Automated Intersection Safety Evaluation using Linear Referencing System Methods

Fan Yang, Ph.D. Candidate
Department of Civil and Environmental Engineering,
University of Wisconsin-Madison,
Madison, WI 53706
Phone: (608)609-3386
Email: fyang29@wisc.edu

Steven T. Parker, Ph.D.
IT Program Manager, TOPS Lab
Department of Civil and Environmental Engineering,
University of Wisconsin-Madison
Madison, WI 53706
PH: (608) 262-2591; FAX: (608) 262-5199
Email: sparker@engr.wisc.edu

Wei Wang, Ph.D., Professor
School of Transportation, Southeast University
No.2 Si Pai Lou, Nanjing 210096, China
Phone：86-25-83795645
Email: wangwei@seu.edu.cn

Bin Ran, Ph.D., Professor
Department of Civil & Environmental Engineering,
University of Wisconsin-Madison,
Madison, WI 53706
Phone: (608)262-0052 Fax: (608) 262-5199
Email: bran@wisc.edu
and
School of Transportation, Southeast University
No.2 Si Pai Lou, Nanjing 210096, China

David A. Noyce, Ph.D., P.E., Professor
Director, TOPS Lab
Department of Civil and Environmental Engineering
University of Wisconsin-Madison
Madison, WI 53706
Telephone: (608) 265-1882, Fax: (608) 262-5199
Email: noyce@engr.wisc.edu

Submitted for Presentation and Publication
to the 92nd Transportation Research Board Meeting
Submission Date: Aug. 1st, 2012

4393 Words + 6 Tables + 5 Figures = 7143 Words

ABSTRACT

Effective evaluation of intersection safety requires the ability to develop meaningful benchmarks to help assess the relative safety risk for a given intersection. One approach is to develop a database of average crash rates over intersections with similar features such as functional class, intersection geometry, and, signalization in order to provide a basis for comparison when evaluating specific intersections for potential safety issues. However development and maintenance of such a database requires significant manual effort. This paper introduces an automated intersection safety data collection method, including an algorithm to update intersection crash rates and geometric features from existing sources. The automation algorithm involves the integration of four separate Wisconsin Department of Transportation (WisDOT) databases through association with a common Linear Referencing System (LRS). The result of the application of the automation algorithms suggest the methodology is feasible and can improve the quality of intersection safety data collection. Although the methodology introduced is specific to Wisconsin data, the results can also be applied to other state DOTs that manage traffic data with respect to an LRS.

KEYWORDS: Linear Referencing System, Intersection Safety, Data Management

INTRODUCTION

Intersection safety is a concern for traffic engineers worldwide and a significantly large proportion of crashes occur at intersections because turning and crossing activities have the potential for conflicts. According to the annual report from National Highway Traffic Safety Administration (NHTSA), about 2,210,000 crashes occurred at intersections in the United States in 2009, which accounts for 40 percent of the total 5,505,000 crashes that occurred across the country. Among these, 6,770 were fatal crashes and 699,000 crashes involved injuries*(6)*.

Federal and State DOTS have expended considerable effort to prevent crashes at intersections. Common procedures for intersection safety management include network screening for sites with potential for safety improvements, diagnosing safety problems at specific sites, countermeasure selection, and before-and-after analysis of the countermeasures. Identifying sites deserving safety improvement is important since resources would otherwise be wasted on unnecessary treatments. Various types of intersection safety evaluation measures have been used by different state DOTs including crash frequency, crash rates, crash severity and Safety Performance Functions (SPFs). Comprehensive analysis of intersection safety require crash data, traffic volume data and other intersection characteristics (area type, number of legs, traffic control devices, etc.) as the input, since most of the evaluation models are based on the relation between road geometry and accident occurrence. Collecting high quality data requires huge financial resource and human efforts, while updating the crash data annually makes these procedures even more time consuming. Most state DOTs*(4, 5)* rely on sampling techniques to determine the statewide standard safety measures, however the sampling process may induce bias and errors in the safety evaluation. Therefore, it's critical to find an automatic way to update the crash information for intersections and collect the intersection related features.

The objective of this research was to develop a method to automatically calculate intersection crash rates for Wisconsin DOT, which can also apply to other DOTs that maintain crash, volume, and roadway attribute data with respect to a Linear Referencing System (LRS). This automation method can also be extended to automatically calculate safety evaluation measures other than crash rates. This research also focuses on developing a method to fully leverage LRS roadway network information to collect intersection geometric data such as number of approaches and area type based on existing datasets.

BACKGROUND

Theory of the Linear Reference System

A Linear Reference System (LRS) is the method of storing geographic locations by using relative positions along a linear element, for example a milepost along a roadway. LRS is widely used in the field of transportation data management. The Highway Performance Monitoring System (HPMS) now requires state DOTs to use an LRS network for spatial referencing purposes *(9)*. The LRS will be integrated into the National Highway Planning Network (NHPN), which serves as a national framework for information exchange and will be provided to the U.S. Geological Survey, the Bureau of Census, the Intelligent Transportation System (ITS) community, and the Bureau of Transportation Statistics (BTS) to represent the higher order highways *(2)*.

The primary advantages of an LRS over coordinate based referencing include: 1) LRS locations are associated with an underlying link/node network which directly relates crashes to roadways and intersections, 2) LRS systems provide a framework for data integration by supporting multiple referencing methods with respect to a common network, and 3) LRS is able to visually map small features such as the crash statistics, pavement management and roadway geometry, so the data can be more readily analyzed. In addition, LRS locations are more easily updated; if a segment of a route is changed only those referencing points on the changed segment need to be updated.

For purposes of intersection safety evaluation, the LRS facilitates the process to find intersection-related crashes. The positions of crashes in Wisconsin are reported as distances to an intersection along a roadway. Whether a crash is intersection-related can be determined by the distance. If traditional geo-referencing system is used, additional process to calculate the distance between crashes and intersections by the geo-coordinates will be needed, which requires more computing time.

The Wisconsin Department of Transportation (WisDOT) developed and currently maintains two geographic information systems based on two separate linear referencing systems (LRSs). The State Trunk Network (STN) covers all state, U.S., and interstate highways, while the Wisconsin Information System for Local Roads (WISLR) covers county highway and local roads. Both LRS's include core roadway centerline networks and roadway attribute information such as functional class and number of lanes. Although the STN and WISLR are distinct systems, the WISLR network includes state trunk highway centerlines and, as such, is the most complete roadway network representation of the two.

Intersection Safety Evaluation Tool (ISET)

The Intersection Safety Evaluation Tool (ISET) *(8)* is a web application supported by the Traffic Operations and Safety (TOPS) Laboratory to assist WisDOT regional offices in identifying high risk intersections with respect to a variety of safety thresholds and analysis levels.

The user interface of ISET is shown in Figure 1. Users can query and compare the state average crash rates for any combinations of intersection features through the ISET tool. ISET also provides the sample size and standard deviation for each query to give engineers a statistical perspective in evaluating the average crash rate. The result is highlighted in red when the sample size is fewer than 30 to alert the users. The information including the location and Google Map link for each sample behind the statistics is also accessible by the users. ISET provides safety engineers quantitative means of comparing intersection and making decision of improvements. However, one must be cautious on using this as the only metric, since comparing one intersection with the state average may be meaningless in terms of its own safety needs.

ISET classifies intersections by seven different features, which are listed as:

- Area Type: Rural, Urban
- Number of Legs: 3 Legs, 4 Legs
- Number of Lanes: 1 Lane, 2 Lanes, 3 Lanes
- Left Turn Lane: Left Turn Lane Exists, No Left Turn Lane
- Traffic Control: Signalized, Two Way Stop Control, All Way Stop Control, Interchange
- Median Type: Divided, Undivided
- Volume Group: <5000, 5000~10000, 10000~20000, >20000

The original ISET database included intersection crash rates from 2001-2003. It was updated in 2010 to incorporate 2003-2007 crash data and traffic counts*(8)*. In both cases, the database was populated through a manual procedure of locating crashes to intersections and compiling volume and attribute information for those intersections. This database contains crash rates for 2000 intersections in Wisconsin covering all types of typical intersections with an unbiased sampling method. This paper uses the 2003-2007 ISET data as the ground truth data to verify the correctness of the result of the automation procedure.

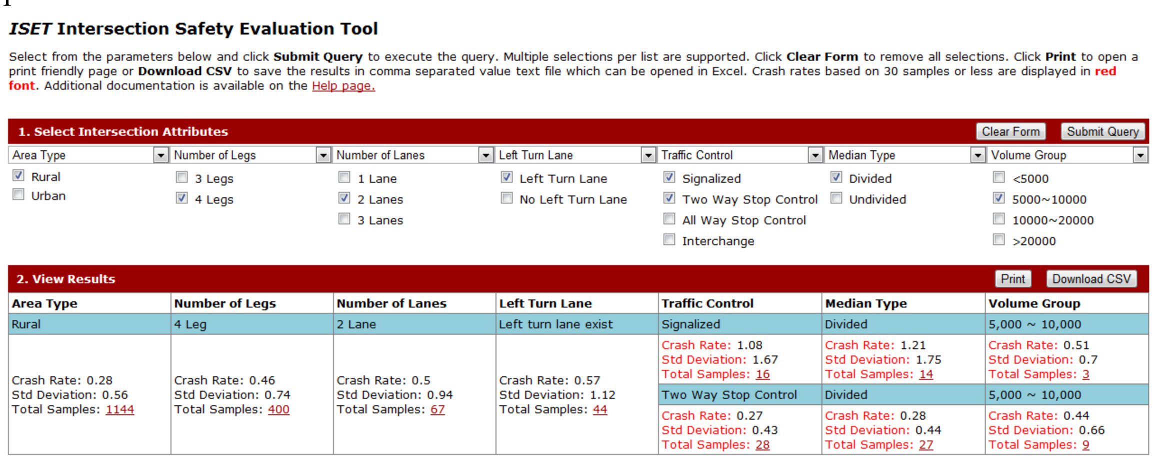


FIGURE 1 ISET User Interface

DATA SOURCES

This paper used four primary data sources, including: the WisDOT Crash Database of police reported crashes, the Wisconsin Information System for Local Roads (WISLR), the WISLR Crash Geographic Information Systems (GIS) database, and the WisDOT Traffic Data System (TRADAS) database. This section introduces the basic information of these databases. Detailed information about specific tables and fields relevant to the automation methodology will be described in subsequent sections.

Wisconsin Information System for Local Roads (WISLR)

The Wisconsin Information System for Local Roads (WISLR) is an internet-accessible system of road inventory data developed and maintained by WisDOT. TOPS Lab has the Oracle tables and ESRI shapefiles of the core network and roadway attribute data.

WISLR adopts the LRS, the intersections and terminals are represented as nodes and the roadways segments are identified by links. Figure 2 displays a portion of the City of Madison local roads map clipped from the WISLR shapefile. The roadway attributes data used in this paper are maintained in three tables: the On-At table, the Roadway Link table and the Over Layer table. Every intersection are stored as a reference point in the On-At table, and the roadway segment are identified by the start reference point and the end reference point in the Roadway Link table. The Over Layer table collects detailed information including the median, road category, access control, urban location, federal urban area, and the functional classification.

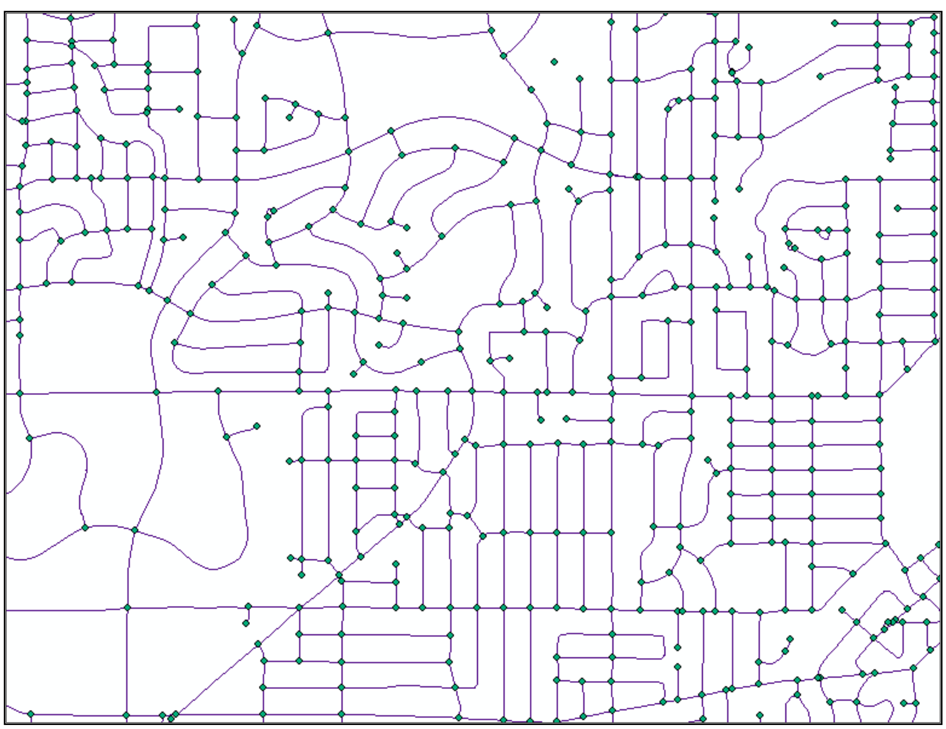


FIGURE 2 WISLR Links and Nodes

Wisconsin Crash Database

The TOPS Lab WisTransPortal system*(8)* contains a complete database of Wisconsin MV4000 Traffic Accident Extract data from 1994 through the current year. This database contains information on all police reported crashes in Wisconsin, including the location of each crash, vehicles involved, and general crash attributes. This database is updated on a monthly basis through coordination with WisDOT Division of Motor Vehicles. The TOPS Lab maintains this database for research purposes and as a service to WisDOT.

Crash information is generally reported by a dispatched police officer via the Wisconsin MV4000 police form and is eventually archived in the WisDOT DMV crash database. Crash locations are reported in terms of relative offset from an intersection, based on on- and at-street name information, which identifies the intersection, and direction and distance information, which identifies the offset. The police officer also reports many other important pieces of information such as the area type, the severity, the roadway condition, the weather, the reason for the crash, and the driver's information, which can be utilized for a variety of comprehensive safety studies,

WISLR Crash Geographic Information Systems (GIS) database

The WISLR Crash GIS database is the integration of the two separate databases mentioned above - the WISLR and the Wisconsin Crash Database. This database is generated through an automated process that locates crash records to the WISLR network in terms of roadway link and link-offset values. The WISLR Crash GIS database provides a pinpoint map of all the intersection and segment crashes that occurred on local roads in Wisconsin, along with the complete crash information associated with each mapped crash. Preliminary quality evaluation on six years of statewide crash data indicates that 93% of all crashes are located to the WISLR network with 98% accuracy on the state trunk highway and 96% accuracy on local roads*(10)*. The integration of WISLR and crash reports provides invaluable access to more comprehensive safety analysis.

WisDOT TRAffic DAta System (TRADAS)

TRADAS is a software system for processing, editing, summarizing, storing and reporting a wide range of traffic data. Wisconsin was the first state in the United States to implement TRADAS in 1993. TRADAS processes and validates all continuous and short duration volume, speed, classification, and Weight in Motion (WIM) traffic data. The data files are processed through a series of quality checks based on AASHTO, ASTM, FHWA and user defined standards. Principal Arterials, Highway Performance Monitoring System (HPMS) Sections, National Highway System (NHS), and minor arterials with an Annual Average Daily Traffic (AADT) greater than 5,000 have counts taken on a three year cycle. Minor arterials with an AADT less than 5,000 and collectors with an AADT greater than 5,000 are on a six-year cycle and low volume collectors have counts taken on a ten-year cycle*(7)*. All TRADAS count sites are located to WISLR links and are available as an ESRI point shapefile.

AUTOMATED INTERSECTION SAFETY DATA COLLECTION METHODOLOGY

This section introduces the methodology to automatically collect intersection safety data. The crash information updating algorithm is described first, followed by a description of the intersection feature collecting algorithm. The important tables and fields of the tables are also described in detail.

Crash Updating Algorithm

The objective of the crash updating algorithm is to automatically calculate and update crash rates for each intersection when new crash information and traffic volume data is available. The algorithm follows the steps below:

Step 1: identify intersections

The first step in this process is to develop a database of all public roadway intersections in Wisconsin. The database only includes public roads because WISLR only contains public owned roadways. Consequently, intersections of a public road with a private road are not included in the database. In the WISLR database, intersections are identified as nodes in the On-At table. The fields used in the algorithm are listed in Table 1.

TABLE 1 Fields in On-At Table

Field	Description
ON_AT_ID	The primary key of the table
LCM_STUS_TYCD	The status of the record. Values include: C="Current" H="Historic"
REF_SITE_ID	Each node is associated with one REF_SITE_ID
ON_AT_TYCD	The function of the node. A node may have multiple functions. Values include: I="Intersection", N="Name Change", M="Muni change", T="Termini", X="Invalid", L="Loop Termini"

Each node is identified with a unique Reference-Site-ID (REF_SITE_ID). The intersections can be identified in the On-At table as REF_SITE_IDs associated with On-At type (ON_AT_TYCD) “Intersection”.

Step 2: assign crashes to these intersections.

The next step is to assign crashes to each intersection. First, the roadway segments connected to the intersection are be identified, and then the crashes located to those roadway segments are screened based on the distance to the intersection, as described below.

In WISLR, the roadway segments are represented as links, the links are stored in the Roadway Link table, which are described in Table 2: The two directions of a roadway segment are stored as two separate links, identified by the start reference point (REF_SITE_FROM_ID) and the end reference point (REF_SITE_TO_ID).

TABLE 2 Fields in Roadway Link Table

Field	Description
RDWY_LINK_ID	The primary key of the table
LCM_STUS_TYCD	The status of the record. Values include: C="Current" H="Historic"
REF_SITE_FROM_ID	The start reference point of a link
REF_SITE_TO_ID	The end reference point of a link
LCM_FROM_TO_DIS	The length of a roadway link

In the Crash GIS Database, each crash record is associated with a WISLR_LINK, by which the Crash GIS table can be connected with the roadway link table. The locations of crashes are represented as a distance along the roadway link.

For each intersection, the crash rate updating program will check both links in each direction for each intersection approach. Although whether a crash is intersection or segment related is given in the Accident-Location field ('I' representing intersection crashes and 'N' representing non-intersection, i.e. segment crashes, in this field) in the crash report, the result is considered unreliable due to conflicting or insufficient information. Based on previous study*(1)*, crashes happened within 0.02 mile (106 feet) scope of an intersection is determined as an intersection crash in this paper. It should be noted that the threshold might be different in other DOTs, for example, the Kentucky DOT uses 0.02 miles radius for urban intersections and 0.05 miles radius for rural intersections*(3)*.

Figure 3 illustrates the intersection of US-10 and Falcon Road in Marshfield of Wisconsin clipped from the WISLR Crash Map*(8)*. Each crash is marked as a dot in the Crash Map and the color indicates the severity of the crash. Table 3 shows the crash records retrieved by the algorithm. As shown in Figure 3, 4 crashes are near to the intersection, one incapacitating crash (yellow), one non-incapacitating crash (orange), and two property-damage-only crashes (blue). Table 3 suggests 4 crash records are within the 106 feet (0.02 mile) scope of the intersection. The identical result indicates the algorithm is correct to collect the intersection-related crashes.

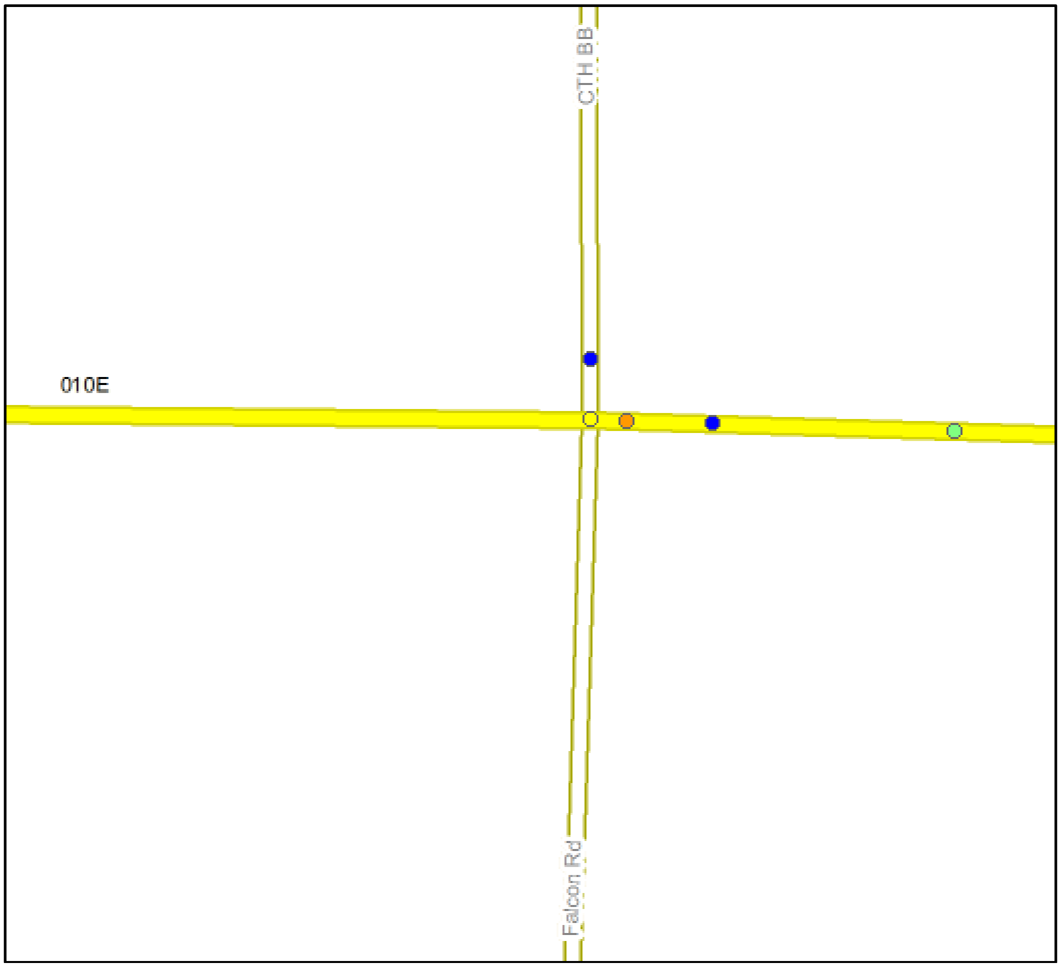


FIGURE 3 A Sample Intersection in WISLR Crash Map

TABLE 3 Crash Records for a Sample Intersection

REF_SITE_ID	ACCDNMBR	ACCDDATE	DISTANCE
4468	071011786	31-Oct-2007 00:00:00	0
4468	080705798	30-Jul-2008 00:00:00	0
4468	090106812	27-Jan-2009 00:00:00	0
4468	080102989	18-Jan-2008 00:00:00	0
4468	061208722	22-Dec-2006 00:00:00	158.387
4468	061208826	22-Dec-2006 00:00:00	158.387
4468	080102979	23-Jan-2008 00:00:00	264
4468	070303854	06-Mar-2007 00:00:00	527.959
4468	071203100	21-Dec-2007 00:00:00	1583.877
4468	081102352	06-Nov-2008 00:00:00	2640
4468	081000261	02-Oct-2008 00:00:00	5227

Step 3: determine entering traffic volume

Traffic volumes for each approach are needed in order to calculate the total entering volume at each intersection. The most up-to-date average Annual Daily Traffic (AADT) data for most links are available from the TRADAS database and associated WISLR GIS files. The volume for each intersection is defined as the maximum volume of the links connected to the intersection. It is important to note that TRADAS volume data is not available for every link in WISLR. The WISLR contains 950,075 roadway links, among which only 76,249 (8%) links are connected to TRADAS. WisDOT used other sources to update the volumes for other links, so 729,481 (76.8%) links have volume data. In particular, due to data collection limitations, the average crash rates in ISET generally use intersection AADT taken from the major road entering volume at that intersection.

Step 4: calculate a crash rate for each intersection.

An intersection crash rate is defined as the average number of crashes per year divided by the average yearly traffic volume at that intersection. The intersection crash rate is calculated in per million vehicles, the equation is defined as:

$$\text{crash rate} = \frac{\#\ of\ crashes\ per\ year}{Annual\ Average\ Daily\ Traffic\ \times 365 \div 1000000}$$

Intersection Geometric Features Collection

This study focused on collecting two of the six ISET intersection features directly from WISLR geometry and attributes, namely the number of approaches and the area type of intersections.

1. Number of Approaches

The ISET intersection types include three-leg (T- intersections) and four-leg (cross- intersections) with some five-way intersections. The number of legs for each intersection can be derived by counting the number of WISLR links connected to an intersection reference site. Considering an intersection approach may be a one-way roadway segment, the number of approaches is determined by the maximum of the from-links and the to-links.

2. Area type

Two methods can be used to collect the area type (rural vs. urban) information for an intersection. Two alternate methods are investigated in this study. The first method is to use the area type reported in the HWYCLASS field of each crash record in the Wisconsin Crash Database; the second method is to query the WISLR database and use the Functional Classification type of the major road to determine the area type of the intersection.

RESULTS AND ANALYSIS

Verification Method

The hand generated 2003-07 ISET data which includes 2000 samples were used as the ground truth data to verify the automation methodology. The intersection geometric features in the 2003-07 ISET dataset were collected by using Google Maps. In particular, the WISLR LRS was not used to locate intersection in the original ISET data, therefore a process was implemented to map the ISET intersections to WISLR through spatial join using ArcGIS. The locations of the intersections in ISET are recorded as addresses. Google API is used to convert the addresses to geo-coordinates. However, the quality of the conversion is not fully guaranteed. 1888 out of the 2000 intersections are mapped to WISLR within 50 meters radius of a node (reference site), among which 170 reference sites are historic nodes that are no longer used. In total, 85.9% of the 2000 ISET intersections (1718 samples) are selected as a basis for verifying the data collected by the automation program including the number of crashes, the number of approaches, and the area type.

Crashes Updating Result Analysis

The number of crashes cannot be compared directly since the ISET data are from 2003 - 2007 while the Crash GIS data are in the year range 2005-2009. However, the general crash distribution should not change significantly in two years. Figure 4 shows the crash distributions by the two data sets. The horizontal axis represents the crash intervals and the vertical axis shows the number of intersections falls in the interval. Most of the intersections have less than 10 crashes.

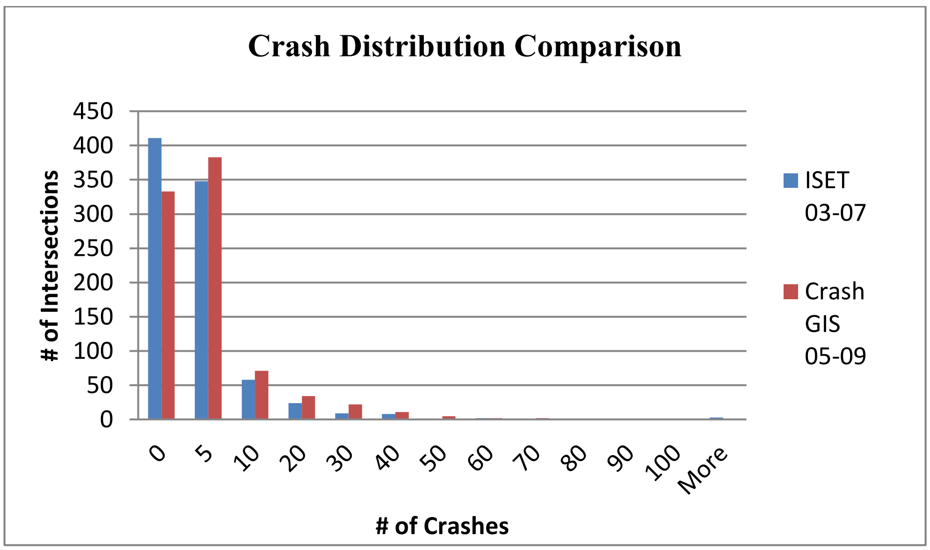


FIGURE 4 Crash Distribution Comparisons

From Figure 4 we can see the crash distributions for the two datasets are very similar, which indicate the automation process is reliable.

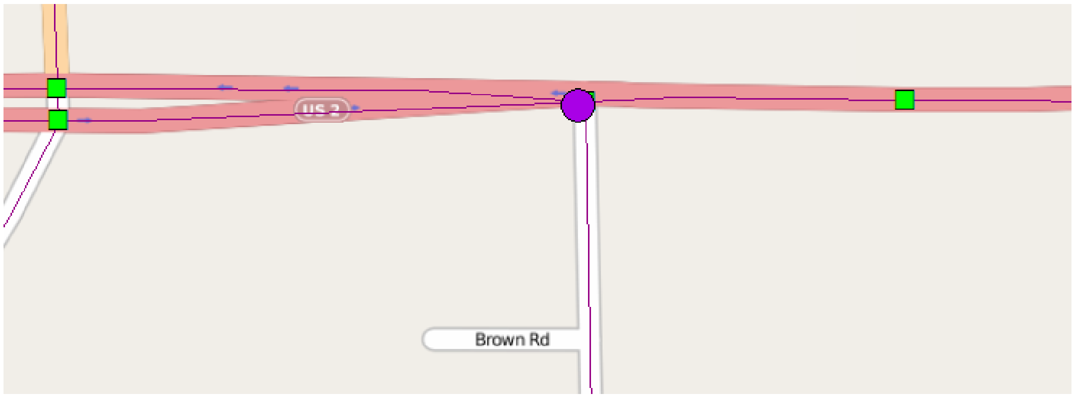
Number of Approaches Collection Result Analysis

Comparing the result with the Number of Legs column in ISET database, 220 results are different, which accounts for 12.8% of the total 1718 records. In order to understand the reasons for the discrepancy, we selected 20 mismatching intersections to check the number of approaches based on the Bing map from WISLR shapefile. 10 are randomly selected from the 4-leg intersections which are estimated as 3-leg intersection, and the other 10 are selected from the overestimated intersections. The result is shown in Table 4, and Figure 4 illustrates some mismatching cases.

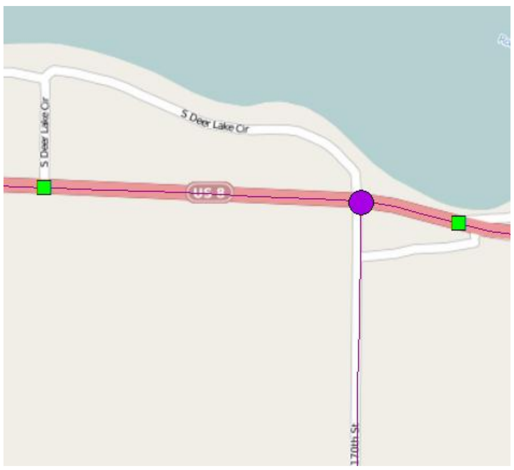
TABLE 4 Reason for Number of Approaches Mismatching

Type	Reason	Number
4-Leg est. as 3-Leg	ISET Data Wrong	5
	Lack Referencing Sites	3
	Intersection Shape Irregular	2
3-Leg est. as 4-Leg	ISET Data Wrong	9
	Intersection Shape Irregular	1

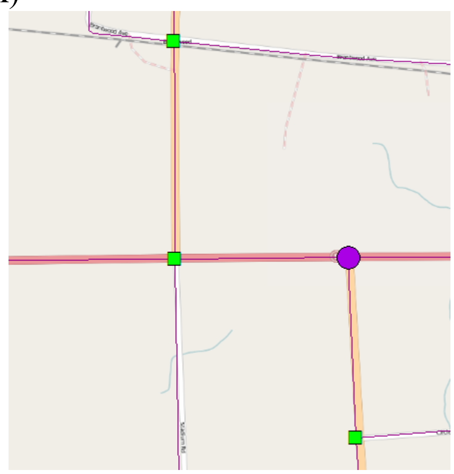
Table 4 suggests ISET data is the major cause of the mismatching, 5 out 10 of the underestimating and 9 out of 10 of the overestimating are due to ISET's error. In the underestimating cases, another important reason is lacking of reference sites on intersection approaches, as shown in Figure 5 (B). The WISLR contains only public roadway data, therefore when an intersection approach is private road, the program will underestimating the number of approaches. However, the private road usually has very low volume, it's reasonable not to count it as an intersection leg. The irregular intersection shape cases are even difficult to decide the number of legs manually. In Figure 5 (A), the 3-leg intersection is counted as 4-leg intersection because there are two referencing sites on the divided highway; In Figure 5 (C), the intersection is regarded as a single intersection where the automation program take it as two separate 3-leg intersections. In sum, 87.2% of the result matches with the ISET data, and about 70% of the mismatching intersections are due to ISET's error. Therefore the automation program to acquire the number of approaches is very reliable.



(A)



(B)



(C)

FIGURE 5 Mismatching Intersection Approaches

Area Type Collection Result Analysis

Both of the two methods are tested and compared: 1) using the officer reported area type from the Wisconsin Crash Database, 2) use the functional classification of the major road segment from WISLR database. Table 5 shows the matching statistics using different databases.

TABLE 5 Matching Rates for Area Type between Different Data Sources

	ISET-WISLR	WISLR-Crash	ISET-Crash	All
# of Matches	414	165	363	459
# of Samples	1718	1621	1697	1621
Matching Rate	75.90%	89.82%	78.61%	71.68%

One of the major disadvantages for using the Wisconsin Crash Database is that the officer reported area type is not available for intersections with no crash history. Therefore this method can only be applied to 1697 intersections, which accounts for 98.8% out of the 1718 intersections. Another issue with this method is that one place may have different area types according to different crash report. 162 intersections (9.5% of 1697) have contradictory officer reported area types, which indicates collecting area type information based on the Wisconsin Crash Database maybe unreliable. Table 6 shows an example where controversy exists. The intersection has only 2 records with different area types which render it difficult to determine the area type. Therefore the area types with most records are used to determine these intersections, which render the total matching rate of 78.61%.

TABLE 6 Example Intersection of Contradictory Area Type

REF_SITE_ID	RDWY_LINK_ID	ACCDNMBR	ACCDDATE	URBCLASS
1255248	3138732	060203846	16-Feb-2006 00:00:00	RU
1255248	3139232	050302280	10-Mar-2005 00:00:00	UR

The information in WISLR is not complete for every roadway links. Only 768 intersections are associated with complete major roadway functional classification information, which only cover 44.7% of the 1718 samples. The reason is that WISLR only contains complete roadway link information for local roads, the information for state highways are maintained in the STN database. Therefore when major road information is not available, the function classification of the minor road is used. All of the 1718 samples can use this method, among which 75.90% matches with the ISET data.

As indicated in Table 5, 71.68% intersection area types match among the three data sources. The matching rate is highest between the WISLR database and the Wisconsin Crash Database. However, we tend to believe using the major roadway's functional classification information in WISLR can best predict the area type for an intersection. As mentioned before in this paper, the intersection location conversion is not 100% insured in ISET, the ISET data might include some errors. The WISLR data were collected by the state DOT and it's used as an official basis to provide funding for local agencies, therefore the WISLR data are more reliable.

CONCLUSION

In this study, a new intersection safety data collection method is proposed to automate the process of intersection crash rates updating and intersection related features collection such as the area type and the number of approaches. In the proposed methodology, four databases - the Wisconsin crash database of police traffic accident reports, the Wisconsin Information System of Local Roads (WISLR), Crash Geographic Information Systems (GIS) database, and the TRAffic DAta System (TRADAS) are combined to produce a database of intersection crashes which can provide precious approach to more comprehensive intersection safety analysis. The results of the automation program are compared with the data from the Intersection Safety Evaluation Tool (ISET). The comparison indicates the manual data collection process may easily induce discrepancy and error, utilizing the automation method could improve the quality and the speed of intersection data collection. This study has implied the advantages of using LRS to manage transportation data, since crashes can be directly related to roadways and intersections. In addition, the study can be applied to other state DOTs that uses LRS to manage traffic data. Future studies could focus on extending this automation method to statewide identification of intersection safety issues. In addition, more rigorous quality check for the automation process should be included in the future.

ACKNOWLEDGEMENT

The authors would like to thank the Wisconsin Department of Transportation for allowing the research team to use their data. The authors would also like to thank Keith Knapp, John Campbell and Cara Kienert who first developed ISET in 2005; and Andrea Bill, Xiao Qin, Rebecca Szymkowski, Heng Wang and Madhav Chitturi who updated the ISET methodology and database in 2010.

REFERENCES

1. Knapp, K. K. and J. Campell *Intersection Crash Summary Statistics for Wisconsin*. University of Wisconsin-Madison, Traffic Operations and Safety Laboratory, 2005.
2. Graettinger, A., X. Qin, G. Spear, S. Parker and S. Forde. Combining State Route and Local Road Linear Referencing System Information. *Transportation Research Record: Journal of the Transportation Research Board*, Vol. 2121, No. 1, 2009, pp. 152-159.
3. Green, E. and K. Agent. *Crash Rates at Intersections*. Lexington, Kentucky, 2003.
4. Srinivasan, R. and D. Carter. *Development of Safety Performance Functions for North Carolina*. Chapel Hill, NC, 2011.
5. Garber, N. and G. Rivera. Safety Performance Functions for Intersections on Highways Maintained by the Virginia Department of Transportation. 2010.
6. NHTSA. *Traffic Safety Facts 2009: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System*. Washington, DC, 2010.
7. WisDOT. Wisconsin Traffic Data System http://wisconsinsafetydataportal.org/index.cfm/roadway/roadway-resources/traffic-data-system-tradas/
8. TOPS. Wistransportal Crash Data Retrieval Facility https://transportal.cee.wisc.edu/applications/crash-data/
9. FHWA. *Highway Performance Monitoring System Field Manual*. Washington D.C., 2012.
10. Forde, S. and S. Parker. Incident Location Tool, Wislr and Wislr Crash Mapping Tool http://www.dot.wisconsin.gov/drivers/drivers/enforce/tracs/tracsusers.htm