Data and System Architecture Improvements for Statewide Crash Mapping and Analysis

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Word Count: 3913 Words + 1 Table = 4163 Words

Submission Date: August 1, 2019

Submitted for Presentation and Publication
To the 99th Transportation Research Board Meeting

ABSTRACT
Crash data analysis and visualization is an important way to improve transportation safety. The Traffic Operations and Safety (TOPS) Laboratory at the University of Wisconsin-Madison, in partnership with the Wisconsin Department of Transportation (WisDOT), has developed several safety tools on its WisTransPortal system to query and analyze Wisconsin crash data. This paper describes a new and comprehensive Crash Mapping and Analysis (CMAA) component of the WisTransPortal for performing map-based visualization and analysis. The primary features of the CMAA system are: 1. daily automated mapping of crash locations from police reported locations (over 95% of all crashes are mapped); 2. an open, service-based framework for data sharing based on ESRI geo-processing services; 3. the integration with the WisTransPortal crash data model. This paper presents the advanced CMAA through two major changes: the framework design and the derivation of crash locations. With the detailed explanation and comparison between the previous method and the new CMAA, the open framework combined with updated crash data source has provided a better resource and environment for development and analysis. The improvements have been validated through two case applications: the CMAA web map and an ArcGIS Online (AGO) web application. These two applications demonstrate how the new framework offers a common service for application development based on a single source of crash data.

Keywords: Crash mapping and analysis, Crash database, Service architecture, Geoprocessing services, WisTransPortal system

INTRODUCTION

With the increased implementation of comprehensive crash attribute databases, transportation planning and safety solutions have become more efficient and reliable with diverse data analysis and task specific applications. The integration and analysis of traffic crash data serves many purposes. By developing a crash analysis system that consists of multiple data sources, geographic information systems (GIS), and publicly available services, the value of crash data can be fully realized. The core idea of this system is not only to have a typical database system with functions such as data input, query, and display but also to enable spatial analysis and provide an Application Programming Interface (API) to support external applications.

The Traffic Operations and Safety (TOPS) Laboratory at the University of Wisconsin-Madison has developed statewide crash data archiving and processing services and applications by using data provided from the Wisconsin Department of Transportation (WisDOT) to support emerging requirements for transportation operations, planning, and research. The WisDOT Wisconsin Information System for Local Roads (WISLR) provides the Linear Referencing System (LRS) with which real-world coordinates can be derived using a route and distance. WISLR supports the Crash Mapping and Analysis (CMAA) application that combines multiple years of highway and local road crashes to perform crash queries, displays all the crashes onto a single map and enables GIS based analysis. The integration of the crash database and GIS allow users to view, analyze, and visualize the data in multiple ways which increases opportunities to solve complex transportation safety problems. Recent enhancements to the new CMAA framework design and its supporting crash database provides open capabilities for users to create applications suited to their needs.

This paper describes the new CMAA with a detailed explanation of both framework design and the derivation of crash locations. It also demonstrates two case applications: a customized CMAA crash map developed with the OpenLayers JavaScript library and an example ArcGIS Online (AGO) application that could be made by external users such as collaborative departments and organizations and other groups with crash data visualization and analysis needs. Both applications were developed from the same underlying ESRI geo-processing services that comprise the core of the new CMAA framework.

RELATED WORK

Many departments of transportation and research institutes have developed crash analysis tools or systems over recent decades. From the late 1990s, the United States Department of Transportation (USDOT) and the Federal Highway Administration (FHWA) have conducted a number of road traffic crash related projects.

FHWA established the Highway Safety Information System (HSIS). HSIS [1] uses data collected by states for management and safety analysis by providing data on crashes and traffic variables. This database contains crash attributes and files, roadway inventory files, and traffic volume files from various states. Data can be extracted in several formats such as Microsoft Excel® and Access®, dBase, ASCII, etc. In general, HSIS helps users to identify and analyze safety problems and design models to predict future crashes.

Traffic Services are carried out by the Texas Department of Transportation in the state of Texas [2]. The goal of their program is to reduce traffic accidents and effectively manage and analyze traffic accident data with identifying accident locations. Crash

Reporting and Analysis for Safer Highways system (CRASH) is a free and secure Internet application for law enforcement agencies to process Texas Peace Officer's Crash Reports (CR-3) electronically. Crash data is entered into the system using Internet connections which affords accessibility and improves data quality.

Ohio Department of Transportation (ODOT) developed the GIS Crash Analysis Tool (GCAT) [3] which is capable of performing queries and displaying traffic crashes based on different attributes such as crash date, crash severity level, weather conditions and collision types.

The Center for Advanced Transportation Technology Laboratory (CATT Lab) in Maryland has developed a large-scale, real-time, and interactive transportation system. The Regional Integrated Transportation Information System (RITIS) [4] provides tools for safety analysis and accident management, emergency management, and the public. This system introduced a real-time visualization system for traffic data.

The University of Minnesota and Claremont Graduate University developed Safe Road Maps [5]. This provides a visualization tool that generates heat maps which attempt to indicate the risk of a crash for specific locations.

Critical Analysis Reporting Environment (CARE) [6] was developed by the Center for Advanced Public Safety at the University of Alabama and uses advanced analytical and statistical techniques to generate information from data. The software provides functions of data and statistical analysis, data mining capability, and report generation. CARE also provides access to real-time statistics on critical systems of traffic citations, crash reports, and criminal incident reports.

The UMassSafe [7] Traffic Safety Data Warehouse is a tool for applying traffic data for analysis including comprehensive databases such as crash, citation, and roadway inventory. Over 16 years of data are available in these databases. The system also has a single database that integrates data about crashes, citations, ambulance trips, and roadway inventory to allow analysts to analyze comprehensive crash experience such as driver behavior, crash characteristics and roadway environment. This improves data integration and is beneficial for extending applications.

FHWA developed Model Inventory of Roadway Elements (MIRE) standard [8] which helps manage critical inventory and traffic elements to improve safety level of roadway. Elements are divided among three broad categories: roadway segments, roadway alignment, and roadway junctions.

Safety Analyst [9], a FHWA tool developed with state and local agencies, provides a set of software tools for safety management. It uses advanced analytics for decision-making processes to identify and manage system-wide field improvement programs to improve road safety in a cost-effective manner. It implements six steps for safety management: network screening, diagnosis, countermeasure selection, economic appraisal, priority ranking, and countermeasure evaluation. Safety Analyst provides a data management tool for users to import and manage crash data of location, date, collision type, severity, relationship to junction and maneuvers by involved vehicles.

Several solutions have been implemented in other parts in the world. European countries have implemented database software including the International Road Traffic and Accident Database (IRTAD), the European Conference of Ministers of Transport (ECMT), and the United Nations Economic Commission for Europe (UNECE). The Software Bureau Transportation Research Lab developed the Microcomputer Accident Analysis

Package (MAAP) based on a GIS platform. It is mainly used for traffic accident management and safety analysis and has interfaces with GIS, Word, and Excel. The system is divided into the database and the analysis components. The system has developed accident data analysis tools which can display the location and attributes of the crash. The software has been used in the UK, Zimbabwe, Jamaica, Fiji, among other places [10]. The Norwegian Public Roads Administration and the Australian Government have also developed a spatially enabled traffic accident management information system for the management and analysis of traffic accidents. These systems were developed with the specific conditions of the state or the country. They have similar functions such as graphical input, editing, topological relationships, two-way query of graphics and data, spatial analysis, and evaluation of crash data.

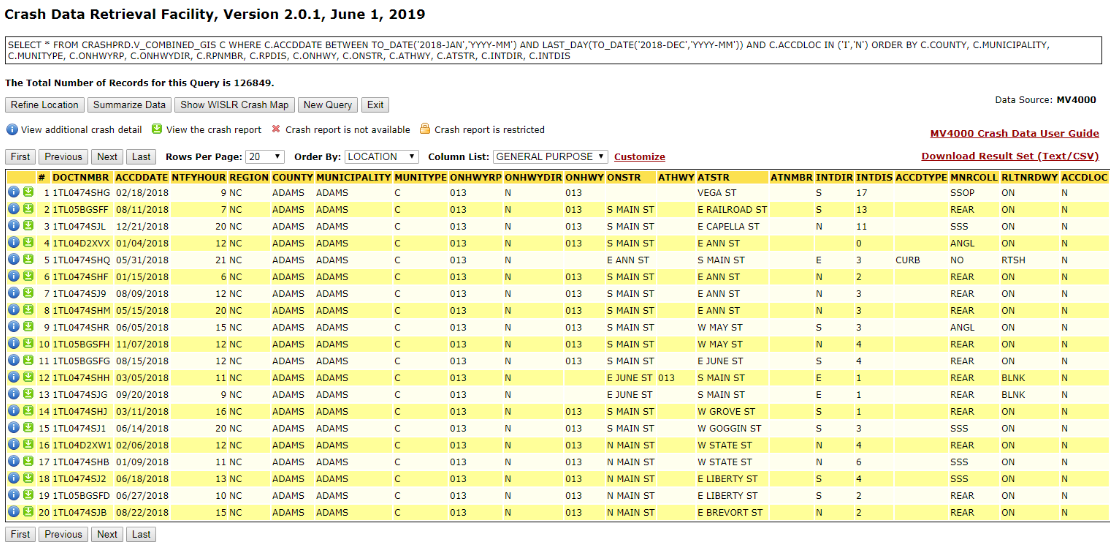
There are numerous crash analysis tools with data and associated applications. However, there are restrictions in many of the currently used crash archival and analysis tools. Although some systems include automated data entry, the frequency of update of crash data varies which often results in time lags. Underreporting crashes is another drawback in some current crash data system. Specifically, noninjury crashes are likely to be missing from the database [11]. There is an expectation that both the number and types of variables collected and the definitions for crash types should be consistent so that data will meet standards across the roadway system. Nevertheless, most systems are limited to the highways and do not include the state's local road system.

States typically have their own crash database consisting of data submitted by local agencies. This method allows for a broad and more timely input of crash data but yields to challenges with data inconsistency and varying definitions for crash data. Many crash database systems are limited in accessibility and analysis tools such that users would find the rigid framework difficult to retrieve and analyze data. The service-based architecture that CMAA has adopted provides an open framework to develop downstream applications using the up-to-date crash data without having to modify the underlying crash system, creating tremendous data retrieval and analysis flexibility for users and overcoming the many challenges experienced in other system.

WISLR CRASH MAPPING AND ANALYSIS

Previous State

The CMAA application is comprised of two major parts: One is the crash data facility which played the role of connecting users and database. With detailed query interface including the location of crash, vehicles involved and general crash attributes, the crash data retrieval facility allows users to retrieve required data from the crash database and generate them to a result table which can be exported for further analysis. An example crash table is shown in Figure 1.



Crash Data Retrieval Facility, Version 2.0.1, June 1, 2019

SELECT * FROM CRASHPRD.V_COMBINED_GIS C WHERE C.ACCDDATE BETWEEN TO_DATE('2018-JAN','YYYY-MM') AND LAST_DAY(TO_DATE('2018-DEC','YYYY-MM')) AND C.ACCDLOC IN ('I','N') ORDER BY C.COUNTY, C.MUNICIPALITY, C.MUNITYPE, C.ONHWYRP, C.ONHWYDIR, C.RPNMBR, C.RPDIS, C.ONHWY, C.ONSTR, C.ATHWY, C.ATSTR, C.INTDIR, C.INTDIS

The Total Number of Records for this Query is 126849.

Refine Location | Summarize Data | Show WISLR Crash Map | New Query | Exit

Data Source: **MV4000**

View additional crash detail · View the crash report · Crash report is not available · Crash report is restricted

MV4000 Crash Data User Guide

First | Previous | Next | Last **Rows Per Page:** 20 **Order By:** LOCATION **Column List:** GENERAL PURPOSE Customize

Download Result Set (Text/CSV)

#	DOCTNMBR	ACCDDATE	NTFYHOUR	REGION	COUNTY	MUNICIPALITY	MUNITYPE	ONHWYRP	ONHWYDIR	ONHWY	ONSTR	ATHWY	ATSTR	ATNMBR	INTDIR	INTDIS	ACCDTYPE	MNRCOLL	RLTNRDWY	ACCDLOC
1	1TL0474SHG	02/18/2018	9	NC	ADAMS	ADAMS	C	013	N	013			VEGA ST		S	17		SSOP	ON	N
2	1TL05BGSFF	08/11/2018	7	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		E RAILROAD ST		S	13		REAR	ON	N
3	1TL0474SJL	12/21/2018	20	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		E CAPELLA ST		N	11		SSS	ON	N
4	1TL04D2XVX	01/04/2018	12	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		E ANN ST			0		ANGL	ON	N
5	1TL0474SHQ	05/31/2018	21	NC	ADAMS	ADAMS	C	013	N		E ANN ST		S MAIN ST		E	3	CURB	NO	RTSH	N
6	1TL0474SHF	01/15/2018	6	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		E ANN ST		N	2		REAR	ON	N
7	1TL0474SJ9	08/09/2018	12	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		E ANN ST		N	3		REAR	ON	N
8	1TL0474SHM	05/15/2018	20	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		E ANN ST		N	3		REAR	ON	N
9	1TL0474SHR	06/05/2018	15	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		W MAY ST		S	3		ANGL	ON	N
10	1TL05BGSFH	11/07/2018	12	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		W MAY ST		N	4		REAR	ON	N
11	1TL05BGSFG	08/15/2018	12	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		E JUNE ST		S	4		REAR	ON	N
12	1TL0474SHH	03/05/2018	11	NC	ADAMS	ADAMS	C	013	N		E JUNE ST	013	S MAIN ST		E	1		REAR	BLNK	N
13	1TL0474SJG	09/20/2018	9	NC	ADAMS	ADAMS	C	013	N		E JUNE ST		S MAIN ST		E	1		REAR	BLNK	N
14	1TL0474SHJ	03/11/2018	16	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		W GROVE ST		S	1		REAR	ON	N
15	1TL0474SJ1	06/14/2018	20	NC	ADAMS	ADAMS	C	013	N	013	S MAIN ST		W GOGGIN ST		S	3		SSS	ON	N
16	1TL04D2XW1	02/06/2018	12	NC	ADAMS	ADAMS	C	013	N	013	N MAIN ST		W STATE ST		N	4		REAR	ON	N
17	1TL0474SHB	01/09/2018	11	NC	ADAMS	ADAMS	C	013	N	013	N MAIN ST		W STATE ST		N	6		SSS	ON	N
18	1TL0474SJ2	06/18/2018	13	NC	ADAMS	ADAMS	C	013	N	013	N MAIN ST		E LIBERTY ST		S	4		SSS	ON	N
19	1TL05BGSFD	06/27/2018	10	NC	ADAMS	ADAMS	C	013	N	013	N MAIN ST		E LIBERTY ST		S	2		REAR	ON	N
20	1TL0474SJB	08/22/2018	15	NC	ADAMS	ADAMS	C	013	N	013	N MAIN ST		E BREVORT ST		N	2		REAR	ON	N

First | Previous | Next | Last

Figure 1 Crash Data Retrieval Facility.

CMAA system was enhanced in 2011 with an online GIS based crash map that combined highway and local road crashes onto a single network. It included controls to dynamically zoom and select crashes from the map. The combination of crash data and maps helps users visualize and analyze the data intuitively. At the backend, the crash database was updated on a monthly basis by post-processing crash locations from the Wisconsin police report. This post processing procedure including merging highway and local road crashes to a single LRS [12], combining those results with the larger crash database in Oracle, and minimizing the unmapped crashes. This system has worked well for many years but was based on an architectural design that tightly coupled the online mapping application to the underlying database system, making it difficult to maintain and modernize to address emerging requirements for crash mapping and analysis.

Problems

The previous CMAA had several issues even after several project phases. The first problem was the data mapping quality issues due to the coordinate generation algorithms. Two customized software were developed for WISLR transformations. The Crash Mapping Automation Tool (C-MAT) software [13] had inherent limitations as its mapping algorithm was based on old crash report. The algorithm parsed the text-based location description and tried to match those descriptions to locations within WISLR. Since the old data source did not have robust location information, ambiguous description of the crash could not be resolved. For example, if two roadways met in two locations, the software was unable to determine which intersection was the appropriate crash located. The other software, a Link-link process, worked well though it was subject to snapping nearby local road crashes to the mainline. This was the result of using an LRS analytic representation for crash mapping. The nearby crashes were snapped intentionally in order to be included in WisDOT highway crash analysis but using those locations for crash mapping had the effect of changing their actual location on the map. Both software had an impact on data accuracy and completeness. Moreover, the post-processing procedure described in previous paragraph include a complex manual operation that was inefficient and prone to human errors.

Another problem was the aging framework. The previous mapping component of the application was built using ESRI's Web ADF in Java which is no longer supported by ESRI. Although the CMAA framework was sufficient to complete current requirements and operations, its design still had drawbacks. The system was tightly coupled with the underlying the database and the framework was not suited for development of external applications.

Data and Architecture Enhancement

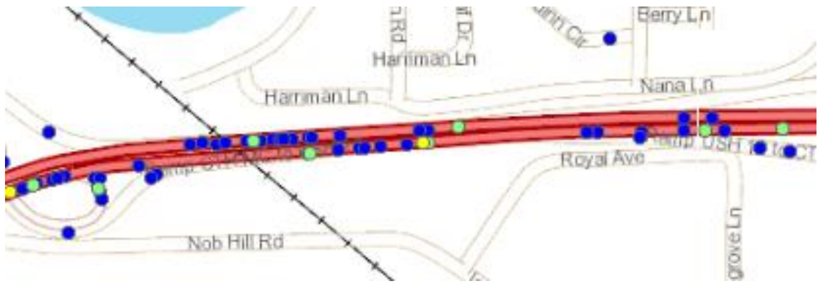
In order to improve the data quality and rigid framework, WisDOT and the TOPS Laboratory provide an optimized solution after careful discussion and analysis. In the beginning of 2017, WisDOT updated their crash report system and used a new report form that introduced several changes including geographic coordinates (longitude/latitude) provided by law enforcement. This meaningful update eliminated the cumbersome manual process to transfer and unify LRS for each crash data. The spatial information solves the problem of deriving crash locations from ambiguous descriptions and errors generated from edge cases in the software algorithm. Law enforcement provided locations can be used directly for mapping and analysis. Table 1 summarizes the comparison of geographic information for several main types of crash data in 2017 and 2018. As seen in the table 1, the percentage of crashes mapped using the new CMAA approach was much higher than the percentage of data mapped using the old WisTransPortal crash mapping algorithm. This ratio continues to increase from 2017 to 2018 which confirms the considerable improvement resulting from the new crash report form. Between the advantages of the law enforcement provided spatial information and the improvement evident in the comparison results, the benefit of location as a component of the crash report is demonstrated relative to the previous approach of deriving GIS locations from crash report roadway name descriptions.

TABLE 1. Crash data mapping completeness comparison

Year	Total Crashes	New CMAA System	Pecentage	Old Mapping System	Pecentage
2017	139870	129509	92.6%	95963	68.6%
2018	143362	136460	95.2%	105570	73.6%

Similarly, data accuracy is also improved due to the direct use of geographic coordinates. The previous crash mapping was calculated and rendered by treating the road as a line segment and the distance between road and crash location as an offset. If the road is a divided highway, the data points rendered to the map appeared on the centerline of the divided highway instead of on the roads themselves as shown in figure 2(a). The new CMAA algorithm which uses the geographic coordinates solved this issue. The crash points can be directly rendered to the real-world locations as shown in figure 2(b). The figure shows crashes rendered at same location and time period. It can be intuitively seen from the figure that both number of crashes and crash location accuracy improved by using the new approach.

a) Old WisTransPortal Crash Mapping System



b) New CMAA System

Figure 2 Crash mapping system Comparison

Using the spatial information to develop a new CMAA has the benefits described above and also reduced the development cost. Without manually using CMAT and customized programming to process the data, developers can easily use spatial information in common desktop GIS software such as ArcMap or Quantum GIS or develop an automated script which greatly reduces the operational time and maintenance cost.

Framework design is another major improvement besides the crash database. An ArcGIS Server Geoprocessing Service was developed for CMAA framework to retrieve crash data from the Oracle database and pass the crash information to the CMAA application to be rendered on the map. By this, the mapping tool is decoupled from the underlying database systems which results in a more flexible framework. The middle tier between the web browser and crash data facility broaden practicality and scalability. The geoprocessing service used by the CMAA map is specific to the application. However, additional geoprocessing services at the same tier in the framework can return results based on user friendly criteria such as a list of counties and year range. The geoprocessing service tier can support external applications built for the specific needs of an organization.

The user interface of the CMAA crash map was rebuilt and modernized. Previous map was built using the discontinued Web ADF framework which was difficult to maintain and had a dated look and feel relative to what would be considered a modern web map. The TOPS lab selected OpenLayers [14] as the mapping library to create the new map. Since OpenLayers is free and open source with a feature rich API and most importantly, it performs well for large queries with crash points rendered in the browser. Figure 3 below shows the new framework design and process flow of the new CMAA.

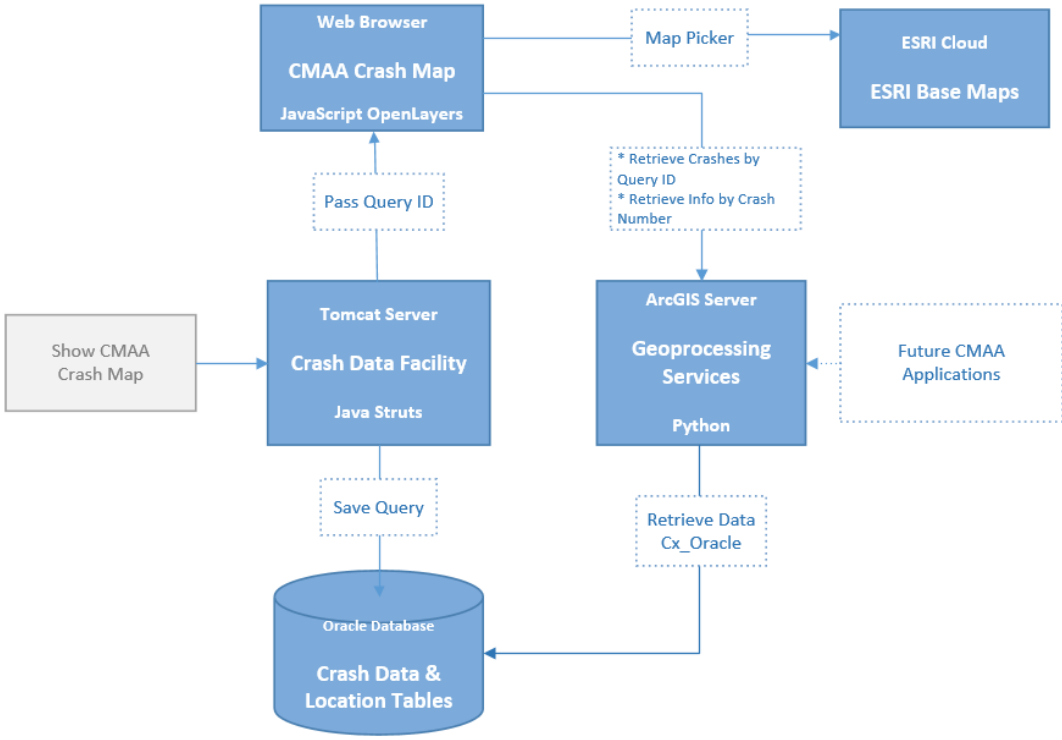


Figure 3 New CMAA framework and process flow

APPLICATIONS

The comprehensive framework and crash data are exemplified in the following two applications: the CMAA Crash Map and a demonstration ArcGIS Online application built with App Builder. Both applications use geoprocessing services to retrieve the spatial information and generate crash points rendered in the browser. These two applications demonstrate how public users, collaborative departments, and organizations can access the crash data through the CMAA framework and build need specific applications.

CMAA Crash Map

The CMAA crash map is generated from a dynamic query with location and attribute information returned as text in the ESRI JSON from an ArcGIS Server geoprocessing service. The client application was built using a combination of established JavaScript libraries including OpenLayers for the mapping component, React [15] for rendering of page components, and Redux [16] to maintain application state. An image of the application is shown in Figure 4. The map displays a user selectable base map with options including various base maps from ESRI and OpenStreetMap [17] or satellite imagery with a locations of interest overlay. The crash map is available to authenticated users and provides a resource that collaborative departments or organizations can use for their objectives.

Crashes retrieved from database for a given query are rendered client side and symbolized based on injury severity. The legend section shows a tabular summary of crashes by injury severity with the number of queried crashes, mapped crashes, and of the mapped crashes, the numbers for the current selection. The number of mapped crashes is typically about 95% of that of queried crashes due to some crashes lacking law enforcement provided coordinates. Interactions with the map are facilitated by several function buttons. Selections can be made interactively with a rectangular extent, free form polygon, or line with user entered buffer distance. Four selection modes let a user create a new selection, add to the selection, subset from a selection, or remove from the selection. Additional functions include navigation, search by location or crash number, and a scale bar. A sidebar with an accordion format provides a convenient way to include additional information such as application status, disclaimer, and simple help information without overly complicating the user interface.

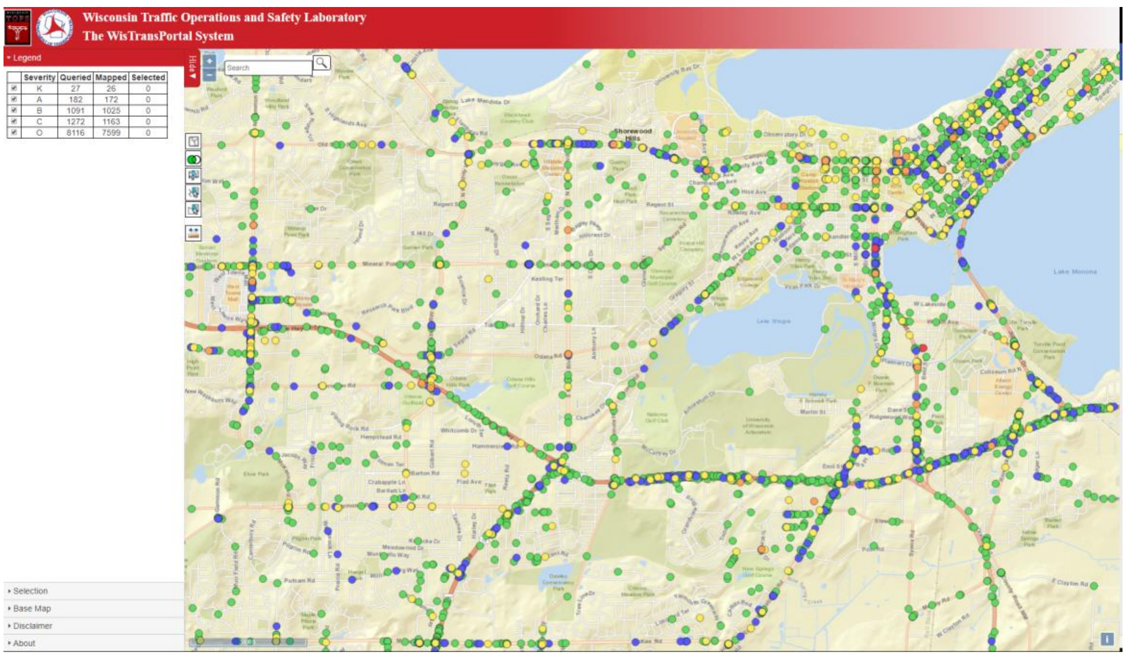


Figure 4 CMAA Crash Map

ArcGIS Online Application

The architecture of CMAA with its use of the geoprocessing services tier allows use of crash data in ArcGIS Online (AGO) applications using Web AppBuilder[18]. For specific use cases supported by the AGO framework, users can enter the administrative interface of Web AppBuilder to create applications with custom layer symbology and configure themes without any coding. A collection of "widgets" provides tools for data retrieval, visualization, and analysis. A geoprocessing widget provides a dynamic user interface to reference a geoprocessing service exposed by the CMAA framework and have it shown as a button on the published application. Figure 5 illustrates the user interface for a CMAA geoprocessing service that takes as input one or more counties and start and end crash year. It displays crash points with different colors by injury severity level. Another 'Infographic' widget shows the proportion of crashes by severity in the form of pie chart which is intuitive and beneficial to analysts. Other components or functions such as legend, selection, print, and measurement have implemented in the application. AGO offers user specific permissions so that members of authorized groups can view or edit applications created by other users. An image of the example AGO application is shown in Figure 5.

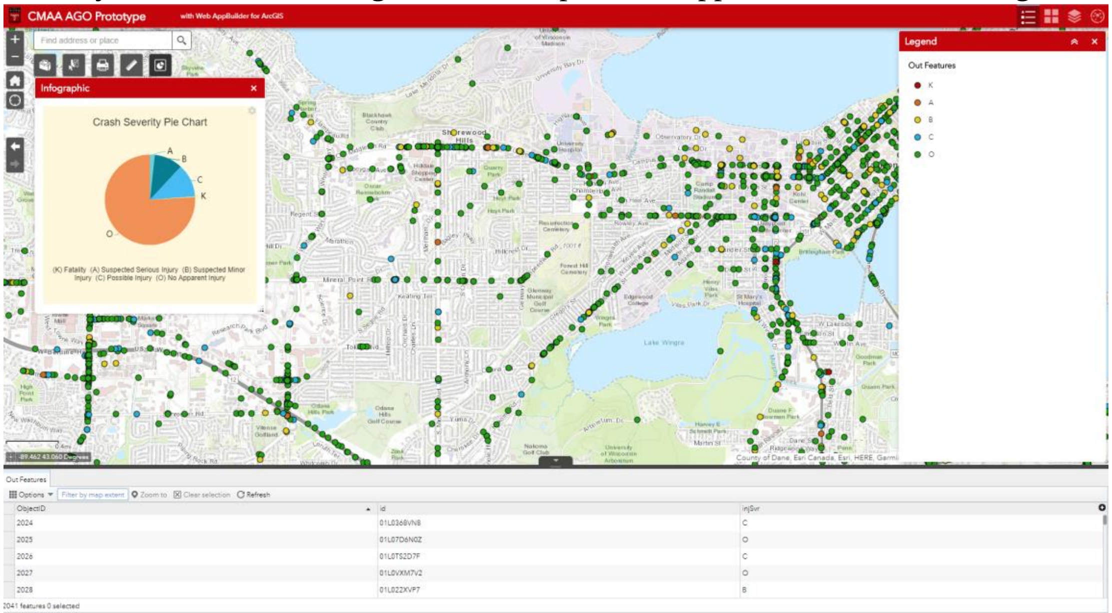


Figure 5 Demonstration ArcGIS Online built with App Builder

Given a collection of geoprocessing services provided by CMAA and an AGO account with sufficient privileges, external users can create specific use case applications and map crashes without going through the query tools provided by WisTransPortal. In this way, the CMAA framework components are decoupled and enables wide access to the underlying crash data.

CONCLUSION

This study proposed a crash mapping and analysis tool that contains the expected functions of a database as well as the ability to support spatial analysis and external applications. The new multi-tier framework design with extensive crash database attributes was developed by TOPS lab and WisDOT to improve the utility of the CMAA application. The modernized crash database provides access to the new WisDOT crash report that solves the long-time manual process problem and improves the data mapping accuracy and completeness. The new framework design adds ArcGIS Server geoprocessing services as a service tier which is easy to open source and share. These services support the CMAA map as well as to provide access to crash data for third-party application developers. Overall, the system deployment and scalability of the new CMAA have been improved.

ACKNOWLEDGEMENT

Development of the WisTransPortal Crash Data Retrieval Facility and the CMAA component was sponsored by the Wisconsin Department of Transportation. The ideas and views expressed in this paper are strictly those of the Traffic Operations and Safety (TOPS) Laboratory.

AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: Steven T. Parker and Glenn Vorhes deviced the project. Tianyi Chen and Haotian Shi wrote the manuscript with support from Steven T. Parker, Glenn Vorhes and David A. Noyce. All authors discussed the results and contributed to the final manuscript.

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