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Rural ITS Solutions for I-40 at Rockwood Mountain and I-75 at Jellico Mountain in Tennessee

University of Tennessee, Knoxville
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Title	Rural ITS Solutions for I-40 at Rockwood Mountain and I-75 at Jellico Mountain in Tennessee
Organization	Department of Civil and Environmental Engineering, University of Tennessee, Knoxville 311 John D. Tickle Building,851 Neyland Drive, Knoxville, TN 37996
Primary Contact	Yangsong Gu, ygu17@vols.utk.edu
Coauthors	Hairuilong Zhang, hzhan101@vols.utk.edu Jing Guo, jguo31@vols.utk.edu Zheng Zhang, zzhan100@vols.utk.edu Nima Hoseinzadeh, nhoseinz@vols.utk.edu Ava Hedayatipour, ahedaya1@vols.utk.edu
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Abstract	Both multi-vehicle and single-vehicle crashes are prone to happen on mountainous interstate highways due to the severe weather, complex terrain, rockslides on the road, etc. It's critical to take measures to reduce the loss of lives and properties caused by crashes. In this project, we focus on two mountainous corridors: I-40 (MM#340-347) at Rockwood mountain and I-75 (MM#150-161) in Tennessee. These two corridors carry heavy freight and passenger transport while are facing high crash rates due to the weather and grade conditions. Carrying out the four pieces of design purposes/rules listed in Page iii, and combining the crowdsourced data, we propose a systematic framework along with a series of economic, easy to complement remedy measures to solve the safety issues. Firstly, we determine the scope and relationships involved in this project. Secondly, we describe our solutions centered on improving road safety, including the data we used, the performance metrics, how to apply the historical data, how to think from the static engineering view, dynamic predictive operations, and robust data management. Thirdly, we analyze the Con-Ops for our solutions. In function, the proposed framework can provide a multi-level crash warning for road users. Meanwhile, by incorporating the crowdsourced data, our solution can make schedules for road construction work. Inside improving the current road driving environment, we also list the corresponding measures to remedy, such as reducing the speed limit to 60 Mph on I-75 (MM#150-161) and mountain consolidation suggestions. In the next section, we evaluate our project from the cost and benefit analysis, before and after analysis and anticipated impacts. Finally, in conclusion, our proposed approach can fully utilize crowdsourced data and be easily implemented for practical traffic issues.
No. of Pages	4 pages intro + 10 pages text + 1 page of references.

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LIST OF ACRONYMS

TDOT	Tennessee Department of Transportation
AADT	Annual Average Daily Traffic
ITS	Intelligent Transportation System
CCP	Connected Citizens Program
FHWA	Federal Highway Administration
API	Application Programming Interface
MM	Mile Marker
GIS	Geographic Information System
Mph	Mile per hour

DESIGN PURPOSES/ RULES

- Reduce crash risk to a large extent;
- Adjust schemes to local conditions, avoid broad-brush solutions;
- Easy to implement and practical;
- Environmentally friendly and economically.

DESCRIPTION OF PROBLEM

Mountainous Interstate are often involved in more traffic incidents since they are highly susceptible to severe weather, complex terrain, road hazards, among other external factors. According to the historical crash report (Figure 1) from the TN Department of Safety and Homeland Security, TITAN Division, more than half fatalities caused by crash happened in rural areas. Serious crash and potential factors pose significant threats to road users' properties and lives. Meanwhile, the traffic jam or break caused by crash significantly reduces the travel time reliability. Thus, it's critical to provide a safe driving road environment by forewarning and precleaning hazards for road users to mitigate the crash severity and crash rates.

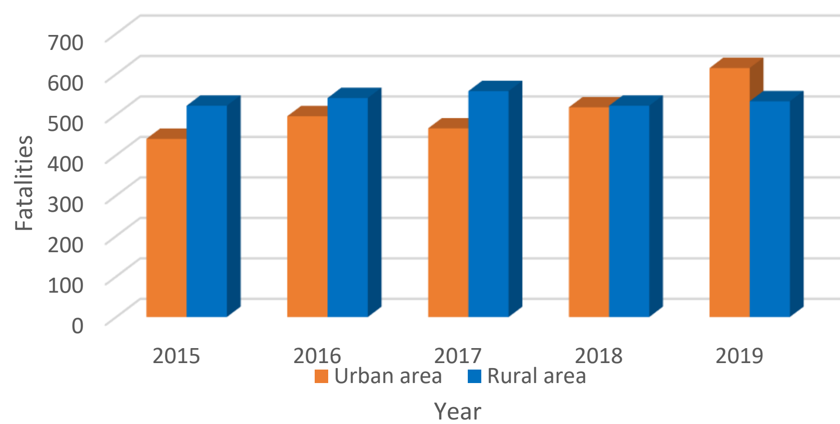
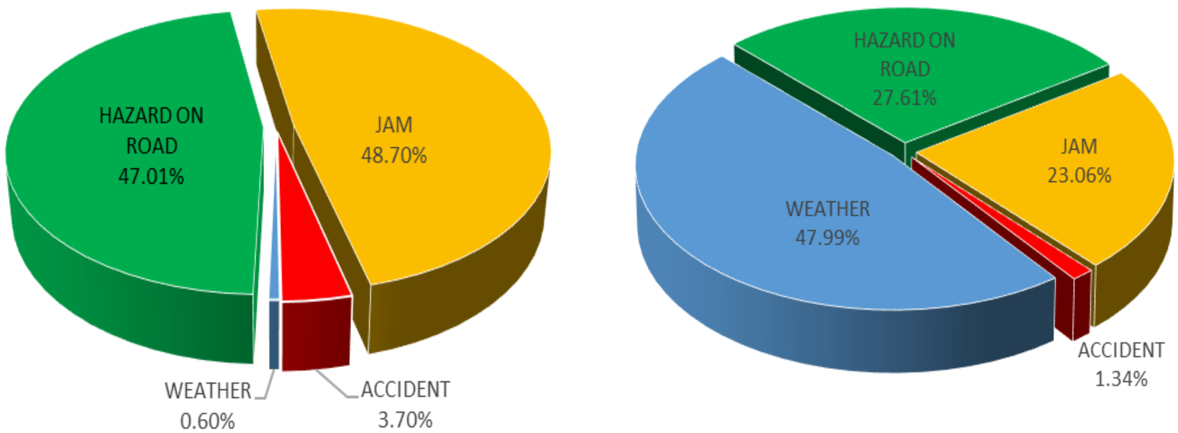


Figure 1. Recent five years of fatality crashes in Tennessee

In this project, we focus on two typical interstate regions located in mountain areas in TN. They are MM#340 to MM#347, Interstate Highway I-40 at Rockwood Mountain, and MM#150 to MM#161, Interstate Highway I-75 at Jellico Mountain, separately. Those two corridors are experiencing high crash rates due to bad weather, grade conditions along with rockslides. By looking at the Waze report on these two corridors, we have a better understanding of the frequent issues that two corridors are facing. Generally, two target corridors are suffering from the Jam, hazards on the road, accidents, and bad weather (Figure 2). However, when looking into their distribution, we found that I-40 (MM#340-347) are mainly sensitive to traffic jams while I-75 (MM#150-161) are prone to get affected by severe weather such as frequent foggy weather. Besides, the second major factor is hazards on the mountain road, which accounts for over one-fourth of total reports.

Table 1 shows the basic road information of two corridors. The Annual Average Daily Traffic (AADT) implies that two corridors are heavily used. Also, the truck percentage indicates that the two corridors carry heavy freight. Meanwhile, the vehicle speed limit for passenger cars is over 60 Mph that is usually designed on "good" road conditions. The road downgrade trends captured from Google Earth gives us insights into the driving road condition. Usually, the significant downgrades, individually or along with wet road surface, could lead to slipping and overturning. Plus, the frequent truck freight, the crash severity is immeasurable.



(a) I-40 (MM#340-347) **(b) I-75 (MM#150-161)**

Figure 2. Frequent Waze report types on target corridors

Table 1. Corridor configuration

Interstate	Direction	Terrain	Lanes	SL(Mph)	AADT	Truck percentage	Grade (E/N)
I-40 (MM#340-347)	Eastbound	Mountainous	2	60	41790	30%	
	Westbound	Mountainous	2	60	48940	26%	
I-75 (MM#150-161)	Northbound	Mountainous	2	70	31170	33%	
	Southbound	Mountainous	2	70	30350	33%	

Objectives

This proposal is trying to improve the road safety in the road segments of I-40 at Rockwood mountain and I-75 at Jellico mountain in Tennessee. As mentioned earlier, the traffic in these two areas is threatened by the rockslides since the geographical location proximity to the mountains. Also, as the crashes reported by Waze data shown, these areas experience high crash-related impacts. Combining weather data shows that the crash rate is also associated with weather conditions, in which severe weather increases the possibility of crashes. Based on the experiences of previous studies and traffic engineering acknowledge, the crash rate is also related to the road grade condition. This report aims to propose strategies to reduce the crash rate and improve road safety in different situations based on factors affecting the crash rate and crash reports. Proposed strategies can be extended to other roads in similar situations.

Requirements

The proposed solution aims to reduce the crash rate and improve road safety. To this end, the project needs to analyze the factors affecting the crash rate by accessing crash rate data such as

Waze data, and combining weather data, grade information, and Google Application Programming Interface (API) data. This solution requirements are present as follow:

- Assessing the crash rate based on big data collected from Waze;
- Identifying how weather affects crash rate by combining crash rate data with weather condition data;
- Identifying how road grade affects crash rate by doing road cross-section and vertical alignment analysis;
- Reducing the crash rate from different aspects;
- Improving road safety.

Stakeholders

Figure 3 presents a framework of interaction between stakeholders. In this framework, TDOT will be in charge of project supervision and providing policies, funds, and the authority of accessing the databases for this project. The partnership with universities, regional agencies, and consultants consists of re-designing, maintenance, and operations of a safer roadway system. Users including travelers, commercial drivers, and business sponsors are the beneficiary of this safer roadway system. In turn, they can also serve as probe vehicles and help with the collection of traffic data.

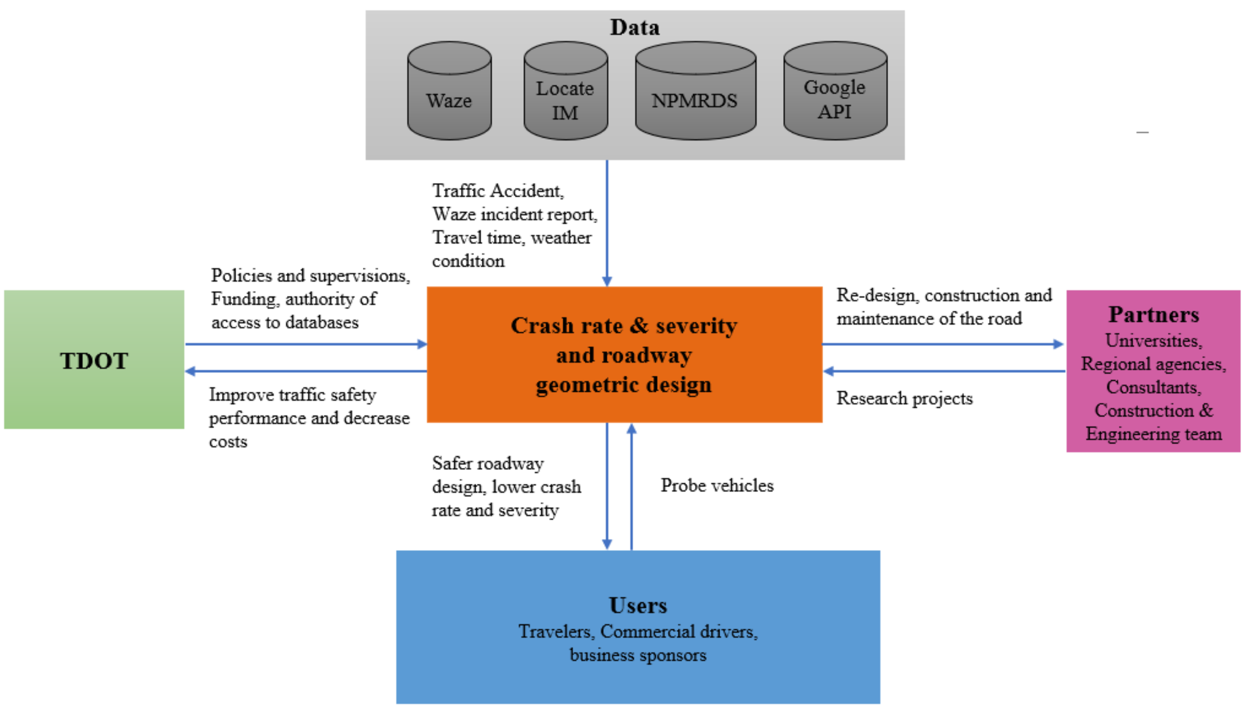


Figure 3. The framework of Stakeholders' relations

Problem Scopes

The proposed solution is essential and challenging in many ways. The study is scoped in the following order to make it more manageable and prosperous.

- The main focus of this solution will be on monitoring and improving roadway safety in the two corridors.
- The proposed solution is mainly a research project. This study can develop the algorithms, assess strategies, and design the infrastructure construction and database servers to implement the system.
- This solution might have some limitations due to the timeliness of crash data.
- The solution might involve in the tradeoff between cost and benefits.

To achieve the goal in this scope, the data collection is critical in providing accurate and effective suggestions. Both historical and real-time data are helpful to this project. Fortunately, TDOT has an agreement successfully with Waze through Connected Citizens Program (CCP) to share data. In terms of incident reports, critical crowdsourced data can be collected for this solution. NPMRDS provides the traffic flow data for evaluating the performance of the target corridors. Locate IM data, which was also released by TDOT, includes the crash records of target corridors. It's also essential to extract the weather condition in target areas including precipitation and temperature from the Waze report and online weather report.

DESCRIPTION OF SOLUTION

Crowdsource data provide us timely and useful instruction in diagnosing problems, predicting, and making decisions. The approach proposed in this project requires crash-related data. First of all, the data used in our framework and their major applications are briefly described in the following sections. Based on the crowdsourced data, a series of specific and systematic measures are put forward to prevent the crash and reduce the crash severity of our target road areas.

Data introduction

In this proposal, probe vehicle data, official data, and Google API data are adopted. TDOT has established partnerships with Waze through Connected Citizens Program (CCP) to share data. Based on the agreement, Waze provides TDOT with users' reports such as jam and weather reports, which is the main dataset used in this project. Also, another kind of probe vehicle data provides us with segment travel time and speed information. Official crash records are from TDOT's Locate IM, which contains the time and location of crashes on the interstate highways. Besides, third party data coming from the weather website and National Oceanic and Atmospheric (NOAA) are downloaded to provide weather information including temperature, humidity, and precipitation. In the following two sections, Waze report data and Google API data are specifically introduced.

Waze report data

Compared with detector-based data, Waze reports are not restricted by land use, which is more flexible. As a Waze user, we can report traffic jams, accidents, work zone, weather, hazard on the road, and so on. The Waze users are moving 'eyes' monitoring the real-time traffic status. The workflow of Waze reports is described in Figure 4. First of all, in the data coming from the Waze, the users report what they encountered according to the designate incident type. Then Waze retrieves reports from all of the users, integrates them, and provides route navigation for users as feedback. Apart from the live data, all of the reports can be achieved in the historical library and serve as the incident library for each specific route, which will help us better understand the health status of routes.

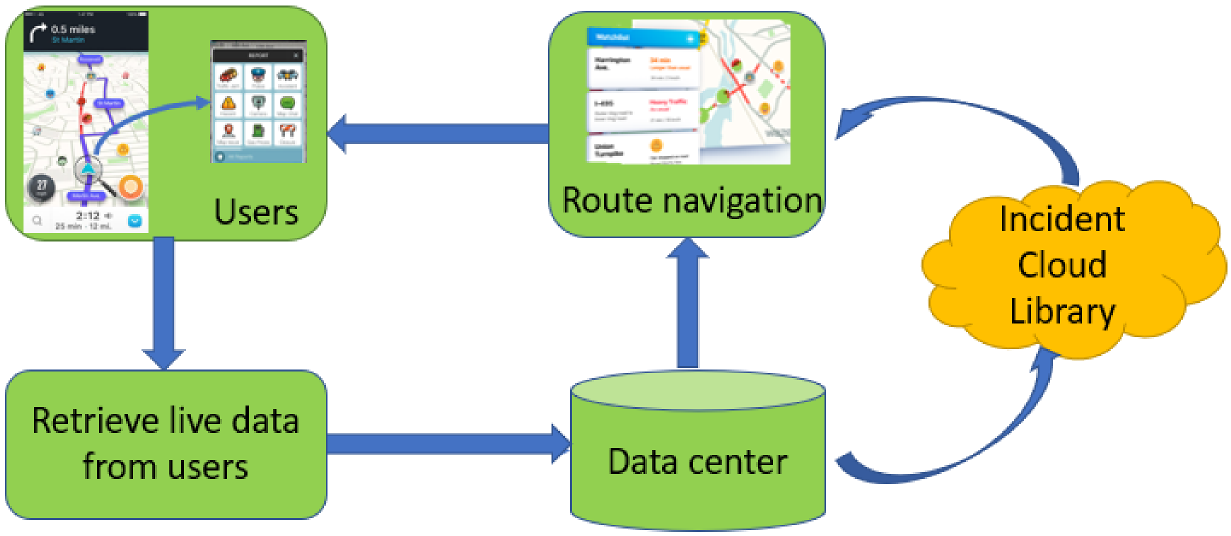


Figure 4. Waze reports retrieval

Google API data

Third-party data like GOOGLE API plays an important role in accessing supporting information. Here, GOOGLE API is a general term that includes all free data websites who provide free data download interfaces after signed the agreement. In this project, we are free to access weather information including temperature, humidity, and precipitation by the API provided by NOAA. Besides, Twitter, a kind of social media, also opened its API. By analyzing tweets from twitters containing traffic information will add the reliability of our decision making. Those API data is free to us, and we fully utilized them as complementary information.

Applying historical data

To reduce the crash rate of these two corridor sections and improve their road safety, the safety status of the road, that is, historical crash statistical analysis, crash spatial distribution, and causes of crash distribution, need to be explored at the first step. This section shows historical data analysis based on the dataset discussed above from 4 aspects: crash rate, crash severity, crash hotspots, and crash cause distribution (Figure 5). Those indexes not only serves as the metrics measuring the corridors safety status but also as inputs for real time predictive in the next static engineering and dynamic remedies.

Crash rate

According to the FHWA's definition, the crash rate is an effective index to measure the relative safety at a particular location and determine the crash level of a particular road by comparing to the average road of the entire transportation network. The crash rate is computed as the number of crashes per 100 million vehicle-miles of travel. Thereinto, total numbers of roadway crashes, AADT, and length of the roadway segment can be obtained from Locate IM and NPMRDS dataset, respectively.

Crash severity

To further clarify the severity of the crash, the fatality rate of the crashes will also be computed as the total number of fatality crashes over the total number of roadway crashes in the project areas. This metric is used to quantify the severity of crashes, which incorporates the hierarchical design.

Hotspot visualization

Making hotspots chart is an effective way to visualize the spatial distribution and density of geographic data, thus help us to discover the segments with high crash risk. Crash hotspots can explain the crashes' location and distribution density, helping us to determine the crash-prone area. To mine the crash hotspots, the following steps are listed:

- Import the road segments shapefile obtained from Google API to ArcGIS software;
- Import the crash data which includes the geographic coordinates information of each reported crashes obtained from Waze and Locate IM dataset;
- And make crash hotspots plot by ArcGIS hotspots tool

Crash cause distribution

Another information open to the public is the crash cause distribution, which is a kind of road safety diagnosis. Only in this way can we act appropriately to the situation. the causes and detail of each crash in the project period and on the study road segment are concluded periodically. In this module, we are dedicated to realizing:

- Combine all detail information of each crash
- Summarize the weather information of each crash, including precipitation, temperature, and other extreme weather
- Collect the vehicles speed before the crash
- Summarize the location information of each crash and record the grade in that segment
- Summarize the cause of the crash

Static engineering measures

Based on the historical crash and weather data collected for the two target mountainous areas, analysis from the static engineering perspective can be done in terms of infrastructure construction work. First, a geometric re-design of the roadway segments is essential, especially for those segments with relatively larger grade conditions. Besides, roadway maintenance is also one of the effective measures we can do to improve safety conditions. Those hotspots found in the last section require special attention because of the high density of Waze incident reports and a high crash rate. Some spots might have a large grade which has already been analyzed while others might not. For those hot spots with normal grade conditions compared to surrounding links, roadway redesign might not work to improve traffic safety. There are possibly some other factors contributing to a high report density and crash rate such as rockslides and flood when extreme weather happens. In this situation, it is necessary to assess the feasibility and necessity of mountain consolidation in these specific areas. Another aspect of engineering analysis consists in providing construction suggestions and operational guidelines. This involves domain knowledge in operations research in terms of minimizing construction costs and the impact of the construction on the current traffic. Also, specifically, for both two corridors, we can install a dynamic message sign in front of the crash hotspots segments; and for interstate highway I-75(MM#150-161), we can reduce the speed limit to 60 Mph to decline the risk of crash especially in foggy weathers referring to the research on the speed limit and crash rates.

Dynamic predictive operation

To build a warning system that contains different levels of the potential crash, we equipped our Road Brain with artificial intelligence (AI) techniques. This system takes advantages of AI's ability that is processing multisource data and measuring the impacts by weight automatically. Hence, it can help us deal with different traffic scenarios.

To be specific, we apply one of the AI techniques, deep learning networks, to train the model. Firstly, we extract features hour by hour from different historical data resources including weather conditions, grade levels, traffic volume, travel time, number of Waze reports. Then we import these features into our model (described as Road Brain) to process the data. Given different accident frequencies and severities, we label the hourly warning levels of the two areas ***from no severity to high severity as No Alert (0%), Yellow Alert (0%-30%), Orange Alert (crash probability 30%-70%), and Red Alert (crash probability over 70%)***, which are regarded as the outputs of models and used to forewarn drivers passing through mountainous highways. The mechanism of the dynamic warning system is shown in Figure 5. After testing the models, we apply it as a dynamic predictive tool. Next time, when we obtain the new hourly data of the inputs as mentioned above, we can apply the model and obtain the different levels of alert. In the end, our warning system will send out warning alerts 1-3 miles away from the dangerous area and the distance is computed based on travel speed and traffic status on that road.

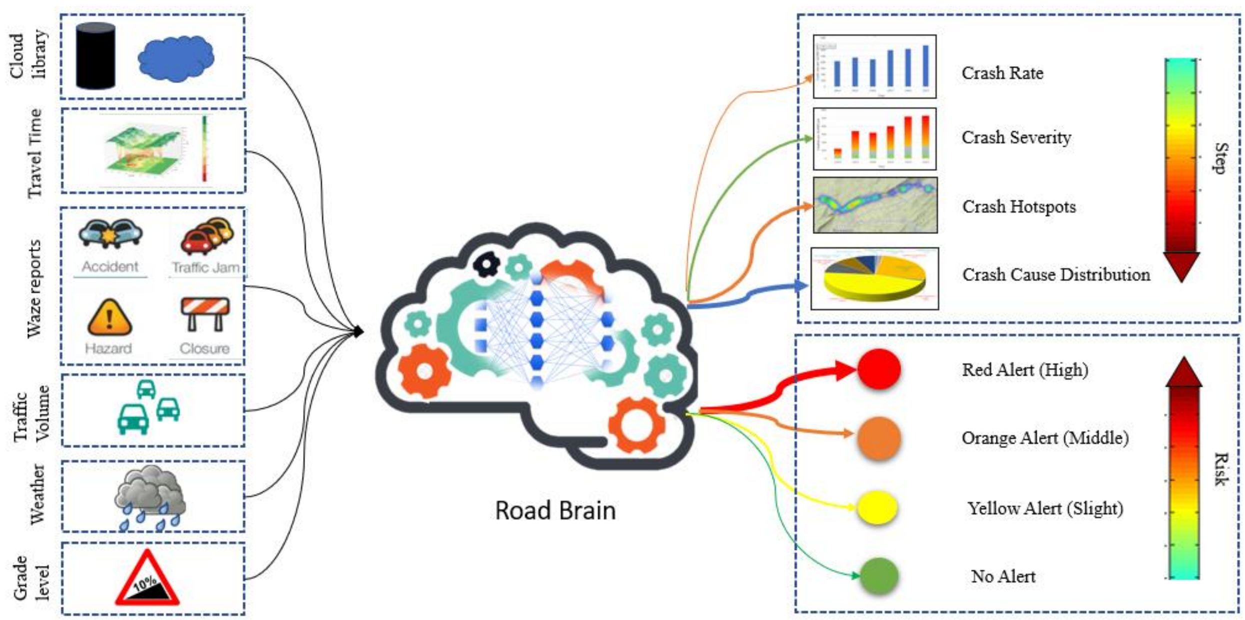


Figure 5. The framework of Risk Warning System

Data management

We want to build a data center to store all of the databases in the cloud library and connect it to our proposed deep learning model. With multiple available data sources, it is more efficient to copy and store them in a new data warehouse. This data center will serve as the database for our analysis work and warning system. The data center can provide necessary and accurate information for all road users through mobile phone applications, text, or dynamic message signs.

Before-After analysis

This rural roadway safety improvement project is designed to last for a long period since the evaluation of the solution can only be done after our measures being taken. This before-after analysis framework is mainly composed of four parts. First, we need to determine what kind of data needs to be collected, such as accident reports, fatality statistics, weather conditions, and so on. To evaluate the safety condition before and after scenarios, quantitative and statistical models can be proposed and developed with the availability of different data.

Before the starting of the construction phase, mining and exploring the historical data are essential and could provide insightful and necessary information for us to get an overview of the traffic condition within these two areas. Measurements that could be calculated in this phase include crash rate, fatality rate, hotspots of high report density, and the distribution of the causes of the accidents.

In response to those most frequent causing factors, some effective engineering measures can be taken to improve road design and thus increasing the safety level. With these measures taken, a reassessment is needed to judge the performance. With newly incoming data, metrics like crash rate, fatality rate, hot spot, and accident causes distribution can be recalculated. Finally, we implement a deep learning method to establish a real-time warning system to provide road users with useful and timely traveling suggestions.

CON-OPS FOR SOLUTIONS

Figure 6 describes the high-level architecture of the proposed system using flow charts. The functional architecture mainly consists of building a deep-learning-based risk warning system incorporating all of the available data sources and exploring the historical data to acquire useful information. The outputs of the data mining include but are not limited to roadway vertical alignment analysis, crash rate and fatality rate computation, hot spot identification and crash causes distribution. The warning system provides different levels of risk notification based on deep learning network incorporating the historical and real-time data. Construction work such as dynamic message sign installation, replacement of speed limit sign, roadway re-design and maintenance constitute in the high-level physical architecture of our project. This involves in equipment purchase, recruiting construction team, scheduling work time and dividing work zone.

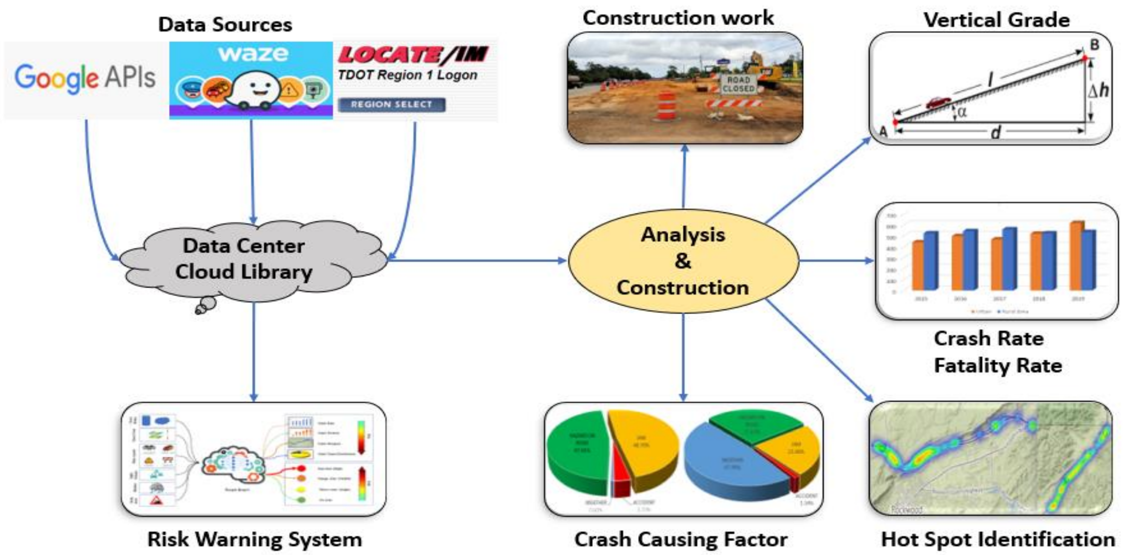


Figure 6. High-level architecture of the proposed system.

COST BREAKDOWN AND TIMELINE

The cost breakdown and timeline are provided in Table 2. Costs and time requirements are estimated for the development of the system. Besides personnel/travel costs for preparation, computation, and analysis, the project's costs mainly come from data management and construction. We need to initialize the equipment for the Data Center such as computers, powers, etc. We also investigate labor and resources to maintain the ongoing incident cloud library. For the constructions, our solutions firstly aim at setting up warning messages and speed limit signs in the mountain area. Then we re-design roadways and consolidate mountains to enhance the safety levels. The timeline for the warning system and construction is anticipated to be 36 weeks. The first month is to build the data center. Another month is to compute the model using AI. After that, we need about 20 weeks to build the warning system signs and re-construct the road with higher safety levels. Finally, we evaluate and report the performances of our solutions and make a before-after analysis.

Table 2. Cost breakdown and Timeline

Stage	Task Name	Cost Type	Period (in Weeks)																																			
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
1	Preparation																																					
	Background Research	Personnel cost																																				
	Target Areas & Segments Selection	Personnel cost																																				
	Field Investigation	Personnel cost/ Travel cost																																				
	Design improvement scheme individually	Personnel cost																																				
2	Data Management																																					
	Data Collection	Free (including Waze)																																				
	Road Brain Construction	Initialization cost																																				
	Incident Cloud Library	Maintenance cost (ongoing)																																				
3	Computations																																					
	Historical Data Mining (Crash/Fatality Indices)	Personnel cost																																				
	Multi-level Risk Warning System	Personnel cost																																				
4	Construction Work																																					
	Install Dynamic Message Sign	Installation cost																																				
	Replace Speed Limit Sign	Installation cost																																				
	Schedule for Road Construction Work	Construction cost																																				
	Roadway Re-design	Construction cost																																				
	Mountain Consolidation	Construction cost																																				
5	Analysis																																					
	Performance Evaluation and Report	Personnel cost																																				
	Before-after Analysis	Personnel cost																																				

ANTICIPATED IMPACTS

The probability of crash predicted based on the inputs of weather, travel time, road grade, and Waze reports (Figure 5) on the specific road section is expected to help to know the possibility of road crash accidents at any time and any place in advance. Different levels of alerts can be divided into green alert, yellow alert, orange alert, and red alert according to the predicted crash probability value from small to large. The prediction results are expected to reduce the crash rate and improve road safety. However, in addition to the benefits of the proposed solution, there are also some concerns in different aspects. The possible impacts of the proposed solution are anticipated from five aspects and shown in Table 3.

Table 3. Anticipated impacts of the proposed solution

Impact aspect	Benefit(s)	Risk(s)
Operational aspect	The transportation department can prepare for crash risk in advance and take corresponding preventive measures	The Crash management plan can be disrupted by incorrect prediction results
Safety aspect	Improve road safety by providing predictive risk of crashes	Reduce the driver's agility when the predictive probability of a crash is low
Mobility aspect	Reduce travel time delay caused by crashes	\
Traffic infrastructure aspect	Reduce road damage caused by crashes	\
Economic aspect	Reduce expenses for accident management and medical assistance	Increase the loss of transportation facilities

CONCLUSION

This proposal aims at mitigating the crash rates and severity on the interstate highway I-40 (MM#340-347) nearby Rockwood Mountain and interstate highway I-75(MM#150-161) close to Jellico Mountain where there experiences high crash rate due to bad weather, road conditions and so on. To achieve this goal, we propose a systemwide and Road Brain centered framework. This framework is supported by historical and live data including Waze, and Google API data. In function, the proposed framework can provide a multi-level crash warning for road users. meanwhile, by incorporating the crowdsource data, our solution can make schedules for road construction work. In improving the current road driving environment, we also list the corresponding measures to remedy such as reducing the speed limit to 60 Mph on I-75 (MM#150-161) and mountain consolidation suggestions. In conclusion, our proposed approach can fully utilize crowdsource data and easy to be implemented for practical traffic issues.

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