A SAFETY DECISION SUPPORT SYSTEM FOR RURAL HIGHWAYS

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ABSTRACT

Given Wisconsin's strong environmental traditions and low population per land area, it is not surprising that the majority Wisconsin land is classified as rural. Rural road crashes consistently account for almost half of the crashes in Wisconsin and 57 percent of 2.9 billion economic loss by crash severity in the state, which has become a pressing issue and a real hurdle for improving overall highway safety. As part of the Wisconsin effort to improve rural highway safety, the research developed a data-driven, solution-based safety improvement decision support system (DSS) for rural roads using computer and GIS techniques.

The safety DSS assists making informed decisions through an analytical approach attempting to replicate the problem identification process by safety analysts in the context of rural safety. The crash location problems are overcome by using an intelligent crash mapping tool (C-MAT) with a stepwise approach applied to choose the "sites of opportunity" by highway functional classification, crash frequency and severity at a certain statistical confidence interval. The system implementation analysis shows that 30 sites located either on rural arterials, collectors or local roads and streets were selected out of 9788 sites in total. The moderate number of locations identified enables WisDOT to conduct an in-depth safety review to address the crash causes and appropriate countermeasures. In summary, the DSS provides an efficient, streamlined, tangible, and data-driven solution to the rural highway safety problem.

Key Words: Decision Support System (DSS), Rural Highway Safety, GIS

INTRODUCTION

Roughly 83 percent of America's land mass is classified as rural. Although the geographic size of rural areas is enormous, rural counties, towns, and villages are less likely to have resources dedicated to road maintenance and safety, which makes these areas more vulnerable to traffic accidents. There are significant differences between urban and rural contexts when assessing risks associated with highway safety. Urban transportation infrastructure normally has higher design standards that can accommodate larger traffic volumes compared to rural highways that carry less volume, or occasionally a high seasonal or recreational traffic volume. Urban areas are better suited for quick incident responses, which can be partially credited to their easy access to emergency services. Rural areas or distant locations, however, have to face the reality of inferior communication and emergency response conditions. The rural safety issue is further complicated by a lack of localities, changing demographic features, and culture of alcohol consumption and seat belt usage. Consequently, despite low volumes and fewer safety conflicts on rural highway systems, more than 60 percent of all traffic fatalities occurred on rural roadways (*1*).

The fact that rural roads carry less than half of America's traffic but account for over half of the nation's traffic fatalities is difficult to be tolerated. Focusing on the differences between rural and urban travel environments and features, the US DOT has championed a $287 million emphasis on five focus areas: safer drivers; better roads; smarter roads; better trained emergency responders; and improved outreach and partnerships (*2*). With raised public awareness of rural safety and flexible federal and local funding mechanisms, more and more local and rural highway safety problems have been addressed through appropriate actions and projects. However, a few issues need to be resolved before an improvement in rural highway safety can be seen. The issues include, but are not limited to, how to collect crash information on rural highway systems, how to locate the areas exhibiting severe safety needs, and how to select and implement appropriate countermeasures to maximize safety benefits. The study developed a data-driven, solution-based safety improvement decision support system for rural highways using a collection of computer and GIS applications. In the context of a rural road network, a stepwise approach to effectively and accurately identify the "sites of opportunity" was developed based on safety performance. All the information generated from the system was eventually disseminated to local decision-makers by means of crash maps, ranked site lists, and safety studies. The decision support system demonstrated an efficient, timely, tangible, and data-driven solution to such a complicated issue.

RURAL CRASH CHALLENGES AND COUNTERMEASURES

According to the US General Accounting Office (GAO) May 2004 publication, titled as: Highway Safety – Federal and State Efforts to Address Rural Road Safety Challenges", crashes on rural highways account for over 60 percent of deaths nationwide and the fatalities per VMT was over twice that of the urban fatality rate (*1*). Over years, safety researchers and practitioners have been intensively investigating the causes for high crash counts/rates in rural areas given the relatively low VMT. Decade-long national studies suggest the following three main categories of causalities (*3*):

- Driver conditions and behavior are a contributing factor in at least 95 percent of all crashes and a primary contributing factor to 67 percent of crashes;
- Roadway design and environment factors claim at least 28 percent of crashes and are identified as a primary factor in approximately 4 percent of crashes; and
- Vehicle conditions are the least important causation and are the primary cause for 4 percent of crashes.

Not as diverse as their urban counterparts, rural road crashes are primarily segment-related single vehicle, head on and intersection related crashes, combining to account for almost 79 percent of rural crashes. As much as 46 percent of all fatal rural segment crashes are single vehicle crashes, 18 percent head-on, and 15 percent intersection crashes (*4*). Sparsely-populated rural cities, villages and towns (CVT) are connected by county trunk highways that are usually designed as major or minor rural collector and local roads with varying conditions. Because of these inconsistencies, drivers have to constantly adapt their speed to varying environments and circumstances that increase the risk of engaging in a collision. Driver behavior is a dominating factor in rural road crashes. Speeding conditions are one of the major safety concerns due to low volume and cultural influence (*5*). Speeding can result in crashes as it can reduce the driver's ability to see around curves, increase stopping time, and increase the distance traveled while the driver reacts to dangerous situations. The consequence of a collision is further exacerbated by low seat-belt usage and slow EMS response times.

The public perception of solving rural road safety problems seems to be unreachable without an extensive, system-wide upgrade of highway design and intensive enforcement and education efforts, both of which are normally cost and resource prohibitive. In spite of the challenges, a few states have made substantial achievements in reducing rural roads crashes. Minnesota county engineers along with Minnesota Department of Transportation (Mn/DOT) and Local Roads Research Board (LRRB) developed a GIS application called the Crash Mapping Analysis Tool (*6*). The tool has a suite of elements such as GIS mapping, querying capabilities and reporting functions. The tool allows local safety decision makers to visually assess vehicle, bicycle and pedestrian safety and allocate safety improvement funds in a proper fashion. Mn/DOT also recognized the need to focus safety projects on the county road system. In 2005, Mn/DOT established a program to grant $2 million to assist counties in deploying low cost, systematic and proactive safety improvements. Twenty-seven Counties participated each receiving a maximum of $75,000 and in 2007 an additional $4.15 million was awarded to thirty seven counties (*7*).

The death toll on California rural roads is ranked as the second highest in the nation. In response, California has formed task forces and established procedures to improve roadway safety through a variety of activities designed to influence driving behaviors as well as other highway safety projects. Examples include the identification of 50 cross-centerline crash locations on two- and three-lane roadways (47 were located in rural areas) and run-off-the-road crash locations (73 percent in rural areas) (*1*). California's Office of Traffic Safety also worked with the state patrol to implement two programs that had rural safety impacts: corridor safety project (16 of 20 corridors were two-lane roads, mostly in rural areas) and traffic collision reduction on county roads project by targeting traffic violations such as speeding, right-of-way violations, failing to drive on the right half of the road, improper turning, and impaired driving through an intensive enforcement effort (*1*).

The "5 percent" list produced by the Iowa Department of Transportation (DOT) not only considered roadway design and environment factors but also included driver behavior and condition (*8*). For example, the sites slated for safety improvements consisted of rural primary roads with the highest fatal and major injury crash density of unbelted drivers and passengers, rural primary roads with the highest fatal and major injury crash density involving an impaired driver, rural expressway and two-lane primary roads with the highest fatal and major injury crash density for speed-related crashes, rural primary and paved secondary roads with the highest fatal and major injury crash density for single vehicle run-off-the-road crashes, and rural interstate/freeway segments with the highest fatal and major injury crash density of multiple-vehicle, cross-median crashes

Each approach taken by different states may vary in the data used, methodologies applied and project selection criteria but in fact, they are all in line with the process of a decision support system. The Wisconsin Department of Transportation (WisDOT) and the University of Wisconsin joined forces to improve a safer road network for people to drive, walk, and bike. Specifically, a rural highway safety decision support system was piloted to assist in making informed decisions for safety investments on rural roads with the aid of integrated data sources and a collection of computer and GIS techniques.

DATA SOURCES AND SYSETM FRAMEWORK

To develop a data-driven, solution-based system, obtaining the appropriate data and establishing the relationship between various data sources are the keys to success. Two primary data sources were considered for developing the system: the WisDOT MV4000 Crash Database of police reported crashes and the Wisconsin Information System for Local Roads (WISLR).

Crash Data

Wisconsin traffic crashes are, by statutory definition, "reportable" if someone is killed or injured, or if the property damage exceeds a certain threshold ($1000 for property related crashes or damage to government-owned vehicles and $200 for all other government-owned property, such as traffic control devices). Crash information is generally reported by a police officer via the Wisconsin Motor Vehicle (MV4000) form and is eventually archived in the WisDOT crash database which contains all crash records extracts from 1994 to date. Note that only state highway crashes are geocoded and stored in GIS shapefile format, making up approximately 43 percent of the total crashes. The rest of crashes on local streets, roads and county highways are not available in GIS format.

Roadway Inventory Data

WISLR is a GIS based software package developed and maintained by WisDOT. It is considered as the official local roads GIS map in Wisconsin. WISLR not only contains a geo-database which describes the spatial relations and cartographic presentation of all local roads in Wisconsin, but also manages local roads data that can be used to meet various business needs of users. According to WisDOT (*10*) "With WISLR, users can produce maps that show the location of road-related data and see trends that might otherwise go unnoticed. For this reason alone, WISLR aids with organized and logical assessments about local road data. This is just one example of what WISLR can do — and there are many other benefits." WISLR was chosen for the system because it provides an opportunity to link important roadway characteristics, traffic conditions, environmental factors and other jurisdictional and administrational information to the crash reports for safety engineering analysis.

System framework

Decision Support Systems (DSS) are a specific class of computerized information systems that support business and organizational decision-making activities. It is intended to help decision makers synthesize useful information from raw data, knowledge, mathematical and statistical models to address problems, identify solutions and make recommendations and project selections. In spite of different classifications and business purposes, every DSS constitutes three fundamental components: 1) the user interface, 2) the database, and 3) the models and analytical tools. The DSS concept has been widely developed and deployed in the areas of medical, military, business, and others, including transportation. One of the well-known examples in transportation is the Maintenance Decision Support System (MDSS). MDSS makes winter maintenance recommendations to maintenance managers by predicting the future condition of the road surface based on current road conditions, weather forecast, available equipment, material, manpower and their performance (*9*). The same concept can be used in improving rural road safety. Although reducing and preventing rural crashes is a complex and daunting task, by compiling critical pieces of information such as roadway inventory and crash data, a decision system can serve as a starting point for safety stakeholders to make recommendations either based on evidence, knowledge, models, or other information.

The flowchart of the system framework is illustrated in Figure 1. Since all state highway crashes are manually reviewed and corrected for their location accuracy and digitized into a GIS format, they are processed in the WisDOT state highway safety management systems are not the target of the rural local DSS. Local rural highway locations, segments, intersections or ramps, along with the crash information are the focus of the system. If a specific location is flagged by the system, relevant information is assembled and conveyed to local communities or the Wisconsin County Highway Association (WCHA) through either highway safety circuit riders or regional safety engineers. Otherwise, locations are required to collect multiple years of data for the support of any safety improvement decisions. In other words, the system can also be used to monitor rural safety performance with the addition of new data every year.

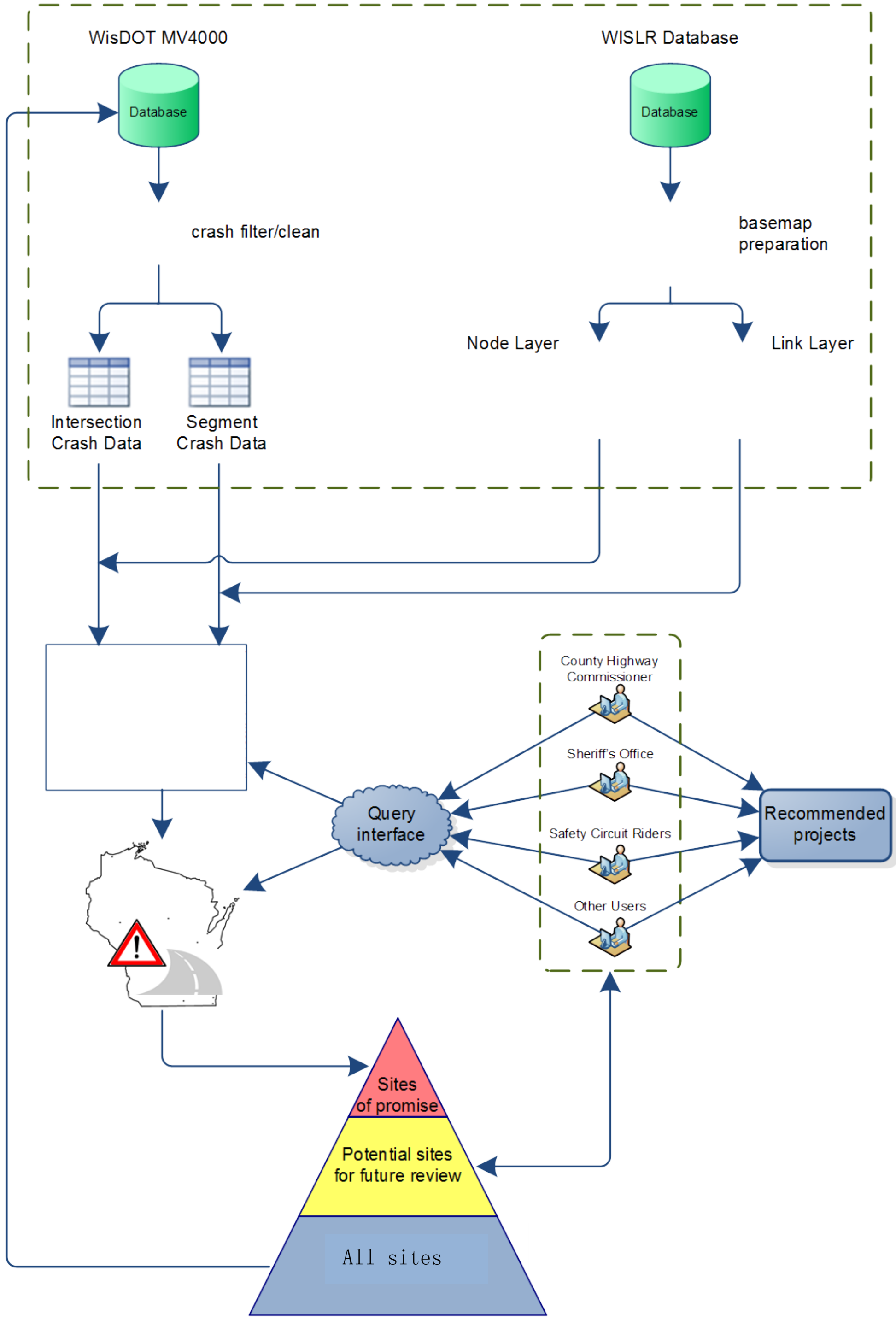

FIGURE 1 System framework flowchart.

METHODOLOGIES

In order to generate an appropriate list of "sites of opportunity", the methodologies were developed in two areas: 1) assembling information from various databases to produce an integrated source for making informed decisions, and 2) based on comprehensive information, developing an approach for selecting sites according to their safety performance.

One of the key hurdles to identifying unsafe sites is the lack of complete and accurate crash location information, especially for crashes that occurred on local roads. For states like Wisconsin who already have both a comprehensive safety management system and a local roadway inventory, locating a crash on a roadway is still not a trivial question. The frequently encountered problems in crash locations are missing information, spelling errors, alias street names, and incomplete roadway information. A Crash Mapping Automation Tool (C-MAT) was developed to facilitate crash location recognition in a rapid and automated manner. A brief description of the four-step procedure is presented below and details can be found in other documents (*11*):

- *Filter*: In this step, if a crash does not have "on street" information, it is removed. Note that the system is developed for locating rural local crashes. Hence, crashes occurred at municipalities whose population exceeds 5000 or state highways are also removed. Other filtering mechanisms include removing crash records with neither "at highway" or "at street" information and those occurring in parking lots and private property. The filtering criteria can be adjusted for new definition of rural local crashes.
- *Partition*: Each crash record is parsed into four text fields, i.e. prefix, street name, roadway type, and suffix if available. The purpose of partition is to maximize the success of matching using the 4-piece information available in WISLR local roads database.
- *Validation*: Real crash location data is not always cooperative with street names in WISLR. For example, street name may have alias; directional prefix information can be as brief as "N." instead of "North"; and street name can be written either by number or by alphabet. All of the information has to be validated and standardized before proceeding to the next step.
- *Match*: The match process is comprised by five levels of matching based on the amount of street name information used in this step: name matching, prefix-name matching, name-type matching, prefix-name-type matching and prefix-name-type-suffix matching. The logic behind this is to start with the most rigorous matching process and gradually relax the condition until a successful match is found.

Once a crash is identified in WISLR with the proper node or link and offset, a GIS map can be automatically produced using ESRI Map Objects 2.3. Mapping crashes in WISLR provides a seamless connection between the two databases and information can be integrated based on a site or a link or any shape of the geometry. As mentioned before, WISLR is the only certified roadway network for Wisconsin local roads which stores important roadway information such as highway classification and AADT.

Combining the two essential pieces of information, a prioritization approach is needed for finishing the final piece of the puzzle. As clearly outlined in the FHWA High Risk Rural Road (HRRR) program, eligible roadway segments or intersections should have higher-than-average crash rates for fatalities and incapacitating injuries. Using the geocoded crash data, a stepwise analytical framework for identifying "sites of opportunity" for rural intersections and segments was established. Because there is no explicit and uniform definition for highway segments in terms of length or other factors, it was decided by WisDOT that intersections are only considered as the unit for analysis in the exploratory stage. The list of significant intersections is produced following the steps modified from the WisDOT 2008 5% report (*11*).

Step 1—Intersection groups:
Intersections are divided into three peer groups by highway functional classification. If extending the analysis to cover all local crashes, a land type factor will be added; thereby a total of 10 peer groups will be available including a group to show if either of the classifications is unavailable).

Step2—Important factors:

- For each peer group, calculate the crash frequency of each intersection.
  Note: Crash frequency is used rather than crash rate, because complete traffic volume data is only available for less than a half of all intersections.
- For each peer group, calculate the proportion of fatal and serious crashes for each intersection because of the emphasis on fatal and incapacitating injury crashes.

Step3—Statistics:

- For each peer group, calculate the average and standard deviation of the crash frequency.
- For each peer group, calculate the average and standard deviation of the proportion of Fatal/Serious crashes.

Step 4—Sites of opportunity:
For each peer group, find intersections that satisfy all of the following three criteria with certain statistical significance. Note that significance is defined as greater than or equal to the average plus one standard deviation, roughly a 67 percent confidence interval (CI),85 percentile of the data.

1. Significant crash frequency, i.e., intersections that have high number of crashes
2. Significant proportion of fatal and serious crashes
3. At least three crashes/year, i.e., at least 15 crashes over five years

Step 5—Sorting:
For each peer group, sort the significant intersections by the proportion of fatal and serious crashes.

Step 6—Results:
For each peer group, select first 15 significant intersections, and intersections which have at least 1.2 fatal and serious crashes per year, i.e., at least six fatal and serious crashes over five years.

IMPLEMENTATION ANALYSIS AND RESULTS

A successful system depends on how reliable and accurate the data is, how robust and comprehensive the methodology is and how the combination of the two can meet the system needs and achieve the safety goals. Needless to say, the quality of data has a critical impact on the outcome, which can be demonstrated step by step in the following analysis during the system implementation.

From 2003 to 2007, 253,964 non-deer related local crashes, defined as those that happened on non-state maintained highways, occurred in Wisconsin. The biggest challenge is to identify crash locations and associated intersections or segments. Since the local crash data are not in a GIS format unlike their state highway counterpart, a Crash Mapping Automation Tool (C-MAT) is used to map each crash to an intersection (or a segment) stored in WISLR.

Of all the 253,964 crashes, 187,240 (73.7%) can be mapped successfully. Though an appreciable amount of crashes did not pass the C-MAT requirements for a successful address match, the 70% plus is considered to be acceptable by WisDOT for the initial screening. The unsuccessful mapping of some crashes is due to issues such as type errors, incorrect coding of location, and others. Some errors can be fixed in a relatively quick manner; others may take a longer time to address. In the 187,240 successfully mapped crashes, 135,956 are intersection related. In addition, of all the 253,964 crashes, 8,803 are severe, fatal or incapacitating, crashes. Of these severe crashes, 6,186 (70.3%) are mapped successfully. The result is a surprise since it might be expected that a higher percentage of successfully mapped fatal or serious injury crashes be mapped because these serious crashes may have more accurate location information compared to the others. 4,215 of the successfully mapped severe crashes are intersection related.

The 187,240 crashes are mapped to 45,756 intersections in WISLR. Using the available business information in WISLR, intersections are categorized by their functional classifications (arterial, collector, and local) and land types (urban, urbanized, and rural) into 10 “peer groups” including one called “other” for unavailable classifications. The functional classification of an intersection is determined by the highest classification of all connecting links. Because the system is especially designed for rural safety, the urban and urbanized area types are not the focus, so only three peer groups are used.

After applying all the criteria against the crash data, it was found that the criteria above are too strict to generate a sizable list. For example, no significant intersections can be obtained in any rural peer groups. The common causes for not being able to generate a sufficient number of sites lie in the minimum number of fatal or serious injury crashes in Step 6. Hence, in the modified procedure, in step 6, the minimum number of Fatal/Serious number of crashes (six) may be reduced. Table 1 illustrates the modified procedures and criteria as well as the “sites of promise” by peer group.

Table 1. Summary of “Sites of Opportunity” by Peer Group

Peer Group	Modified Criteria	Total	Selected	%
Rural Arterial	• At least 1 fatal and serious crash	59	5	8.47%
Rural Collector	• At least 2 fatal and serious crashes	3460	12	0.35%
Rural Local	• At least 2 fatal and serious crashes	6269	13	0.21%

In spite of unprecedented awareness and funding opportunities for rural road safety, resources are still tight. The situation may continue to worsen with more and more locations being identified using the safety DSS. For example, the same criteria can be applied to other local crashes in the area types of “urban” or “urbanized”. A sample of system output, a map of “sites of promises” along with the highway class information, is displayed in Figure 2. Other supporting information includes the summary statistics by crash characteristics, collision diagrams, possible countermeasures, and police reports.

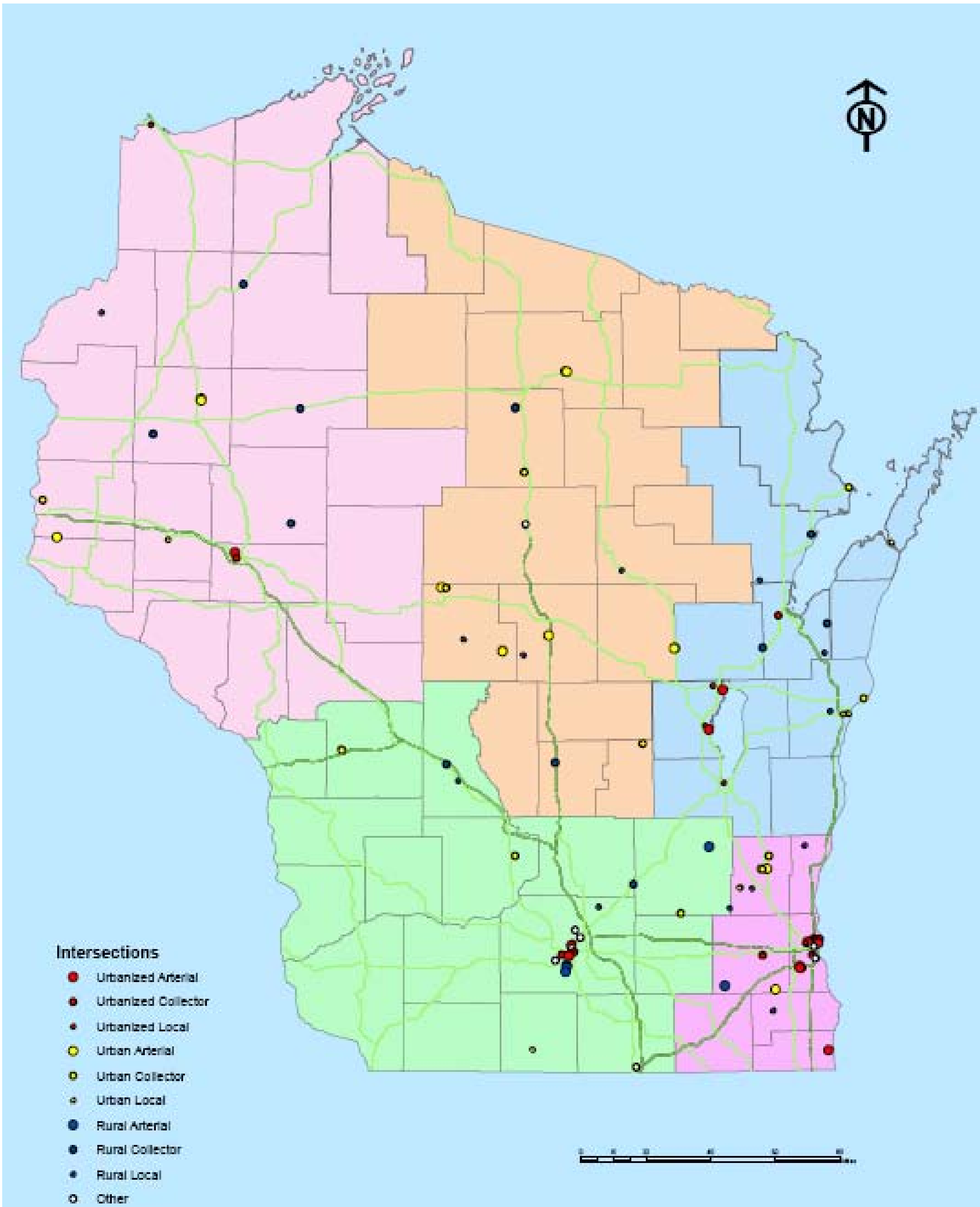

Figure 2. “Sites of Opportunity” by Peer Group

CONCLUSIONS AND FUTURE EXTENSIONS

Rural roads carry less than half of America's traffic but account for over half of the nation's traffic fatalities. Responding to a global rural road safety challenge, the US DOT has launched an aggressive effort to address five key areas: safer drivers; better roads; smarter roads; better trained emergency responders; and improved outreach and partnerships. As part of the Wisconsin effort to improve rural highway safety, a prototype of a data-driven, solution-based safety decision support system was developed for rural roads using a collection of computer and GIS techniques.

The rural highway safety DSS assists decision-making through an analytical approach attempting to replicate the problem identification process by safety analysts in the context of rural safety. The crash location problems are overcome by using an intelligent crash mapping tool (C-MAT) with a stepwise approach applied to choose the "sites of opportunity" by highway functional classification, crash frequency and severity at a certain statistical confidence interval. The DSS provides an efficient, streamlined, tangible, and data-driven solution to the rural highway safety problem.

Certainly, the application can be extended to other areas such as local crashes occurring in urban or urbanized areas. Once a consensus decision regarding the segment length is reached, the list can easily include local segments because all of the local crashes are already in a GIS format and can be easily joined to the corresponding WISLR links based on their spatial relationship.

Furthermore, though safety performance can be measured comprehensively through the data-driven ranking methodology, it does not reveal information regarding how many crashes can be possibly reduced; a measure of the curable capacity. One way to measure this is the excess number of crashes (the difference between the observed and expected number of crashes). The expected number of crashes can be estimated through the accident prediction models built on the available business data in WISLR such as highway functional classification, AADT, traffic control, lane widths, shoulder width, etc. Including crash prediction models for rural highways will be the most important future extension and enhancement of the system.

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