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Utilizing GIS to Develop a Non-Signalized Intersection Data Inventory for Safety Analysis

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ABSTRACT
Roadway data inventories are being used across the nation to aid state Departments of Transportation (DOTs) in decision making. The high number of intersection and intersection related crashes suggest the need for intersection-specific data inventories that can be associated to crash occurrences to help make better safety decisions. Currently, limited time and resources are the biggest difficulties for execution of comprehensive intersection data inventories, but online resources exist that DOTs can leverage to capture desired data.
Researchers from The University of Alabama developed an online method to collect intersection characteristics for non-signalized intersections along state routes using Google Maps and Google Street View, which was tied to an Alabama DOT maintained geographic information systems (GIS) node-link linear referencing method.
A GIS-Based Intersection Data Inventory Web Portal was created to collect and record non-signalized intersection parameters. Thirty intersections of nine different intersection types were randomly selected from across the state, totaling 270 intersections. For each intersection, up to 78 parameters were collected, compliant with the Model Inventory of Roadway Elements (MIRE) schema. Using the web portal, the data parameters corresponding to an average intersection can be collected and catalogued into a database in approximately 10 minutes. The collection methodology and web portal function independently of the linear referencing method; therefore, the tool can be tailored and used by any state with spatial roadway data. Preliminary single variable analysis was performed, showing that there are relationships between individual intersection characteristics and crash frequency. Future work will investigate multivariate analysis and develop safety performance functions and crash modification factors.
***Keywords* –** Data Inventory Web Tool, Geographic Information Systems, Non-Signalized Intersections, Transportation Safety

I. INTRODUCTION

The National Highway Traffic Safety Administration reports that in 2012, there were 45,637 fatal crashes across the United States, of which 27.3% were intersection, or intersection related. Out of all fatal, injury, and property damage crashes, 47.6% were intersection, or intersection related. Approximately half of crashes across the nation can be attributed to intersection design and conditions [1]. Improving roadway safety is one of the top priorities of state Departments of Transportation (DOTs) across the nation. Many DOTs utilize roadway data inventory databases to aid in decision making for better roadway design, improvements, and maintenance. Due to the number of crashes associated with intersections, DOTs have started creating intersection-specific data inventories, with data such as location, geometry, and current conditions [2, 3]. The Model Inventory of Roadway Elements (MIRE), released by the Federal Highway Administration (FHWA) in October 2010, lists critical data to be included in state agency's roadway and intersection data inventories that can be utilized for safety analysis and aid in decision making for safety improvement investments. MIRE was intended to be a tool for state DOTs to implement into their Strategic Highway Safety Plans [4]. In 2012, the FHWA passed the Moving Ahead for Progress in the 21st Century Act (MAP-21) which created a standardized, multi-issue transportation improvement program that addresses transportation challenges from construction to safety. MAP-21's guidance for State Safety Data Systems outlines Fundamental Data Elements (FDEs) as a subset to MIRE, making the dataset more refined, yet still useful for safety management [5].

MIRE and MAP-21 both stress the importance of the geolocation of safety data. Many states have linear referencing methods associated with geographic information system (GIS) technology for the mapping of crash locations, but associating these occurrences with intersection characteristics is challenging, due to a lack of data, time, and resources.

Geometric and conditional characteristics of intersections that may contribute to crashes can be correlated with existing crash frequency data to allow for statistical analyses [2, 6, 7]. For efficient analysis, intersection characteristics and roadway facilities need to be cataloged in an organized database format. Currently, limited time and resources are the largest hurdles for implementing statewide intersection data inventories. Field data collection at all intersections is costly, not always safe, and time consuming, deeming this approach impractical. States are searching for, and are in need of, a low-cost and efficient methodology to collect, store, and retrieve intersection data parameters that can be employed for safety analysis.

The Alabama Department of Transportation (ALDOT) recognizes the importance of an intersection data inventory, which can be used to identify factors that may contribute to crashes. To produce an intersection data inventory, ALDOT supported a project to develop and begin using an online tool to collect non-signalized intersection data. Following work by Lefler, et al, this project develops and demonstrates the use of existing aerial and street view imagery from Google Maps in combination with geo-referenced intersection node and roadway link shapefiles [3]. Google Maps and Google Street View can be used as forms of remote sensing, eliminating the need for excessive time and resources to collect data parameters in the field. By taking data collection out of the field and onto the web, the risk involved in field data collections is completely eradicated and the cost is greatly reduced. Utilizing existing DOT linear referencing system data in conjunction with the Google Maps online resource, a complete dataset of necessary safety relevant parameters can be cataloged.

To test the developed data collection approach, a significant number of randomly selected non-signalized intersections were analyzed. Along state routes, ALDOT maintains a node-link linear referencing method and a route-milepost linear referencing method. Using these systems and a randomizing technique, intersection nodes in Alabama were selected for data collections. In order to create an accurate depiction of all types of non-signalized intersections along state routes, intersections were divided into nine different categories by the following criteria; two different intersection areas: rural or urban, two intersection designs: 3-leg or 4-leg, and two lane types: 2-lane or Multi-lane. Crossroad ramp terminals were also included. Thirty intersections of each type were cataloged, producing a total of 270 intersections. A sample size of 30 intersections of each intersection type provides a large sample dataset, which can be used for statistical analysis of correlations between geometric or situational factors of intersections and crash frequencies. Additional intersections will be catalogued as time and resources permit.

A GIS-Based Intersection Data Inventory Web Portal was created for efficient collection and recording of intersection data parameters in an organized database that can be exported to a shapefile for use in a desktop analysis. This methodology is independent of the linear referencing system; therefore, this tool can be used by any state with spatial roadway datasets.

II. INTERSECTION DATA COLLECTION METHODOLOGY

A methodology for collecting intersection characteristic data that may be contributing to crashes was developed through extensive background research, advisement from ALDOT, and trial and error troubleshooting. For this study, the methodology was only executed on non-signalized intersections along state routes in Alabama. There are nearly 30,000 intersections along state routes in Alabama with the vast majority of them being non-signalized. Therefore, research efforts were focused on non-signalized intersections, as they are most frequently encountered. Furthermore, non-signalized intersections have a different dataset of parameters relevant to safety considerations than signalized intersections; therefore signalized intersections should be handled in a separate project. The developed methodology for non-signalized intersections is fully extensible to all non-signalized intersections along all roads in the nation with linear referencing systems or roadway data in GIS.

2.1 INTERSECTION SELECTION

Intersections along state routes were divided into nine different categories to provide a comparison of how different intersection types may affect roadway safety. Intersection categories included: Rural 3-leg 2-lane, Rural 4-leg 2-lane, Rural 3-leg Multi-lane, Rural 4-leg Multi-lane, Urban 3-leg 2-lane, Urban, 4-leg, 2-lane, Urban 3-leg Multi-lane, Urban 4-leg Multi-lane, and Crossroad Ramp Terminals.

A spatial analysis was completed to differentiate nodes along states routes as rural or urban. Intersections in areas with populations less than 5000 were classified as rural nodes while intersections in areas with populations greater than 5000 were classified as urban nodes [8]. A randomizing technique was applied to both rural and urban intersections to select a random intersection as a starting point. All four rural intersection types were found from the randomly selected rural location, and all four urban intersection types were found from the randomly selected urban location. The crossroad ramp terminal intersection type was found from either the rural or urban starting location. The final dataset consisted of 135 rural intersections and 135 urban intersections.

2.2 INTERSECTION DATA PARAMETERS

The intersection and leg data parameters chosen to collect and compile data for were selected based on their potential safety impact on intersection safety. The elements selected were also based on requests by ALDOT, previous work by Lefler, et al, and guidelines by the FHWA in MIRE, the Highway Safety Manual, and MAP-21 [3, 4, 5, 9]. Table 1 displays the data parameters that were incorporated into the inventory database. Each parameter describes either an intersection attribute or a specific leg attribute about the intersection; therefore, both an intersection table and leg table were included in the database organization. The intersection level data and leg level data are associated to the nodes and links in the linear referencing system, respectively.

Crossroad ramp terminals have extra intersection and leg level parameters that do not pertain to the other eight intersection categories. Table 1 indicates the extra ramp parameters in italics, as well as parameters for circular intersections and railroad crossings, which were not investigated in this study. While this study did not investigate circular intersections or railroad crossings, these parameters were built into the database for MIRE compliance and future use. Furthermore, Table 1 indicates various parameters that have set categories with the word "coded," such as leg traffic control and median type. These categorical parameters were coded with integers during this study, mitigating spelling errors that could hinder the relational database.

2.3 TOOL DEVELOPMENT FOR RECORDING DATA

The Alabama node-link linear referencing method and route-milepost linear referencing method in GIS supplies a NodeID for each intersection. General intersection level data such as county, city, and GPS coordinates are available from the GIS data sources. The linear referencing methods also provide a LinkID for each roadway, supplying road names and state route mileposts. Each node and link was given a statewide NodeID and LinkID to serve as a unique field for each of the intersection and leg tables, respectively. The unique NodeID was referred to as the IntersectionID. Because some intersections could share the same leg, a LegID was generated by concatenating the IntersectionID and leg number to provide a unique field used to identify specific legs. Any state's unique identification method could be used with this tool.

A leg numbering convention was applied to standardize the method for naming and collecting leg level data. The major road was numbered first, followed by the minor road. Considering the orientation of the road, the legs were numbered first by North to South, or West to East. For crossroad ramp terminals, the interstate was considered the major road. In the case of two crossing state routes, the state route named with the smallest number took precedence.

A database model and table schema were developed for the functionality and development of the GIS-Based Intersection Data Inventory Web Portal. The database model shown in Fig. 1 (a) illustrates how all the parameters are attributed to either the node or link in the linear referencing system. Each node is an intersection with various intersection attributes, and each intersection has multiple legs that hold various leg attributes. If the intersection is a crossroad ramp terminal, an if-statement unlocks the extra parameters for that specific type of intersection, while still inheriting the parameters of an intersection. The same logic applies for circular intersections and railroad crossings. Fig. 1 (b) shows the table schema in which each primary key is underlined. The table schema also displays the data type used for each data parameter.

Table 1 Intersection and Leg Data Parameters (Italics Denote Extra Parameters for Crossroad Ramp Terminals, Circular Intersections, and Railroad Crossings; (coded) Refers to Categorical Parameters)

Intersection Level Parameters		
Intersection ID	Intersection Milepost	*Ramp Speed Limit*
NodeID	County	*Number of Approaches within 250 feet of Ramp Terminal*
Intersection Category (coded)	City	*Distance to Adjacent Ramp Terminal*
Area Type (coded)	Ecoregion	*Number of Circular Lanes*
Number of Legs	Terrain (coded)	*Circular Lane Width*
Intersection Traffic Control Type (coded)	Skew Angle	*Inscribed Diameter on Circular Intersection*
Intersection Geometry (coded)	Offset	*Bike Facility on Circular Intersection*
School Zone	Offset Distance	*Railroad Crossing Number*
Latitude	Distance to Next Public Intersection	
Latitude	Intersection Photo	
Lighting	Comments	

Leg Level Parameters

LegID
Statewide LinkID
LinkID
Leg Number
Leg Type (coded)
Leg Route Type (coded)
Leg Route Name
Approach Mode (coded)
Leg Speed
Leg Width
Number of Lanes
Number of Merge Lanes
Pavement Type (coded)
Orientation (coded)
Median Type (coded)
Median Width
Leg Traffic Control Type (coded)
Transverse Rumble Strips
Number Left Turn Lanes
Left Turn Lane Width
Left Turn Lane Length
Left Turn Offset Distance
Number Right Turn Lanes
Right Turn Lane Width
Right Turn Lane Length
Right Turn Channelization (coded)
Right Turn Movement Control (coded)
Pedestrian Crossing Control (coded)
One Way
Turn Prohibitions (coded)
Left Turn Sight Distance View (coded)
Left Turn Sight View Photo
Right Turn Sight Distance View (coded)
Right Turn Sight View Photo
Annual Average Daily Traffic (AADT)
AADT Year
Peak Hour Volume
Comments
Circular Entry Width
Number of Circular Entry Lanes
Number of Circular Exclusive Right Turn Lanes
Circular Entry Radius
Circular Exit Width
Number of Circular Exit Lanes
Circular Exit Radius
Pedestrian Facility on Circular Intersection
Crosswalk Location on Circular Intersection
Circular Intersection Island Width

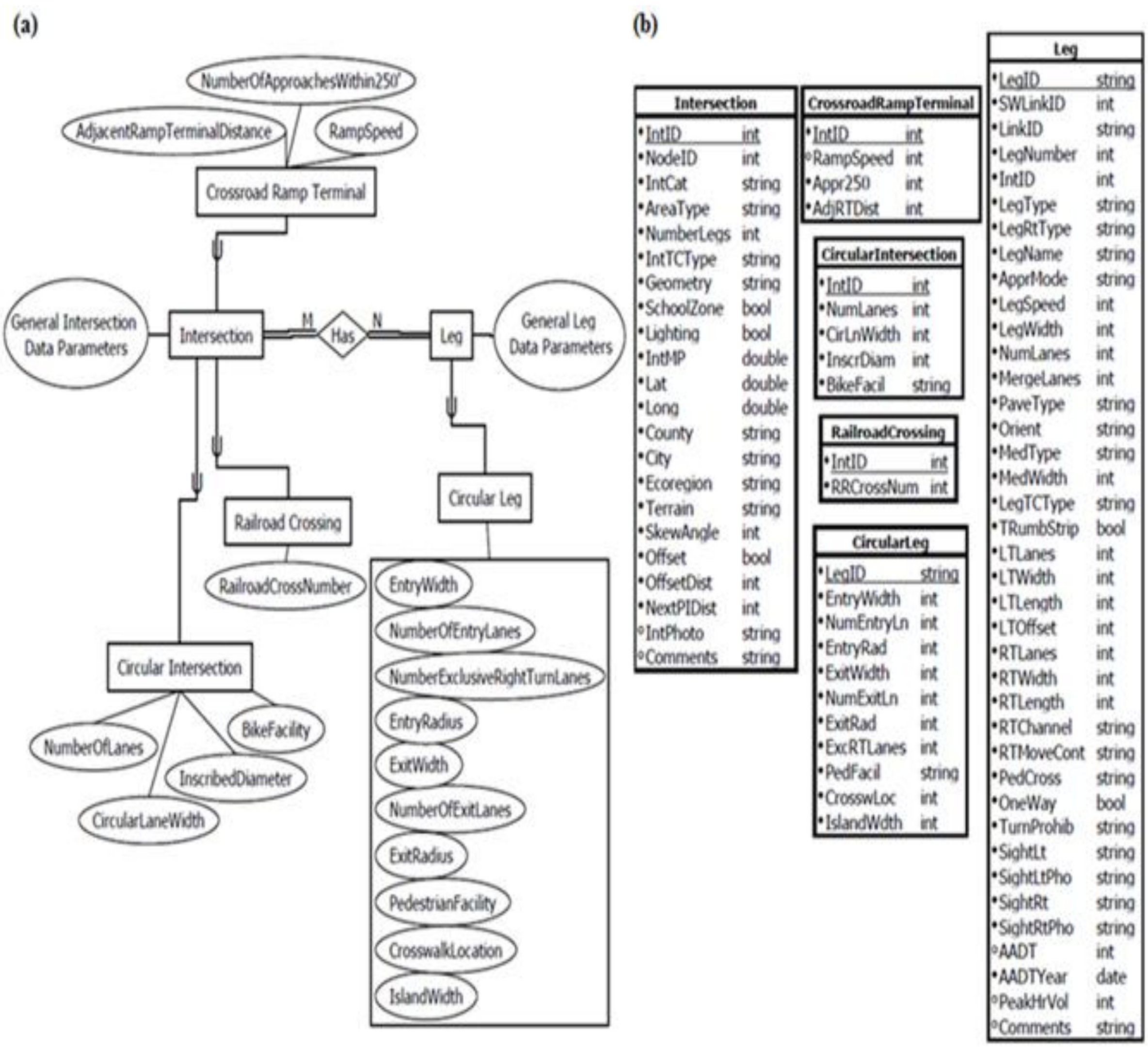

FIGURE 1 (a) Database model illustrating intersection and leg attribute connections. (b) Table schema highlighting primary keys and attribute details.

The GIS-Based Intersection Data Inventory Web Portal was designed in order to view both Google Maps and an ESRI basemap with nodes and links. Figures 2 through 5 show a series of screenshots of the web portal. Fig. 2 shows the basic layout of the web portal, showing the Google Maps basemap on the left and the ESRI basemap on the right [10, 11]. The two basemaps stay in sync during zooming in and out, reducing the time spent searching for an intersection in both views. The portal has a downward pointing arrow in the top right hand corner to download the cataloged data to a shapefile for use in desktop. The portal also has searching capabilities. A search can be conducted on Node or LinkIDs in a certain county or city. The portal highlights and automatically zooms to that intersection in both maps.

Collection of intersection and leg level data through the portal is aided by color coding GIS elements (intersection and roadway legs) with data entry screens. Fig. 3 shows an intersection and data entry screen where general intersection level data is catalogued. The portal is color coded to help determine which intersection element is being collected. For example, the yellow background of the data entry screen matches the yellow color of the intersection node. Fig. 3 also shows drawing and measuring tools that can be used to collect parameters like skew angle and lane widths. Lastly, Fig. 4 shows leg one in Google Street View, for data collection of parameters such as limited sight distance and leg traffic control type. Furthermore, the table in Fig. 4 illustrates categorical parameters with set options as previously mentioned in Table 1. In the portal, the options are supplied in drop down menus. For example, Fig. 4 shows the drop down menu for median type.

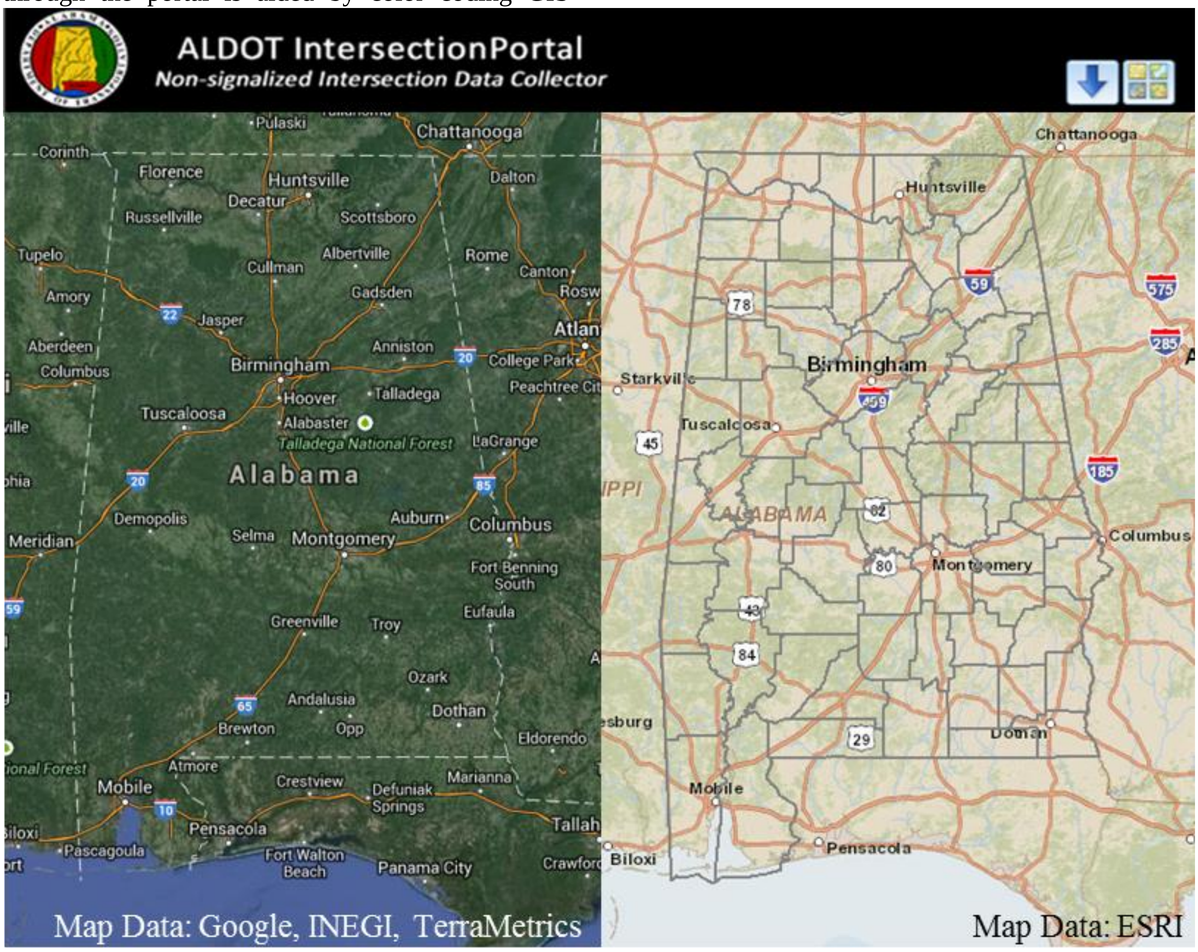

FIGURE 2 ALDOT Intersection Data Inventory Web Portal Data Collection Tool: a dual view GIS tool with a "download to shapefile" button (upper right downward pointing arrow) and searching capabilities using Google Maps and ESRI basemap with the Alabama linear referencing methods *(10, 11).*

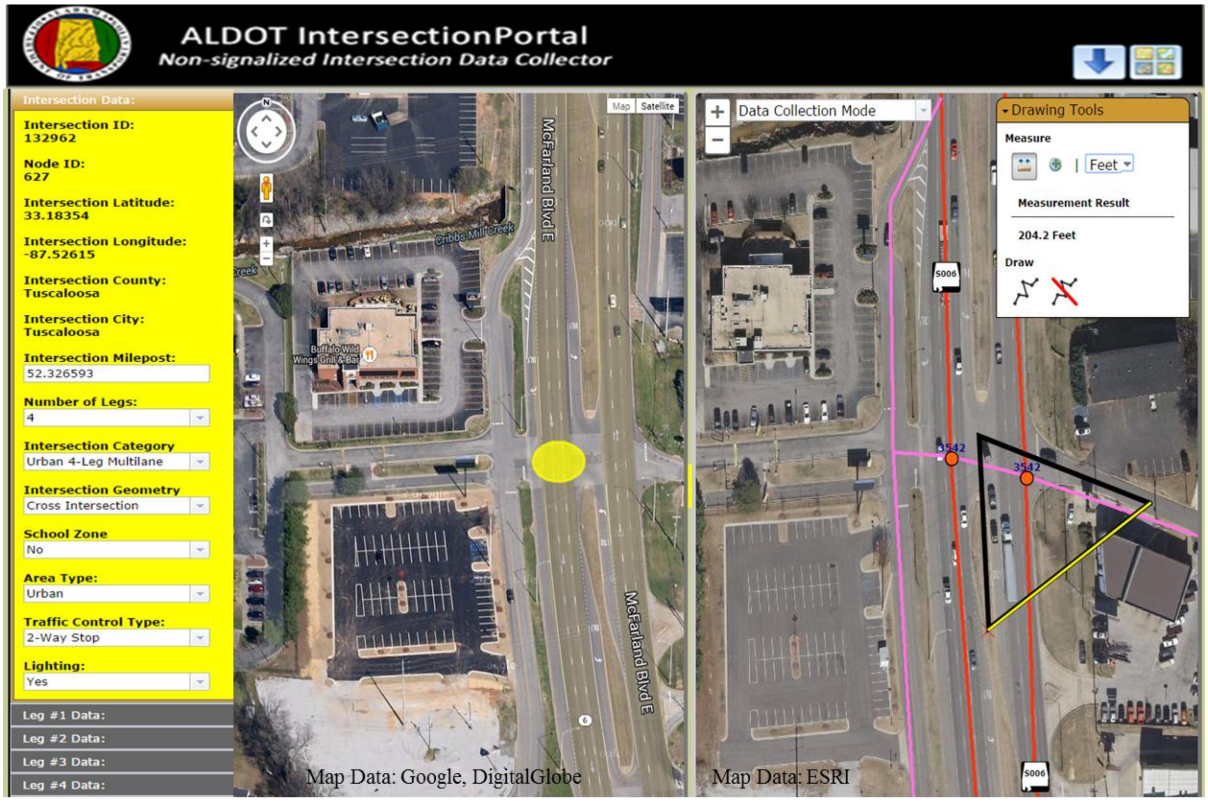

FIGURE 3 Web Portal in data collection mode, using Web Portal drawing and measuring tools to collect parameters such as median width, leg widths, and turn lane lengths (*10, 11*).

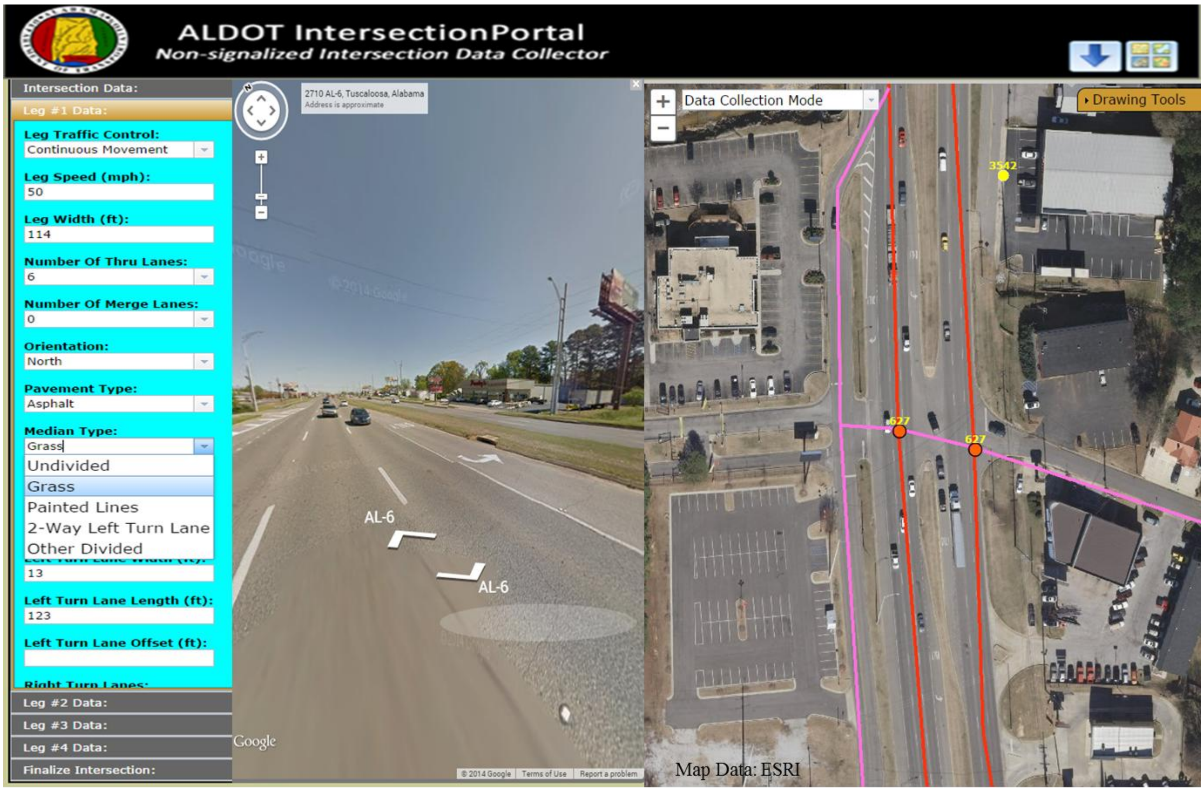

FIGURE 4 Web Portal in data collection mode showing parameter drop down menu example in the data entry screen and Google Street View example *(10, 11)*.

2.4 COLLECTING AND RECORDING INTERSECTION DATA

The parameters required for the data inventory, as noted in Table 1, were either obtained from: existing data in the associated GIS linear referencing method, assigned by a visual observation or count, calculated by a simple measurement, or investigated in Google Street View. For Alabama, examples of existing data in the GIS node-link linear referencing method maintained by ALDOT included intersection milepost, county, and city. Examples of parameters requiring an assignment by visual observation or count included the number of legs, median type, and number of left and right turn lanes. Skew angle and turn lane widths are examples of data parameters requiring a measurement. Lastly, Google Street View was utilized for parameters such as speed limits, leg traffic control type, and limited sight distance. Depending on available datasets for other states, some of these parameters may exist; however the four data collection methods (existing, assigned, calculated, or observed) can be expected regardless.

2.5 CALCULATED AND OBSERVED PARAMETER DATA COLLECTION DETAILS

Calculated and observed intersection parameters require a level of interpretation by the data entry tool user. Procedures for consistently collecting these parameters were developed and field measurements were taken to verify the consistency of the approach. Examples of these parameters are skew angle, intersection offset, leg, lane, and median width, and sight distance.

The skew angle was measured by drawing lines of a representative length along each intersection leg on the aerial photo in the web portal. The legs of the triangle formed are measured and analyzed using the law of cosines. The difference between 90˚ and the angle calculated is recorded in the database. This procedure is graphically shown on the right-hand side of Fig. 3.

An offset intersection is an intersection where the opposing centerlines of the road legs do not line up. The offset distance was determined by drawing centerlines of each minor road leg. The measuring tool was used to measure the offset distance. As per typical design, intersections were only considered offset if the offset distance was greater than six feet. The measuring tool was also used to measure the distance to the next public intersection, which includes parking lots, gas stations, schools, and other public driveways.

Use of the measuring tool was also employed to collect intersection leg, lane, and median widths. These widths were measured from edge line to edge line of each element. By measuring leg widths and turn lane widths along with collecting the number of lanes on each leg, a proxy for individual lane width was obtained.

Google Street View was also used to collect data parameters for the intersection inventory database. By “driving” down the street in Google Street View, the major and minor road speed limits were identified from street signs and recorded. The database and web portal are designed to handle speed limits that are different on opposing legs. Google Street View was also used to determine if any leg of an intersection had limited sight distance to execute a left or right turn. The sight distance parameter flags a turn direction as having a limited sight view if rolling grades or hills or large objects interfere with driving decisions. Although limited sight distance is determined by observations made by the tool users, the results were shown to be consistent among many users.

For crossroad ramp terminals, the measuring tool was used to determine the distance to the adjacent ramp terminal, as well as buffer 250 feet outside the interchange on the minor crossroad leg. The number of public intersection approaches within the 250 foot buffer was counted and recorded.

In addition to the set intersection parameters, a free form comment field is available in the tool. The comment field allows a user to explain intersection or leg circumstances that are worth noting. Some common comments seen in this study were: parking spaces on the leg, and specifying if the leg is on a downgrade or upgrade. Parking spaces on a leg is important to note because the width of the parking spaces will be recorded in the leg width, however the parking space width should not be considered when using the leg width as a proxy for individual lane widths.

2.6 WEB PORTAL DATA COLLECTION ACCURACY

Field measurements were performed at three intersections to determine the accuracy of collecting data from online sources such as Google Maps, Google Street View, and ESRI [9, 10]. The three intersections included both a rural and urban 3-Leg 2-Lane intersection, as well as a rural 4-Leg 2-Lane intersection. Multi-lane intersections were omitted from the study for safety reasons. A total of 13 measurements were collected, including ten leg widths and three skew angles.

Of the ten leg width measurements, the greatest difference between the field measurements and web portal measurements was three feet. This discrepancy occurred at an intersection that has a painted line median ending as the leg width increased approaching the intersection. The discrepancy can be attributed to the field and online measurements being taken at different distances away from the intersection. It should be noted that this unique situation was noted by the online data collection personnel and stored in the system as a comment.

All three of the intersection skew angles measured in the field fell in the same skew angle range category as the web portal. Therefore, small skew angle differences between field measurements and online measurements did not affect the results.

In summary, the online measuring tool used in the GIS-Based Intersection Data Inventory Web Portal has deviations from field measurements, but online length measurements are 90% reliable within two feet. Online categorical angle measurements matched field angle measurements.

III. RESULTS

A total of 30 non-signalized intersections of nine intersection types have been collected, totaling 270 intersections, covering 42 counties and 90 municipalities in the state of Alabama. Currently, data for one intersection can be completely collected and catalogued in approximately 10 minutes. There are approximately 28,800 signalized and non-signalized intersections along state routes in Alabama. At present, the exact percentage of non-signalized intersections is unknown. With an estimate of 90% of the 28,800 intersections being non-signalized, statewide implementation would require 4300 hours. Because statewide implementation would require a large resource commitment, a systematic approach to add intersections to the database is underway. Starting with 100 non-signalized intersections that have the highest crash frequency, the GIS-Based Intersection Data Inventory Web Portal will be continually used to add additional intersections to the database. The logic used to develop the web portal could be tailored and expanded upon to create web portals for data collection for other inventory types, such as signalized intersections.

The intersection database can be used to produce summary statistics of the collected intersections, which can be used to estimate statewide characteristics. Characteristics of intersections across a state would give state DOTs insight for decision making for safety improvements. In future work, the intersection data inventory will be used to draw correlations to existing crash data to potentially identify geometric and conditional intersection characteristics that may be contributing to more crashes. This project performed preliminary statistical analysis; however, the work done only looked at intersection characteristics and crash frequency individually, so interactions that exist in the field are overlooked. Any findings were not conclusive. Future work will require additional intersections for statistical representation, and in-depth multivariate analysis.

3.1 NON-SIGNALIZED INTERSECTION DATA INVENTORY STATISTICS

A variety of statistics can be generated from the inventory database. For instance, of the 270 intersections investigated, 17.4% of the intersections have limited sight distance on at least one of the intersection legs, 21.5% of the intersections are offset, and only 12.2% of the intersections have a pedestrian crossing control on any of the intersection legs. Fig. 5 shows two pie charts illustrating data inventory statistics for skew angles and median types. Fig. 5 (a) displays the percentage of intersections based on intersection skew angle. Of the intersections investigated, 17.0% have a skew angle greater than 30˚, which according to the American Association of State Highway and Transportation Officials standards, is not ideal for a safe intersection design. Fig. 5 (b) shows the percentages of medians types on intersection legs investigated in this study. A total of 955 intersection legs are represented in Fig. 5 (b), of which 76.4% of the legs are undivided. Correlating intersection parameters such as skew angle and median type with crash frequency will allow safety engineers the ability to determine if these parameters pose a threat to intersection safety.

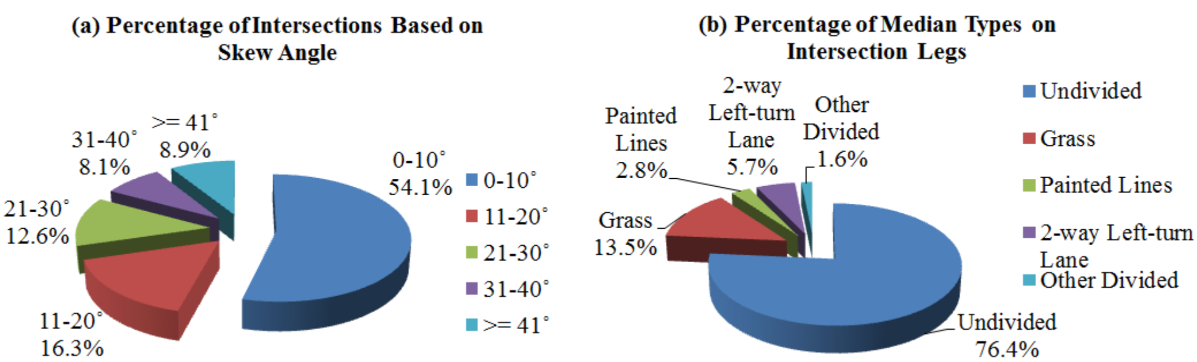

FIGURE 5 (a) Pie chart showing the percentage of intersections categorized based on skew angle. (b) Pie chart showing the percentage of median types on non-signalized intersection legs.

3.2 PRELIMINARY CRASH FREQUENCY CORRELATIONS

A crash dataset from the Critical Analysis Reporting Environment (CARE) maintained by the Center for Advanced Public Safety (CAPS) at the University of Alabama was utilized for preliminary crash frequency correlations with data catalogued in the non-signalized intersections along state routes data inventory. A dataset covering the past 5 years was used. From 2009-2013 along mileposted routes (state, federal, and interstate), there were 286,475 crashes in Alabama. Of those, 60.2% occurred at intersections or were intersection related. The high number of intersection related crashes in Alabama specifically reiterates the need to understand intersection geometrics and conditions that are potentially contributing to crashes.

A total of 2127 crash events from the dataset were located within a 600 foot buffer around the 270 catalogued intersections in the intersection data inventory for Alabama. Using a spatial join in ArcMap for GIS, a crash count at each intersection was determined. The number of crashes occurring at each intersection was normalized by annual average daily traffic (AADT), to produce the number of crashes in 5 years per 1,000,000 vehicles passing through each intersection.

Single variable analysis was performed to investigate various intersection parameter influences on crash frequency. As seen in Fig. 6, when examining skew angle and the number of normalized crashes, the scatter plot appears to show that as skew angle goes up, the rate of crash frequency goes down. The indirect relationship that the preliminary analysis shows is inconsistent with typical intersection design and the AASHTO Green Book, which recommends a 90 degree crossroad intersection for safety. Using single variable analysis fails to incorporate any interactions from other data parameters associated with the intersection and its corresponding legs.

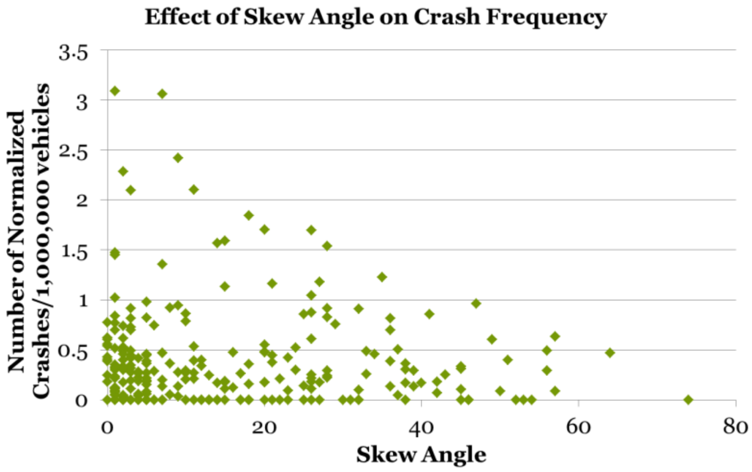

FIGURE 6 Scatter plot showing the apparent indirect relationship between intersection skew angle and number of normalized crashes per 1,000,000 vehicles traveling through the intersection by single variable analysis.

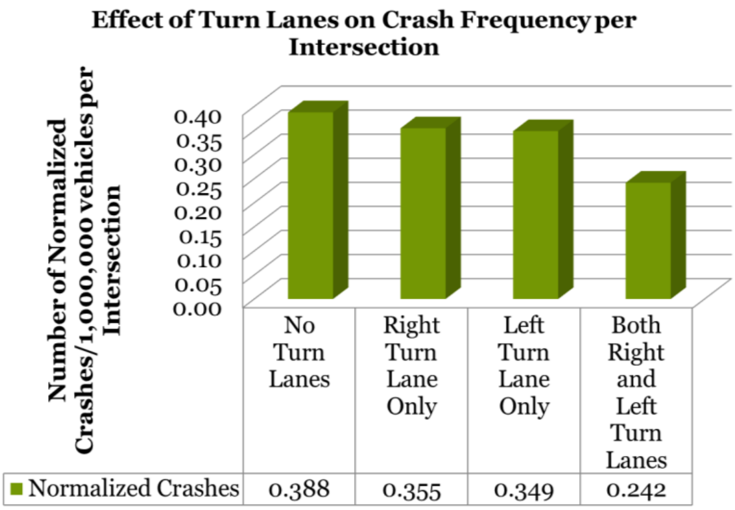

FIGURE 7 Bar chart showing the apparent average crash rate reductions when turn lanes are incorporated in the intersection design by single variable analysis.

A single variable comparison exemplifies the possible findings a more extensive statistical analysis could produce. As shown in Fig.7, when looking at the average normalized crash frequencies at intersections with no turn lanes, either right or left turn lanes, or both right and left turn lanes, the findings appear to show that when there is either a right turn lane or a left turn lane, the crash frequency decreased from no turn lanes at nearly the same rate.

Conclusions such as the bar chart in Fig. 7 would aid ALDOT, or other state agencies doing similar work, in funding allocations and optimizing treatment options at non-signalized intersections along state routes. It should be reiterated however that this preliminary statistical analysis did not account for other interactions and factors at the intersections. In other words, the findings are not conclusive, but do show the possibilities of analysis that the data inventory can catalyze.

IV. CONCLUSIONS

Using GIS-based data in conjunction with existing aerial and street view imagery from Google Maps and ESRI, an intersection data inventory was produced. Spatial and conditional intersection data was successfully catalogued into a GIS-Based Intersection Data Inventory Web Portal. The web portal was designed as an all-in-one tool, successfully allowing for a time- and cost-effective data collection and database population technique. This project produced an efficient approach to collect and organize intersection data in an intersection data inventory. By taking data collection out of the field and onto the web, the risk involved in field data collections is completely eradicated and the cost is greatly reduced. A field measurement study confirmed that the web-based data collection is accurate. The web-based intersection inventory tool can be customized with any state's spatial roadway dataset, making the tool a potential solution for all DOTs interested in intersection data collection.

The statistically significant data stored in the portal provides ALDOT with a valuable intersection data inventory with a wide range of MIRE compliant data parameters that can be used for safety analysis, potentially associating any geometric or conditional intersection factors that may be contributing to crashes. Preliminary single variable analysis was performed, showing that there are relationships between intersection characteristics and crash frequency. Future work will investigate statewide implementation as well as multivariate analysis for correlating intersection parameters with crash data to develop safety performance functions and crash modification factors.

V. ACKNOWLEDGEMENTS

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