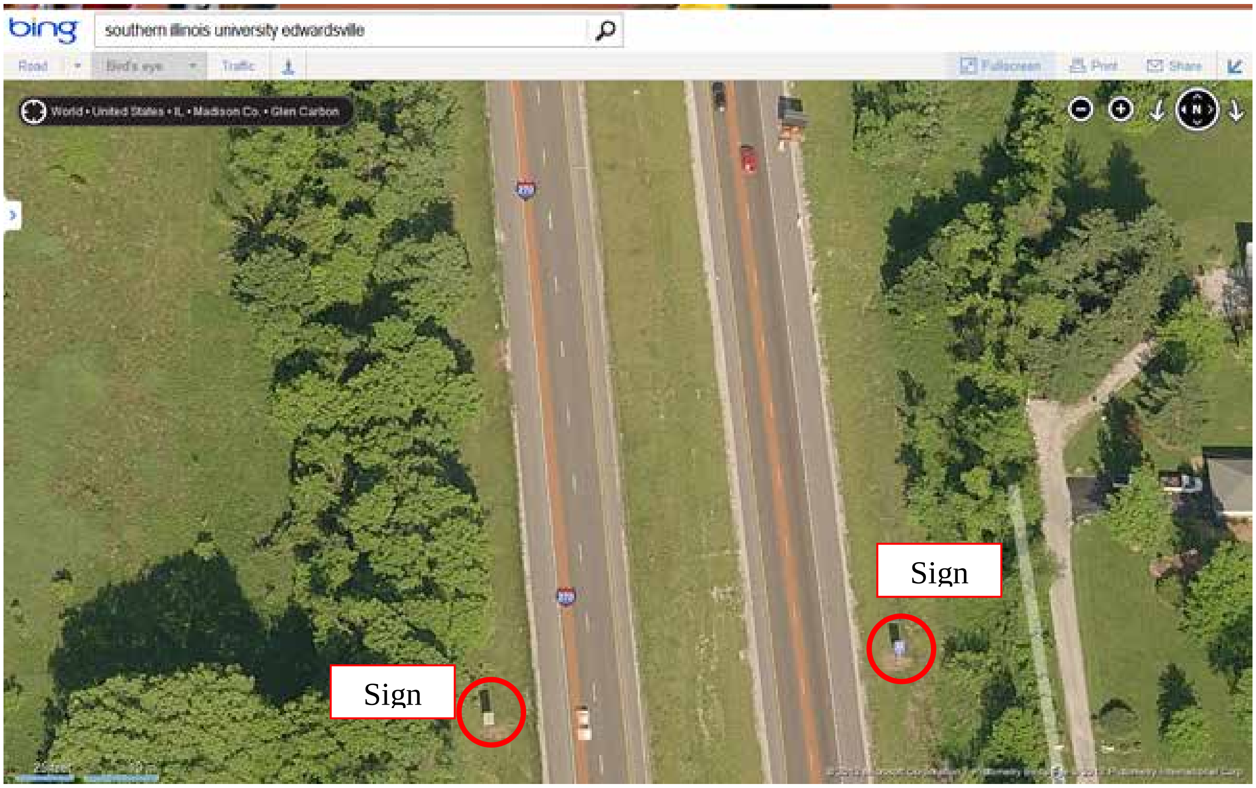
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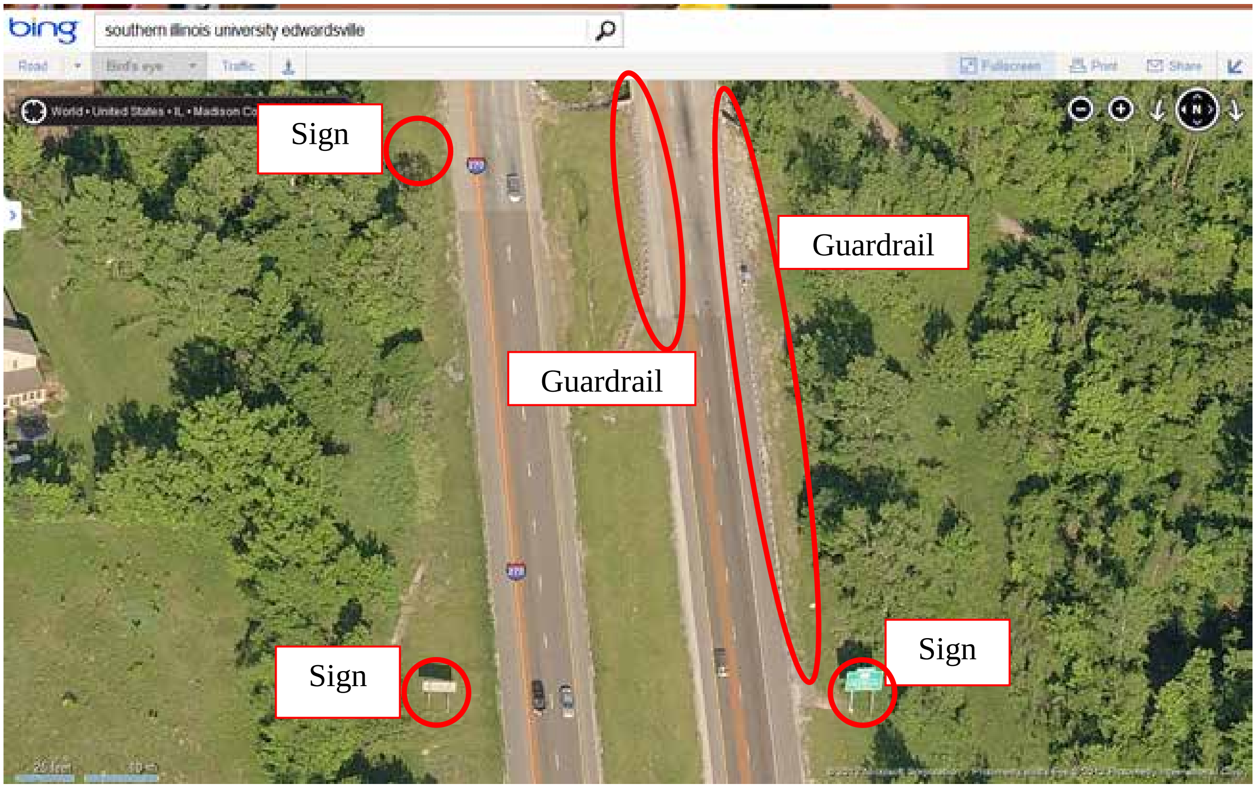
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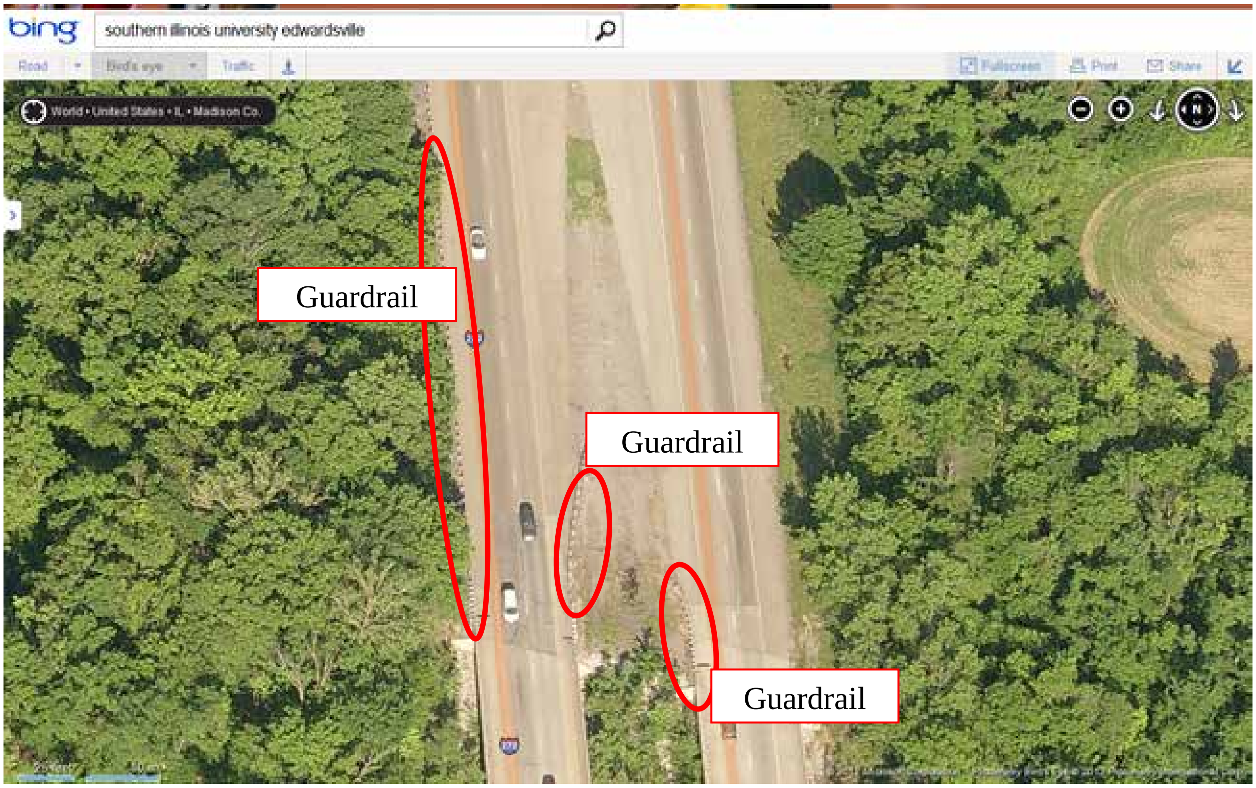
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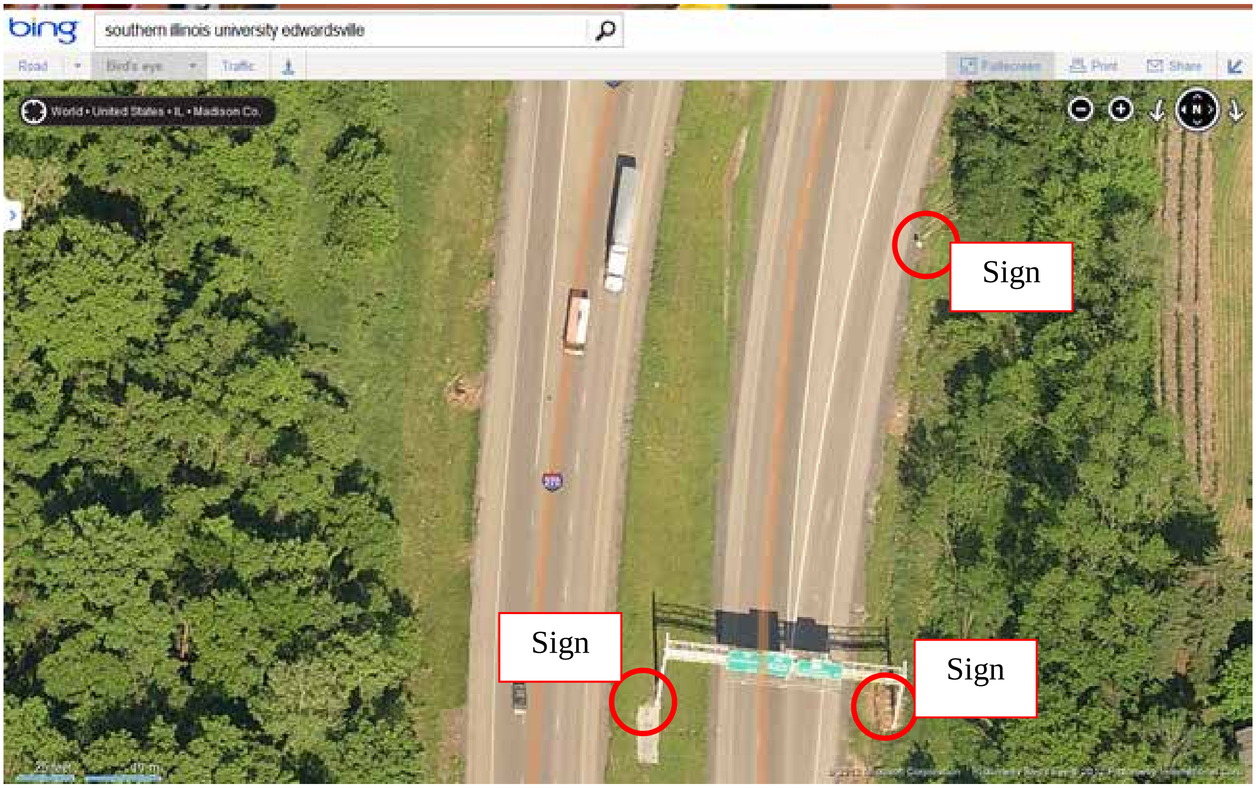
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APPENDIX G SURVEY QUESTIONNAIRE FORM

- o **Highway Asset Inventory Platform**
    - r GIS
    - r Oracle
    - r SQL
    - r Excel
    - r Access

- o **Asset Inventory Method Technology Used**
    - r Field Inventory
    - r GPS/GIS
    - r Video Log
    - r Photo Log
    - r Terrestrial Laser Scanning
    - r Mobile Terrestrial Laser Scanning
    - r Airborne LiDAR
    - r Aerial Imaging
    - r Satellite Imaging
    - r Other

- o **Conventional Survey Technology**
    - r Bridge Rails
    - r Driveway Intersections
    - r Fences
    - r Fire Hydrants
    - r Glare Screens
    - r Guardrails
    - r Impact Arrestors
    - r Jersey Barriers
    - r Junction Boxes
    - r Light Poles
    - r Luminaries
    - r Milepost Paddles
    - r On-Street Parking
    - r Rock Outcroppings
    - r Rumble Strips
    - r Shoulders
    - r Sign Supports
    - r Signals
    - r Trees
    - r Tree Groups
    - r Utility Poles
    - r Walls

r Roadside Slopes
r Slide Areas
r Horizontal Curve Data
r Longitudinal Slope Data
r Other

o **GPS/GIS Data Logger Technology**

r Bridge Rails
r Driveway Intersections
r Fences
r Fire Hydrants
r Glare Screens
r Guardrails
r Impact Arrestors
r Jersey Barriers
r Junction Boxes
r Light Poles
r Luminaries
r Milepost Paddles
r On-Street Parking
r Rock Outcroppings
r Rumble Strips
r Shoulders
r Sign Supports
r Signals
r Trees
r Tree Groups
r Utility Poles
r Walls
r Roadside Slopes
r Slide Areas
r Horizontal Curve Data
r Longitudinal Slope Data
r Other

o **Video Log Technology**

r Bridge Rails
r Driveway Intersections
r Fences
r Fire Hydrants
r Glare Screens
r Guardrails
r Impact Arrestors
r Jersey Barriers
r Junction Boxes

r Light Poles
r Luminaries
r Milepost Paddles
r On-Street Parking
r Rock Outcroppings
r Rumble Strips
r Shoulders
r Sign Supports
r Signals
r Trees
r Tree Groups
r Utility Poles
r Walls
r Roadside Slopes
r Slide Areas
r Horizontal Curve Data
r Longitudinal Slope Data
r Other

o **Photo Log Technology**

r Bridge Rails
r Driveway Intersections
r Fences
r Fire Hydrants
r Glare Screens
r Guardrails
r Impact Arrestors
r Jersey Barriers
r Junction Boxes
r Light Poles
r Luminaries
r Milepost Paddles
r On-Street Parking
r Rock Outcroppings
r Rumble Strips
r Shoulders
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r Signals
r Trees
r Tree Groups
r Utility Poles
r Walls
r Roadside Slopes
r Slide Areas
r Horizontal Curve Data

  - r Longitudinal Slope Data
  - r Other

- o **Terrestrial Laser Scanner Technology**
  - r Bridge Rails
  - r Driveway Intersections
  - r Fences
  - r Fire Hydrants
  - r Glare Screens
  - r Guardrails
  - r Impact Arrestors
  - r Jersey Barriers
  - r Junction Boxes
  - r Light Poles
  - r Luminaries
  - r Milepost Paddles
  - r On-street Parking
  - r Rock Outcroppings
  - r Rumble Strips
  - r Shoulders
  - r Sign Supports
  - r Signals
  - r Trees
  - r Tree Groups
  - r Utility Poles
  - r Walls
  - r Roadside Slopes
  - r Slide Areas
  - r Horizontal Curve Data
  - r Longitudinal Slope Data
  - r Other

- o **Mobile Terrestrial Laser Scanner Technology**
  - r Bridge Rails
  - r Driveway Intersections
  - r Fences
  - r Fire Hydrants
  - r Glare Screens
  - r Guardrails
  - r Impact Arrestors
  - r Jersey Barriers
  - r Junction Boxes
  - r Light Poles
  - r Luminaries
  - r Milepost Paddles

r On-Street Parking
r Rock Outcroppings
r Rumble Strips
r Shoulders
r Sign Supports
r Signals
r Trees
r Tree Groups
r Utility Poles
r Walls
r Roadside Slopes
r Slide Areas
r Horizontal Curve Data
r Longitudinal Slope Data
r Other

o **Airborne LiDAR Technology**
r Bridge Rails
r Driveway Intersections
r Fences
r Fire Hydrants
r Glare Screens
r Guardrails
r Impact Arrestors
r Jersey Barriers
r Junction Boxes
r Light Poles
r Luminaries
r Milepost paddles
r On-Street Parking
r Rock Outcroppings
r Rumble Strips
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r Signals
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r Tree Groups
r Utility Poles
r Walls
r Roadside Slopes
r Slide Areas
r Horizontal Curve Data
r Longitudinal Slope Data
r Other

- o **Satellite Imagery Technology**
  - r Bridge Rails
  - r Driveway Intersections
  - r Fences
  - r Fire Hydrants
  - r Glare Screens
  - r Guardrails
  - r Impact Arrestors
  - r Jersey Barriers
  - r Junction Boxes
  - r Light Poles
  - r Luminaries
  - r Milepost Paddles
  - r On-Street Parking
  - r Rock Outcroppings
  - r Rumble Strips
  - r Shoulders
  - r Sign Supports
  - r Signals
  - r Trees
  - r Tree Groups
  - r Utility Poles
  - r Walls
  - r Roadside Slopes
  - r Slide Areas
  - r Horizontal Curve Data
  - r Longitudinal Slope Data
  - r Other

- o

- o **Aerial Imagery Technology**
  - r Bridge Rails
  - r Driveway Intersections
  - r Fences
  - r Fire Hydrants
  - r Glare Screens
  - r Guardrails
  - r Impact Arrestors
  - r Jersey Barriers
  - r Junction Boxes
  - r Light Poles
  - r Luminaries
  - r Milepost Paddles
  - r On-Street Parking

  - r Rock Outcroppings
  - r Rumble Strips
  - r Shoulders
  - r Sign Supports
  - r Signals
  - r Trees
  - r Tree Groups
  - r Utility Poles
  - r Walls
  - r Roadside Slopes
  - r Slide Areas
  - r Horizontal Curve Data
  - r Longitudinal Slope Data
  - r Other

- o **Asset Categories Inventory**
  - r Bridge Rails
  - r Driveway Intersections
  - r Fences
  - r Fire Hydrants
  - r Glare Screens
  - r Guardrails
  - r Impact Arrestors
  - r Jersey Barriers
  - r Junction Boxes
  - r Light Poles
  - r Luminaries
  - r Milepost Paddles
  - r On-Street Parking
  - r Rock Outcroppings
  - r Rumble Strips
  - r Shoulders
  - r Sign Supports
  - r Signals
  - r Trees
  - r Tree Groups
  - r Utility Poles
  - r Walls
  - r Roadside Slopes
  - r Slide Areas
  - r Horizontal Curve Data
  - r Longitudinal Slope Data
  - r Other

- o **Equipment Cost Rating**

r Unacceptable
r Fair
r Good
r Very Good
r Excellent

o **Data Accuracy Rating**
  r Unacceptable
  r Fair
  r Good
  r Very Good
  r Excellent

o **Data Completeness Rating**
  r Unacceptable
  r Fair
  r Good
  r Very Good
  r Excellent

o **Crew Hazard Exposure Rating**
  r Unacceptable
  r Fair
  r Good
  r Very Good
  r Excellent

o **Data Collection Cost Rating**
  r Unacceptable
  r Fair
  r Good
  r Very Good
  r Excellent

o **Data Collection Time Rating**
  r Unacceptable
  r Fair
  r Good
  r Very Good
  r Excellent

o **Data Reduction Time Rating**
  r Unacceptable
  r Fair

    - r Good
    - r Very Good
    - r Excellent

- o **Data Reduction Cost Rating**
    - r Unacceptable
    - r Fair
    - r Good
    - r Very Good
    - r Excellent

- o **Data Storage Requirement Rating**
    - r Unacceptable
    - r Fair
    - r Good
    - r Very Good
    - r Excellent

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