CPBS
Center for Pedestrian and Bicyclist Safety

A Tier-1 University Transportation Center

Elevating Traffic Safety in Native American Communities: A Comprehensive Approach with Online Mapping and Crowdsourcing Solution

June 2025	A Report From the Center for Pedestrian and Bicyclist Safety

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About the Center for Pedestrian and Bicyclist Safety (CPBS)

The Center for Pedestrian and Bicyclist Safety (CPBS) is a consortium of universities committed to eliminating pedestrian and bicyclist fatalities and injuries through cutting-edge research, workforce development, technology transfer, and education. Consortium members include: The University of New Mexico; San Diego State University; The University of California Berkeley; The University of Tennessee Knoxville; and The University of Wisconsin Milwaukee. More information can be found at: https://pedbikesafety.org

Disclaimer

Acknowledgments

This study was funded, partially or entirely, by a grant from the Center for Pedestrian and Bicyclist Safety (CPBS), supported by the U.S. Department of Transportation (USDOT) through the University Transportation Centers program. The authors would like to thank CPBS and the USDOT for their support of university-based research in transportation, and especially for the funding provided in support of this project.

TECHNICAL DOCUMENTATION

<table>
<tr><td>1. Project No.
24UNM04</td><td>2. Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">4. Title and Subtitle
Elevating Traffic Safety in Native American Communities: A Comprehensive Approach with Online Mapping and Crowdsourcing Solutions</td><td>5. Report Date
June 2025</td></tr>
<tr><td>6. Performing Organization Code
N/A</td></tr>
<tr><td colspan="2">7. Author(s)
Su Zhang https://orcid.org/0000-0002-0396-2518
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N/A</td></tr>
<tr><td colspan="2" rowspan="2">9. Performing Organization Name and Address
Center for Pedestrian and Bicyclist Safety
Centennial Engineering Center 3020
The University of New Mexico
Albuquerque, NM 87131</td><td>10. Work Unit No. (TRAIS)</td></tr>
<tr><td>11. Contract or Grant No.
69A3552348336</td></tr>
<tr><td colspan="2" rowspan="2">12. Sponsoring Agency Name and Address
United States of America
Department of Transportation
Office of Research, Development, and Technology (RD&T)</td><td>13. Type of Report and Period Covered
Final Research Report – June 1, 2024 to May 31, 2025</td></tr>
<tr><td>14. Sponsoring Agency Code
USDOT OST-R</td></tr>
<tr><td colspan="3">15. Supplementary Notes
Report available at the CPBS website [https://pedbikesafety.org] and DOI https://doi.org/10.21949/zsqz-9q68</td></tr>
<tr><td colspan="3">16. Abstract -This research introduces a web-based crash reporting and analysis tool designed to address traffic safety disparities in New Mexico, particularly within Native American communities. Grounded in Community-Based Participatory Research (CBPR) and Volunteered Geographic Information (VGI), the platform enables local residents to report traffic collisions through an interactive map interface, supplementing under-reported official datasets. To enhance data integrity, the system includes user authentication, IP-based geolocation, and a quality control workflow for reviewing submissions. Gamification elements such as leaderboards promote ongoing engagement, while integrated web analytics track user activity and tool usage. By empowering communities to participate directly in data collection and visualization, this tool supports more equitable infrastructure planning and offers a scalable model for improving traffic safety through localized, community-informed data.</td></tr>
<tr><td colspan="2">17. Key Words
Traffic Safety, Web Application, Online Mapping, Crowdsourcing, Volunteered Geographic Information</td><td>18. Distribution Statement
No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified</td><td>20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
44
22. Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized.**

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
^oC	Celsius	1.8C+32	Fahrenheit	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

Elevating Traffic Safety in Native American Communities: A Comprehensive Approach with Online Mapping and Crowdsourcing Solutions

A Center for Pedestrian and Bicyclist Safety Research Report

June 2025

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Acronyms, Abbreviations, and Symbols

CBPR	Community Based Participatory Research
FARS	Fatality Analysis Reporting System
GDAL	Geospatial Data Abstraction Library
GUI	Graphical User Interface
NMDOT	New Mexico Department of Transportation
OSM	Open Street Maps
QA/QC	Quality Assurance/Quality Control
UUID	Universally Unique Identifier
VGI	Volunteered Geographic Information

Abstract

This research introduces a web-based crash reporting and analysis tool designed to address traffic safety disparities in New Mexico, particularly within Native American communities. Grounded in Community-Based Participatory Research (CBPR) and Volunteered Geographic Information (VGI), the platform enables local residents to report traffic collisions through an interactive map interface, supplementing under-reported official datasets. To enhance data integrity, the system includes user authentication, IP-based geolocation, and a quality control workflow for reviewing submissions. Gamification elements such as leaderboards promote ongoing engagement, while integrated web analytics track user activity and tool usage. By empowering communities to participate directly in data collection and visualization, this tool supports more equitable infrastructure planning and offers a scalable model for improving traffic safety through localized, community-informed data.

Executive Summary

This research addresses the growing need for more inclusive and accurate traffic collision data by building a community-centered web application that allows local residents – particularly within Native American communities – to report crashes and interact with spatial tools for traffic safety analysis. Grounded in the principles of Community-Based Participatory Research (CBPR) and Volunteered Geographic Information (VGI), the platform serves both as a data collection tool and as a medium for civic engagement.

The project modifies an existing crash mapping application to incorporate VGI functionality, enabling community members to submit reports through an interactive map interface. These submissions are structured using a standardized form aligned with New Mexico Department of Transportation (NMDOT) datasets. To support this expanded functionality, a user management system was developed, allowing individuals to create accounts, log in, and manage submissions. Authentication was implemented using best-practice hash-salt techniques to ensure data security.

A core focus of this work was developing a quality control process to address the known limitations of VGI data. IP addresses are logged and geolocated to help detect automated or malicious submissions. Reports are reviewed through a dedicated QA/QC interface, where trained users can approve or deny entries. Web analytics were also incorporated to monitor site engagement, assess the use of individual tools, and evaluate user behavior patterns – insights that help guide iterative improvement of the platform.

To encourage sustained use, gamification features were added, including a leaderboard that ranks users based on approved submissions. This not only increases participation but also fosters a sense of ownership and motivation around improving local safety conditions.

Ultimately, this tool was built to serve communities that are historically underrepresented in transportation datasets and planning processes. Native American communities experience significantly higher rates of pedestrian and vehicle collisions, a trend tied to systemic disinvestment, low car ownership, and limited infrastructure. By equipping these communities with a way to report incidents and view collision patterns, the platform aims to bridge data gaps and inform resource allocation.

This project demonstrates how the integration of CBPR, VGI, and accessible web technology can help generate meaningful, community-driven data while empowering users to play a direct role in shaping safer transportation networks. Future work will involve outreach and dissemination efforts to increase platform visibility and deeper statistical analysis comparing VGI data with formal state records. The tool is open-source and scalable, designed to be adapted by other agencies or regions facing similar disparities in traffic safety and reporting infrastructure.

Introduction

Traffic collisions are responsible for over 3200 deaths a day, and disproportionately affect vulnerable users including pedestrians, motorcyclists, cyclists, and users of micro-mobility devices such as e-scooters (WHO, 2023). The prevalence of traffic collisions causes not only untimely deaths but also raises the burden on both the local economy (on average, countries spend about 3% of their GDP on traffic collisions) and the surrounding community, with family members and friends having to take time off work to care for injured parties and come together to pay off expensive treatment (Bougna et al., 2022).

Reducing the frequency and severity of traffic collisions will require effort from the community to identify and fix problems with current infrastructure and laws. One way to increase community engagement is through the practice of community based participatory research (CBPR). CBPR encourages local members to assist with research pertaining to their own community. This fosters long-lasting relationships and trust between researchers and the community, leading to increased community engagement and adoption of research suggestions. Enabling community members to contribute to traffic collision databases offers a promising approach to harnessing public engagement and local knowledge in efforts to reduce the frequency of traffic incidents. Web-based tools that visualize traffic collision hot spots can empower community members to identify high-risk areas and make more informed decisions to enhance their personal safety.

Formal crash datasets generally come from federal or state agencies and will often consist of only fatal or serious crashes such as the Fatality Analysis Reporting System (FARS) (US Department of Transportation, 2020). In addition to excluding less severe cases, datasets such as this are often reported by police officers at the scene, who have been shown to under-estimate injuries (Ferenchak & Osofsky, 2022). Studies utilizing formal datasets can significantly misrepresent the rates of traffic collisions and mischaracterize local hot spots (Younes & Noland, 2025; Fischer et al., 2022). One way to supplement these formal datasets and to bridge the gap between reality and data is by utilizing civic engagement in the form of volunteered geographic information (VGI).

VGI is a use of community engagement in which community members actively participate in scientific data collection. By utilizing this form of crowdsourcing, large datasets can be created in a timely manner. While VGI data has been adopted by several studies to address this gap (Chand et al., 2021; Fischer et al., 2020, 2022; Hologa & Riach, 2020), there has been some doubt as to the quality of VGI generated data. A primary challenge with VGI is ensuring data quality, as contributions can come from individuals with varying levels of expertise, accuracy, and motivation. To mitigate this concern, any submitted data should be reviewed by an expert and data collectors should be subject to some level of training to increase the overall experience level of the contributor base. If data quality concerns are accounted for, VGI data can be used to successfully augment datasets that are under-reported or expensive to generate with formal means.

This study aims to address two key research objectives: (1) to explore how Volunteered Geographic Information (VGI) can help mitigate the issue of under-reported traffic collisions, and (2) to examine how an online traffic crash mapping portal can support community engagement and informed decision-making related to traffic safety in Native American communities. To address the first objective, a crash-reporting tool will be integrated into an existing dynamic crash-mapping platform, enabling users to contribute localized collision data that supplements official records from the New Mexico Department of Transportation (NMDOT). This approach is intended to enhance the completeness and spatial resolution of traffic collision data across New Mexico. In pursuit of the second objective, the study will leverage VGI as a means to foster community involvement, raise awareness of high-risk areas, and promote caution among residents in and around identified traffic hot spots.

Literature Review

Community Based Participatory Research

CPBR is a framework that highlights using feedback from community members to improve and shape ongoing research. Research using this framework can utilize the knowledge and experience of community members to iteratively improve the community and knowledge generation. CBPR has been utilized in a variety of fields including public health (Franco et al., 2021; Harris, 2021; Haynes et al., 2022; Lindsjö et al., 2021; Nguyen et al., 2021; Roncoroni & Tucker, 2024; Yau et al., 2024), waste reduction (Amauchi et al., 2022), environmental exposure (Davis & Ramírez-Andreotta, 2021; King et al., 2021), and crash reporting (Chand et al., 2021; Fischer et al., 2022; Hologa & Riach, 2020).

CBPR focuses on building relationships with community members and relying on that relationship to perform research in a way that benefits both the community and researchers. Researchers can facilitate this relationship by presenting prototypes or preliminary results early and often. The loop of iterative community feedback created by this process leads to community engagement, relationship building, and constructive criticism of research. The benefits of fostering these relationships include improved adoption of research results, increased research in the community, and peer-reviewed published papers (Amauchi et al., 2022; Parker et al., 2020; Wallerstein et al., 2020; Williamson et al., 2020).

Increased community engagement in research correlates strongly with adoption of research suggestions, increases the trust between researchers and the community, and leads to stronger research done in an ethical manner (Bilotto et al., 2019). Community engagement can encompass a plethora of activities, ranging from community members participating directly in research to holding regular meetings with community members to update progress and collect feedback. Researchers can enhance the relevance and impact of their work by integrating scientific methods with the expert local knowledge held by community members. Collaborating closely with the community helps build trust and establish meaningful relationships, which in turn fosters greater confidence in research findings. This trust encourages community participation and helps ensure that research is grounded in local context and priorities (Amauchi et al., 2022; Parker et al., 2020; Wallerstein et al., 2020; Williamson et al., 2020).

CBPR has also been utilized to study and correct disparities among minority groups. Various research has implemented CBPR to mitigate disparities in health-care treatment in vulnerable populations including homeless and minority communities (Franco et al., 2021; Haynes et al., 2022; Lindsjö et al., 2021; Nguyen et al., 2021; Roncoroni & Tucker, 2024). By utilizing CBPR methodologies, these studies not only identify disparities in the treatment of vulnerable communities, they also make an impact on these communities by engaging with the community and providing solutions for the problems addressed. CBPR methodologies have also been utilized in a similar way to address inequities in mental health (Harris, 2021; Yau et al., 2024), domestic violence (Ragavan et al., 2020), and victims of humanitarian crises (Afifi et al., 2020).

In summary, CBPR offers a powerful framework for conducting research that is both ethically grounded and socially impactful. By centering community voices and fostering long-term partnerships, this approach not only enhances the validity and local relevance of research but also helps address systemic inequities across diverse fields. The collaborative nature of CBPR ensures that research outcomes are not only academically rigorous but also practically meaningful, contributing to lasting improvements in community well-being. As demonstrated across areas such as public health, environmental justice, and traffic safety, CBPR enables researchers and communities to co-create solutions that are informed, equitable, and sustainable.

VGI Data Availability and Quality

VGI is a subset of CBPR, and utilizes engaged and motivated community members to collect local information on a variety of subjects. This practice can quickly and efficiently generate large datasets that researchers can utilize. Applications of VGI include tracking of flood damage and other natural disasters or emergencies (Bayazidy-Hasanabad et al., 2021; Chow et al., 2023; Tavra et al., 2024), species tracking (Uyeda et al., 2020), and bicycle crash reporting (Fischer et al., 2022; Hologa & Riach, 2020; Tavra et al., 2024).

A significant benefit of VGI is that it can be collected quickly and efficiently as opposed to formal methods that can take years or decades to collect data that is immediately out-of-date (Bai et al., 2024; Hologa & Riach, 2020; Nelson et al., 2021; Tavra et al., 2024; Watkinson et al., 2023). VGI data can be collected quickly by concerned individuals, which can greatly increase the amount of data available during a disaster such as a wildfire or flood. In such instances, the speed that VGI data is generated at far outweighs data quality concerns, and observations of where a disaster is spreading to do not typically require expert opinions, limiting the amount of negligent errors (Bayazidy-Hasanabad et al., 2021; Chow et al., 2023; Tavra et al., 2024). VGI data collection can also be useful when formal data collection would be too time-consuming, in these cases by the time a full dataset is collected it is inaccurate. This functionality of VGI data collection has been utilized to map out bicycling infrastructure (Nelson et al., 2021) as well as city infrastructure in larger projects such as the open street mapping (OSM) project (Bertolotto et al., 2020), as well as in emergency management (Bayazidy-Hasanabad et al., 2021; Chow et al., 2023; Tavra et al., 2024).

While VGI can be used to bridge data gaps when incidents are under-reported, there are also data quality issues that need to be addressed when utilizing VGI data. There are several factors that can lead to inaccurate data collection on the part of data collectors including contributor experience level and motivation. The experience level of contributors is a significant factor in the quality of VGI reported data. Amateur contributors, while well-intentioned, can create data errors through negligent observations. There have been efforts to mitigate these types of errors through training and quality control (QC) processes (Honarparvar et al., 2021; McGough et al., 2024). At the other end of the spectrum, VGI data also has the benefit of involving local community experts in the data collection, leading to high quality data with local insights. When it comes to experience level, effort should be made to include local experts while utilizing training to improve the knowledge base of amateur contributors (McGough et al., 2024).

Contributor motivation is another factor to consider, not only for data quality purposes, but also to promote contributions to VGI projects. Some of the common motivations for contributions are improvement to the local environment, use of data created, gamification rewards, civic responsibility, and malignant purposes. When there is a clear purpose for the VGI project, such as wildlife preservation (Uyeda et al., 2020), individuals who care deeply about their local environment are incentivized to engage with the VGI campaign. Many projects allow contributors to use the continuously evolving dataset for their own uses, incentivizing users to provide accurate data about their local environment. Examples of this type of VGI campaign include OSM, BikeMaps.org, and fitness tracking services (Bertolotto et al., 2020; Fischer et al., 2020, 2022; Hologa & Riach, 2020; Nelson et al., 2021).

Gamification has been utilized with several VGI campaigns to increase user engagement. Gamification can be defined as adding characteristics or elements from games to non-game settings to enhance the user experience (Landers et al., 208). This concept has been used in a number of settings to give contributors a sense of purpose while collecting information, adding an intrinsic motivation for users to contribute to the campaign. Some examples of gamification in VGI settings include generating a navigable GPS-based map setting with a user-avatar, goal-achievements, leaderboards, and interactive elements (Apostolopoulos & Potsiou, 2022; Kim et al., 2020; Laato & Tregel, 2023; Watkinson et al., 2023).

Civic responsibility can also be considered a motivation for contributors, usually during disaster response VGI campaigns. The focus of disaster response VGI campaigns is centered around allocation of resources and fast-paced decision making. Concerned citizens can provide information in these campaigns that community leaders can use to determine where to focus relief efforts and to track spreading disasters such as floods or fires. These datasets often focus on collecting a small amount of non-expert data about the emergency status and relaying this to a central headquarters. Because the complexity of information is low, there is a smaller chance for negligent errors on the part of contributors (Bayazidy-Hasanabad et al., 2021; Chow et al., 2023; Tavra et al., 2024).

Malicious contributions represent a known challenge in VGI campaigns (Haworth et al., 2018). While the motivations behind such behavior can vary, studies have shown that these contributions often exhibit identifiable patterns, enabling detection and mitigation through careful data validation techniques. One such pattern is a mass amount of submissions from a single location, which can be tracked utilizing web analytics as discussed below. Similarly, web analytics can also be used to determine the relative geographic location of submission. When the submission occurs a great distance from the data being submitted, it can be inferred that there is some malicious intent behind the submission (Akella et al., 2023). Lastly, implementing a QC process in which all submissions are reviewed can catch suspicious cases early (McGough et al., 2024).

Traditionally under-reported datasets such as traffic collisions are good candidates for VGI campaigns (Haworth et al., 2018). VGI can be utilized to augment such datasets by encouraging community members to contribute to the dataset (Aldridge, 2023; Chand et al., 2021; Fischer et al., 2022; Hologa & Riach, 2020). For example, the only formal dataset looking at traffic collisions is the FAR dataset, which only records fatal collisions (US Department of Transportation, 2020). This excludes a large portion of samples which would aid in identifying incident hot-spots. Although approximately 3,000 fatal traffic collisions occur daily worldwide, the number of non-fatal injuries is substantially higher, with an estimated 30,000 incidents reported each day (Mohammed et al., 2019). By focusing only on fatal collisions, many formal datasets are excluding non-fatal incidents, which may reveal infrastructure or factors which are instrumental in causing non-fatal incidents (Chand et al., 2021).

Analytics

Website analytics can be used to determine website visitation, the utility of various web-based tools, and user satisfaction. Common analytical metrics include the IP addresses of website visitors (Abdelwahed et al., 2021; Martinez et al., 2023; Ogrodniczuk et al., 2021), the number of repeat visitors (Bennett et al., 2021; Ogrodniczuk et al., 2021; Önder & Berbekova, 2021), items copied to a clipboard (Kirsh, 2020; Kirsh & Joy, 2020), and user clicks (Abdelwahed et al., 2021; Jansen et al., 2022; Önder & Berbekova, 2021). These analytics allow researchers and web developers to infer user behavior patterns based on observed interactions.

By tracking the IP addresses of visitors, developers can assess the volume of site traffic. Tracking this value over time can reflect the effects of outreach efforts, site redesigns, or functionality updates. For example, some sites experience progressive increases in user sessions over several years, suggesting that content and interface improvements may contribute to sustained engagement (Ogrodniczuk et al., 2021). The relative location provided by IP addresses can also support the QC process in VGI studies. For instance, in OpenStreetMap (OSM), it would be unlikely for an IP address originating in the Netherlands to legitimately edit roads in San Francisco, CA (Bai et al., 2024; Bertolotto et al., 2020).

Beyond traffic volume, analytics help assess how users engage with specific tools. Metrics such as click frequency and clipboard copying provide insight into which tools are considered useful, underused, or unclear (Jansen et al., 2022; Muruganandham et al., 2022; Önder & Berbekova, 2021). When clipboard interactions are analyzed, copied content can be categorized to identify high-interest areas or gaps. This form of passive, iterative feedback allows designers to make continuous improvements without burdening users with surveys or interviews.

Website analytics can also serve as a proxy for user satisfaction. Metrics such as revisit frequency, session duration, and interaction rates can be used to infer how effectively a site meets user needs. These indicators help developers track satisfaction with new tools, features, and design choices over time.

Traffic Safety Disparities in Tribal Communities

Traffic fatalities have risen over recent years, especially in marginalized communities including tribal communities (Chavez Orellana et al., 2024; Raifman & Choma, 2022). As infrastructure continues to be built around motorized vehicles, identifying communities with the highest risk of incidents is imperative. There has been a myriad of work investigating various causes of traffic collision causes and the relative outcomes of traffic collisions. Socioeconomic factors have been found to be the most significant variable in predicting both traffic collision occurrence as well as severity (Babaei et al., 2022; Chia-Yuan et al., 2022; Chinnappa Nanjunda, 2021; de Cos et al., 2022; Hamann et al., 2020; Roll & McNeil, 2022; Sanders and Schneider, 2022; Williams et al., 2022).

Research has shown that communities with lower socioeconomic status experience higher rates of traffic collisions, particularly those involving pedestrians and cyclists. This trend is especially relevant for many Native American communities, where economic disparities and limited access to private vehicles contribute to increased reliance on walking and public transportation (Sanders & Schneider, 2022). Lower car ownership rates result in a higher volume of pedestrian activity, which in turn increases the frequency of pedestrian-vehicle interactions and the likelihood of collisions. This risk is further amplified by commuting patterns common in underserved areas, where many individuals work irregular hours and must navigate roadways during low light or off-peak times (Roll & McNeil, 2022; Hamann et al., 2020; Babai et al., 2022). Addressing these patterns is essential to improving traffic safety and equity in Native communities.

Redlining refers to a government-sponsored practice starting in the 1930's in which areas were graded on a scale from A-D (Aaronson et al., 2021; Taylor et al., 2023). In theory, areas graded A or B were predicted to have an increase in desirability over the next 10-15 years, while areas graded as C or D were predicted to have a decline in desirability over that same period. In practice, neighborhoods with predominantly White populations were typically assigned grades of A or B, while areas with higher concentrations of minority residents were disproportionately given grades of C or D. Areas given higher grades were eligible for housing and investment loans while areas with lower grades were not. This practice, while not explicitly continued today, has led to neglected infrastructure in communities graded as C or D. In regards to traffic collision frequency, areas graded with a C or D generally have minimal infrastructure available for pedestrian safety including crosswalks, sidewalks, and traffic lights (Aaronson et al., 2021; Taylor et al., 2023). This lack of infrastructure in minority areas can lead to worsened conditions for pedestrians and vehicles. Combining this with the general low-income status of many tribal communities can lead to increased pedestrian presence (Roll & McNeil, 2022; Hamann et al., 2020; Babai et al., 2022), which will lead to increased vehicle-to-pedestrian interactions in areas with limited infrastructure to support these encounters.

Tribal members are significantly over-represented in collisions, with various studies finding that tribal members have a much higher rate of collisions (~4x that of non-tribal communities) and fatalities (1.4x that of non-tribal communities) (Chavez Orellana et al., 2024; Wang et al., 2024). The first step to reducing this inequity is providing and collecting data on how and why tribal communities are facing the brunt of traffic collisions. There has been limited effort to create crash-reporting software for tribal communities (Vachal et al., 2020), however there has been no effort to include gamification or more advanced spatial statistical toolsets within this software. By generating new and up-to-date crash-data for tribal and other minority communities, researchers can begin to understand why these disparities exist.

Conclusion

By utilizing CBPR in the integration of VGI data, along with educational and gamification components, this research will collect data on traffic collisions in New Mexico while actively engaging the community and promoting safe driving habits. The resulting data can support future research aimed at identifying and reducing disparities in traffic collision frequency and severity across various socioeconomic groups. Website analytics will be used to mitigate common data quality challenges associated with VGI by incorporating location data into the quality control process. Analytics will also help assess the success of the site by tracking user engagement and visitation. Overall, this research brings together the concepts outlined above to develop a robust, interactive web tool that encourages community participation and contributes to reducing the frequency and severity of traffic collisions in New Mexico.

Data and Methodology

Previous Work

This project builds upon a dataset provided by the NMDOT, covering traffic collisions from 2012 to 2021. The data, originally in CSV format with point features, was collated and imported into a PostgreSQL database to enable web-based analysis and visualization. This database structure also served as a template for integrating VGI, with key fields outlined in Table 1. While the NMDOT dataset offers valuable baseline information, it likely reflects under-reporting of crashes within the state. To address this limitation and promote broader community involvement, this project incorporates VGI to supplement the official dataset and enhance local engagement in traffic safety monitoring. The data utilized for this project is currently accessible at https://www.dot.nm.gov/planning-research-multimodal-and-safety/modal/traffic-safety/traffic-records /.

Various pre-processing steps were needed to prepare data for analysis. *Day of the Week, Alcohol Involvement,* and *Crash severity* were converted from categorical data to numerical, while *Day of Week* was converted to a string value, and *Alcohol Involvement* was converted to a Boolean value. Lightning and weather were also identified as useful, however as there is currently no way to quantify these variables in a meaningful way, they were left as string values. The numeric values are utilized in the tools described below, and these fields were used the collection of VGI data to ensure consistency.

This project builds upon a Graphic User Interface (GUI) web portal that was designed to visualize data from NMDOT and perform geostatistical analysis. The portal was built using JavaScript, HTML, and CSS programming languages, and utilizes the OpenLayers package. By utilizing a python Flask API, users are able to interact with the web portal and run a select number of geostatistical tools on subsets of the entire NMDOT or VGI datasets. The analytical tools used in this project include Getis Ord General G, Getis Ord GI*, Point Density Estimation, Kernel Density Estimation, Global and Local Moran's I, Mean Center, and Median Center. The toolset was developed using the python programming language utilizing several supporting libraries such as the Geospatial Data Abstraction Library (GDAL). GDAL allows the creation and manipulation of spatial data, and is widely used because of the level of control it gives over data and metadata. The tool module can be found at https://pypi.org/project/crash-mapping-tools/0.0.2/. Each of the tools was modified from its original form to account for use of VGI data, which is further discussed below.

Table 1. VGI Crashes database table

Field	Data Type
Crash Severity	Integer
Data Type	Field
Alcohol Involvement	Boolean
Crash Severity	Integer
Day of Week	Integer
Number of People Killed in Crash	Integer
Number of People With Incapacitating Injuries (Class A) In Crash	Integer
Number of People With Visible Injuries (Class B) in Crash	Integer
Number of People With Possible Injuries (Class C) in Crash	Integer
Number of People Injured (Class A+B+C) In Crash	Integer
Number of People Not Injured (Class O) In Crash	Integer
Number of Vehicles, Bicycles, and Pedestrians Involved	Integer
Number of People in Motor Vehicles	Integer
Number of People Not In Motor Vehicles	Integer
Number of Motor Vehicles Involved	Integer
Total Number of People in Crash	Integer

To implement VGI data into the current workflow required making changes and additions to the crash mapping API and Database to support the new functionality. The following sections cover the main topics that drove the development of new features, illustrated in Figure 1.

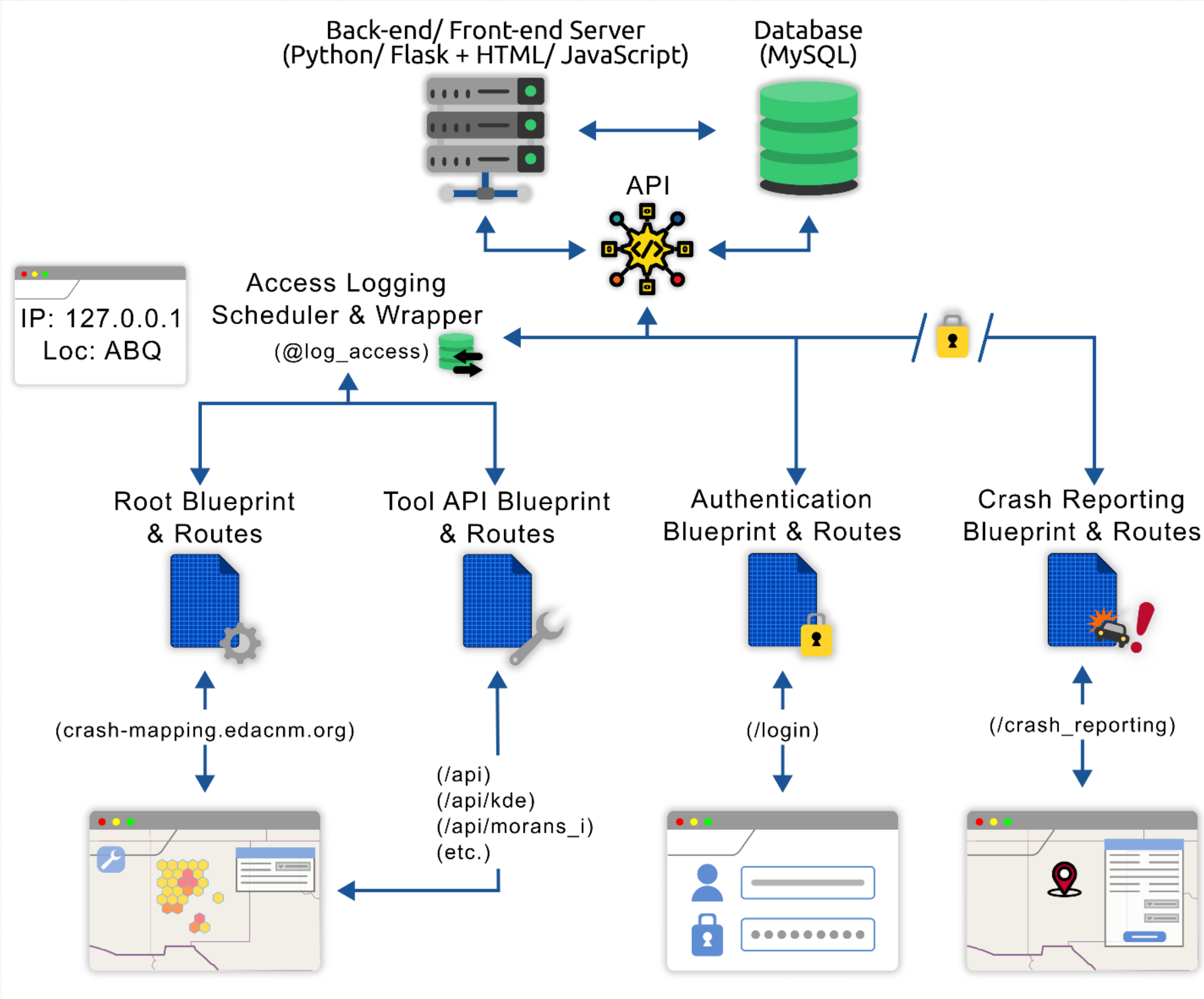

Figure 1. System architecture for the crash mapping portal. The figure illustrates the general framework of the site and how each site component is connected through the API.

Authentication

A key step in implementing the updated system involved establishing web authentication to restrict access to specific pages and site functionalities. This ensured that only users with verified accounts could access protected features, enhancing both security and data integrity. The flask_login module was leveraged in the project as it was designed to work with the flask framework. This module provided the functionality to handle logging users in and out of the application, while the team focused on creating custom credential verification for comparing user input with the stored user information in the database. To allow user authentication, two new tables were created in the database, Users and UserRoles. The Users table stores essential user information necessary for linking individuals to their submitted reports. It includes the following fields: *id*, *family_name*, *given_name*, *email*, *user_role_id*, *user_salt*, *user_hash*, and *active*. The UserRoles table is used to identify a user's access level and has columns *id* and *name*. These fields support user authentication, role assignment, and account status tracking within the system. The data contained in UserRoles is a predetermined set of three user roles, Admin, Data Manager and Reporter, which is used to limit access to what users can access in the website. Reporters are only allowed to create new reports. Data Managers are allowed to create reports and QA/QC reports that have been submitted by other users. Admins have all the same privileges as Reporters and Data Managers and includes the ability to manage users and access the site statistics page. This allows user management and the ability to limit unauthorized persons from accessing more sensitive pages in the site including administrative site tools.

It is important to note that user passwords are not stored directly in the database. This may sound counter-intuitive but this is intentional as it is generally best practice to not store plain text passwords when implementing web authentication (Prakash & Basha, 2025). For password comparison and storage, we use secure password salted hashing. This practice stores two strings in the database, the user's salt and the hash generated from their password. Salted hashing is a process to enhance password security by appending, or prepending, a unique string to the user's input (Salting) and then hashing the string. For our approach, we take the salted password and hash it using the Secure Hash Algorithm 256-bit (SHA-256), a cryptographic hash algorithm that generates unique hashes, and compare the generated salted hash to the hash that exists in the database. A benefit to this method is the increased difficulty of finding a password that matches any precomputed hash using a lookup table in the case that someone gains access to the server.

Table 2 and 3 gives examples of users and their hashes; one without salts and the other with salts. Notice in the example below, that the users Hank and Dean have the exact same hash. This is because they are both using 'venture1!' as their password. Since these passwords are just being hashed, it is easy to identify users with the same password; therefore, a bad actor would only need to find a matching password once to acquire the passwords for both accounts.

Table 2. Users and SHA-256 Hashes (Without Salt)

User	Password	Hash
Hank	venture1!	9b8b1304d9afaff7ef7d85361765ca1221289b5d5ee0c0fa396f9b2b8b51eb45
Dean	venture1!	9b8b1304d9afaff7ef7d85361765ca1221289b5d5ee0c0fa396f9b2b8b51eb45

To mitigate against lookup tables, and other brute force methods, we use the previously described salting method to salt the password before hashing. In Table 3 below, it is an updated example of users with the same password but have unique salts to hash their password.

Table 3. Users and SHA-256 Hashes with Salts

User	Password	Salt	Hash
Hank	venture1!	89d5b862-1119-4f8c-8f6c-3361009609af	de27f249dd1602d8e7570348e0f0fbd4c50d9e09d5b6b69d6861f98e7bcfb26c
Dean	venture1!	dd1e81e7-671c-416f-b9a0-2c535e69fe5a	033a9c0c9ffdbd2e61027f2bc2132e0c6a316f9353d555ead0e5279af4a78540

While every effort is made to follow established cryptographic best practices and adhere to the guidelines set forth by the Open Worldwide Application Security Project (OWASP), formerly known as the Open Web Application Security Project, no security method can guarantee complete protection (Manico et al., n.d.). We can only keep up to date with our understanding of attack vectors and well-known exploits to lessen the possibility of intrusions and make it difficult for bad actors to extract information from compromised systems.

User Management

The user management portion of the application encompasses three main segments: Tokens, Account Registration, Verification, and Password Resets and Admin User Management.

Tokens

Tokens are simple guides that are used to verify accounts following registration and to aid in resetting forgotten passwords. To store tokens, two tables were created named Tokens and TokenTypes. The Tokens table was created with the columns *user_id*, *token*, *expire_date*, and *token_type_id*. The *user_id* column allows for connecting tokens to specific users when the token is requested. The *token* column is a Universally Unique Identifier (UUID) that is generated using the python UUID module using UUID4. The *expire_date* column is used to set a limit on the amount of time that a token is good for, which ensures tokens cannot continue to be compared indefinitely and are removed from the database when expired. The *token_type_id* column is used to identify the specific token, whether it's a password reset or email verification token. When a request is made to email verification or password reset routes, a token is created, formatted and then sent by email to the requesting user as a link.

Account Registration, Verification, and Password Resets

A significant challenge in deploying a publicly accessible web application is the high volume of automated scraping activity it attracts. Implementing account registration was a critical step in enabling VGI functionality, as it significantly reduces the likelihood of spam submissions from automated web scripts scanning publicly accessible sites. The account registration process is straightforward, requiring only the user's given name, family name, and email address. The web app goes a step further and restricts access to the site by requiring anybody who registers to verify their email. This ensures that only verified accounts can log in and submit reports. This measure alone significantly reduces automated submissions, as most machine-driven scripts can follow links and populate forms but are halted at the account verification stage. Since these scripts typically do not include valid email addresses or complete the verification process, the login requirement serves as an effective barrier to spam. Along with allowing users to register, it was necessary to allow automated password resets so that there is little direct administration needed. The password reset and email verification both take advantage of the tokens previously described. Password reset tokens are linked directly to individual user accounts, making the reset process secure and straightforward. This approach ensures that only the person with access to the registered email address can initiate a password reset. Unlike some platforms that allow users to change their email addresses after registration, this application does not permit such changes. This restriction helps mitigate security risks and reinforces the use of email addresses for user validation and uniqueness.

Admin User Management

Admin User Management is a set of tools and functionality for effective site user management to help maintain the longevity and security of the web application. This was implemented to provide administrators the ability to create, edit, and manage users and their roles in the site. The Admin User Creation page is similar to the registration page, with the added benefit of being able to specify a role when creating a user. It is important to note that assigning a user an administrator role does not bypass the email verification process. All users, regardless of role, must complete the verification steps outlined in the automated email to activate their accounts. The Edit User page provides a table of users and displays user info including *given name*, *family name*, *email*, the users role, whether the user is active and a button to edit the specific user. When editing an individual account the administrator is provided with all the same information they could see in the table with the ability to edit all information except for the users email. For the same reason as registration, emails are not allowed to be changed as these are used as unique identifiers for users. The active field was created as part of the **Users** table as a way to manage and identify the verification status of individuals. When a user first registers, an account is created for them but active is set to *False*. When the user follows the verification link, this sets a user's status to active and allows the user to log in to the site. Administrators have the ability to change this status depending on the user's circumstance. As an example, in situations where a person is found to only submit fraudulent or inappropriate reports, an admin has the option to remove the user's active status, preventing the individual from logging in. This status cannot be change by password reset and persists after an admin saves the user information.

Data Reporting

To support data reporting functionality, a new Python blueprint named crash_reporting was added to the Flask application. This blueprint serves as a way to organize the web application by grouping all static resources and routes related to crash reporting in one place. In Python terms, it functions as a submodule of the larger crash mapping application, using Flask's blueprint system to maintain modularity and cleaner code organization. To store VGI data, two new database tables were created: VGIReportedCrashes and ReportStatus. The VGIReportedCrashes table is modeled closely after the original Crashes table used for NMDOT data but includes an additional relationship to the ReportStatus table. This linked table is used to track the status of each report throughout the QA/QC process, with status values including Pending Review, Approved, and Denied. The data reporting consists of two main components, the Report and QA/QC. When a user accesses the report page, they are presented with an interactive map that allows them to place a point indicating the location of the crash (Figure 3). After selecting the location and clicking 'Next,' the user is directed to a form (Figure 4) where they can enter crash details. This form mirrors the structure of the NMDOT dataset, including all the same fields to ensure consistency between VGI and official data sources. Most of the fields are integer values with only three fields being categorical or Boolean (Figure 4). The fields that are categorical fields are presented as drop down options and are converted to numerical values based on the conversions received from NMDOT when the form is submitted.

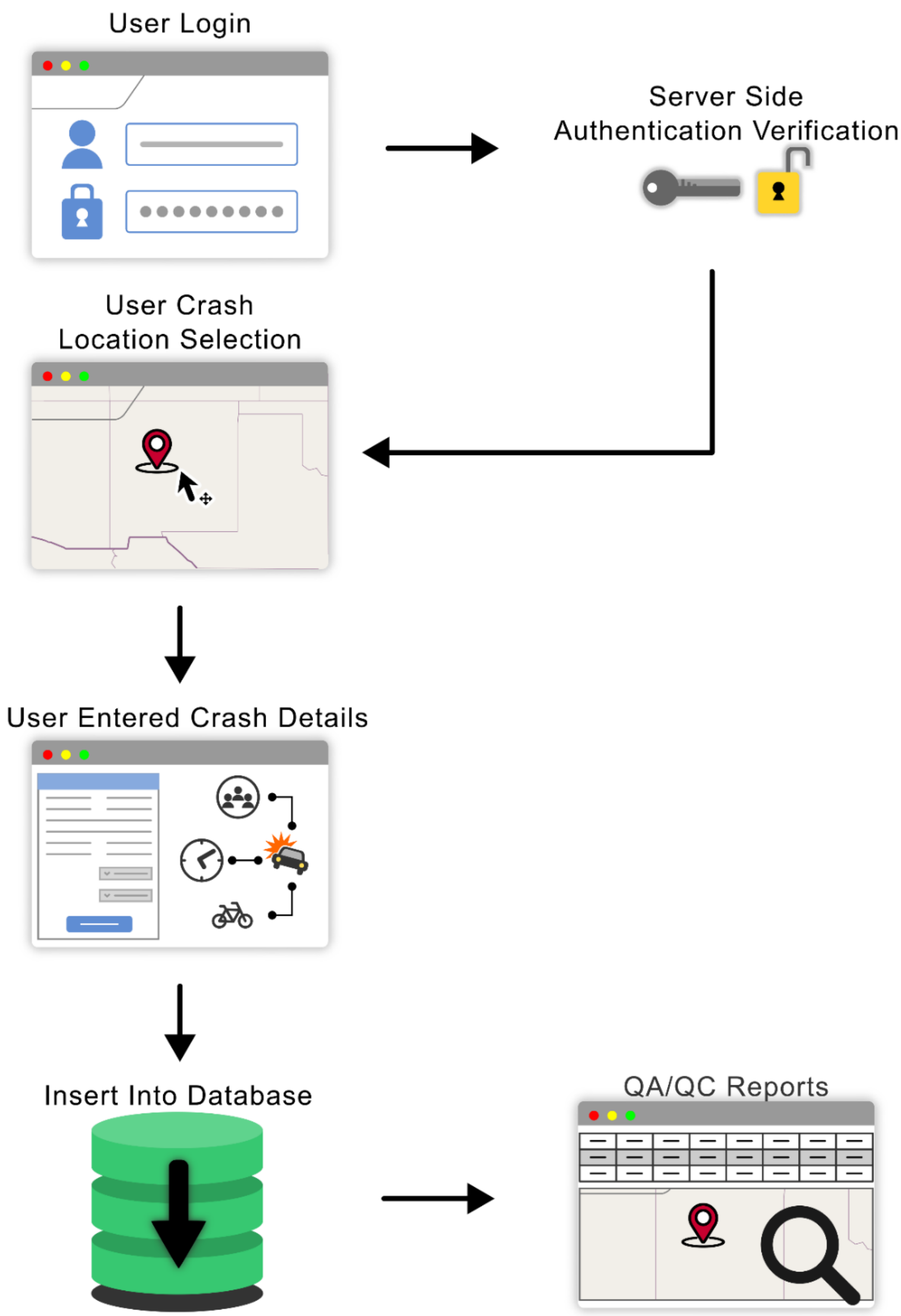

Figure 2. Workflow of the reporting process. This figure depicts the workflow of reporting from sign-in to QA/QC.

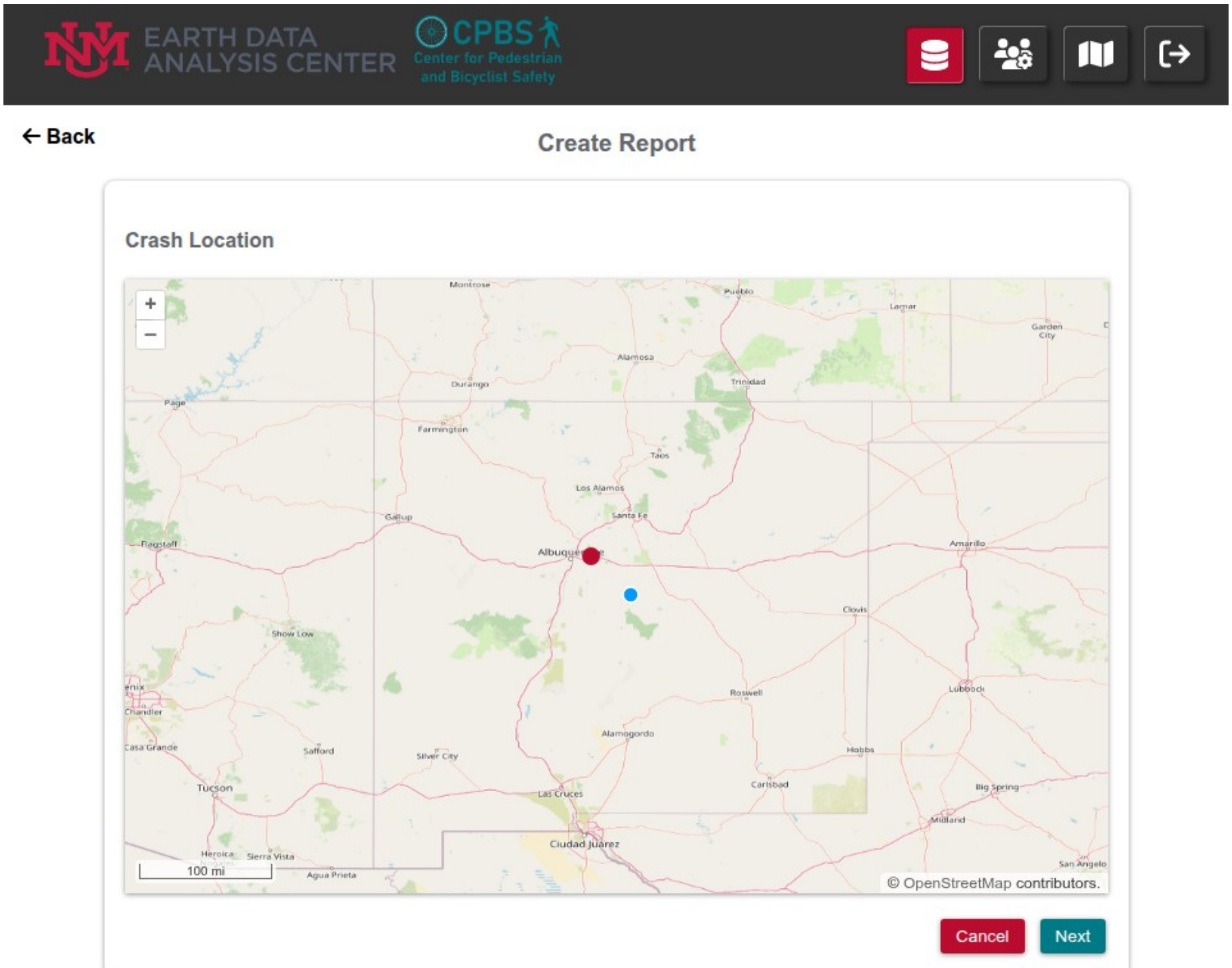

Figure 3. Crash reporting location selection page. This is the first step in reporting a crash. Users are presented with a map and asked to place a point at the location the crash was witnessed.

When a form is submitted, it is marked as Pending Review in the database. This status ensures that only un-reviewed reports are retrieved and displayed to users accessing the QA/QC page, streamlining the validation process. The QA/QC page consists of a table of reports organized by date and a map of the points (Figure 5). When a row on the page is hovered over, the corresponding point on the map is highlighted, allowing the user to quickly visualize the location of the reported crash. In order to cut down on false reports it was necessary to add the general location of the reporter to the info in the report. As part of the report submission process, the user's IP address is logged and geolocated to determine their city and state. This geographic information is included in the QA/QC interface to assist data reviewers. Each report row includes a selection checkbox, allowing reviewers to select multiple entries. Two action buttons at the bottom of the page enable reviewers to approve or deny selected reports at their discretion.

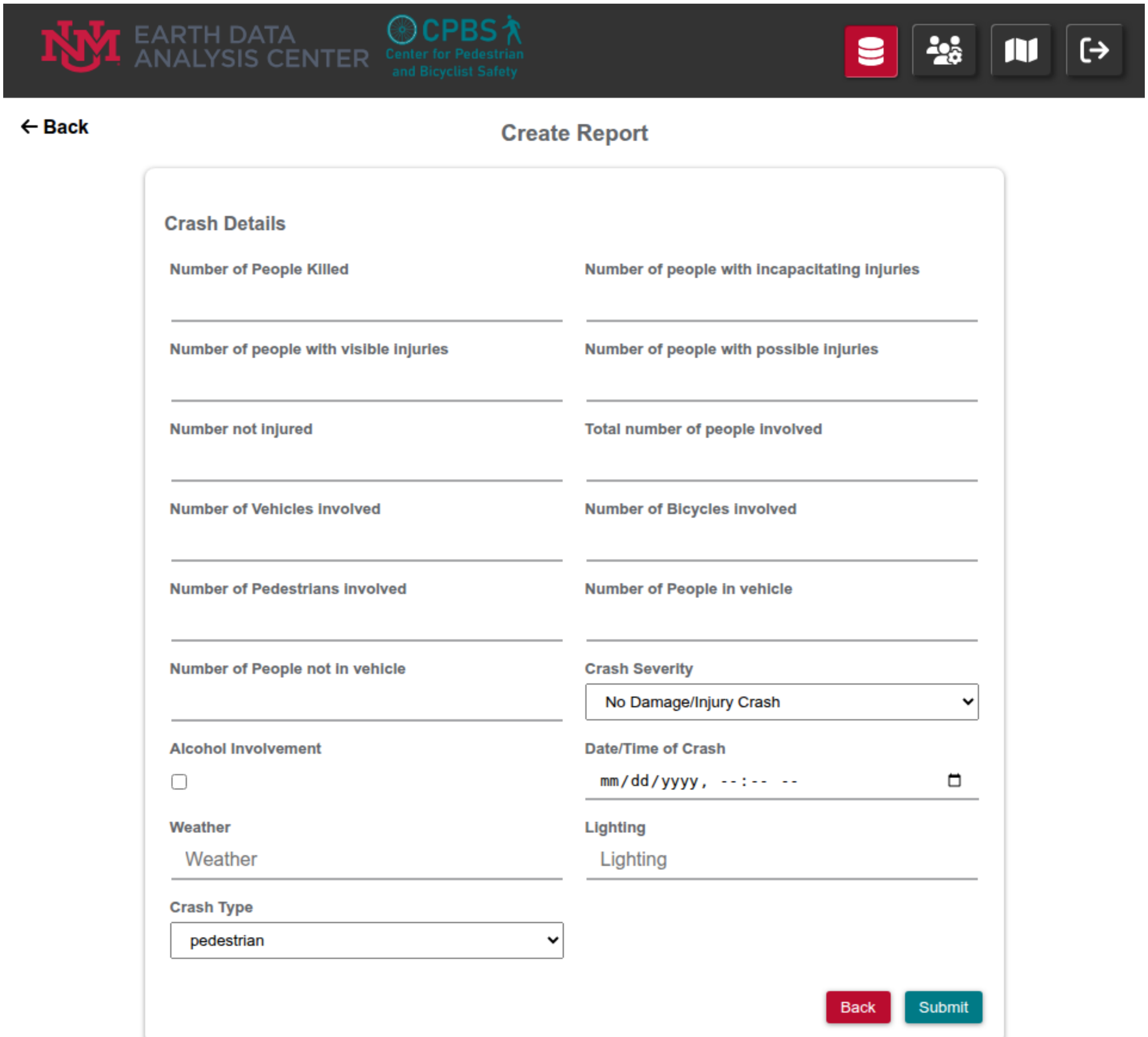

Figure 4. Crash reporting detail form page. This is the second and final step in reporting a crash. The form is for adding important supplementary information about reported crashes.

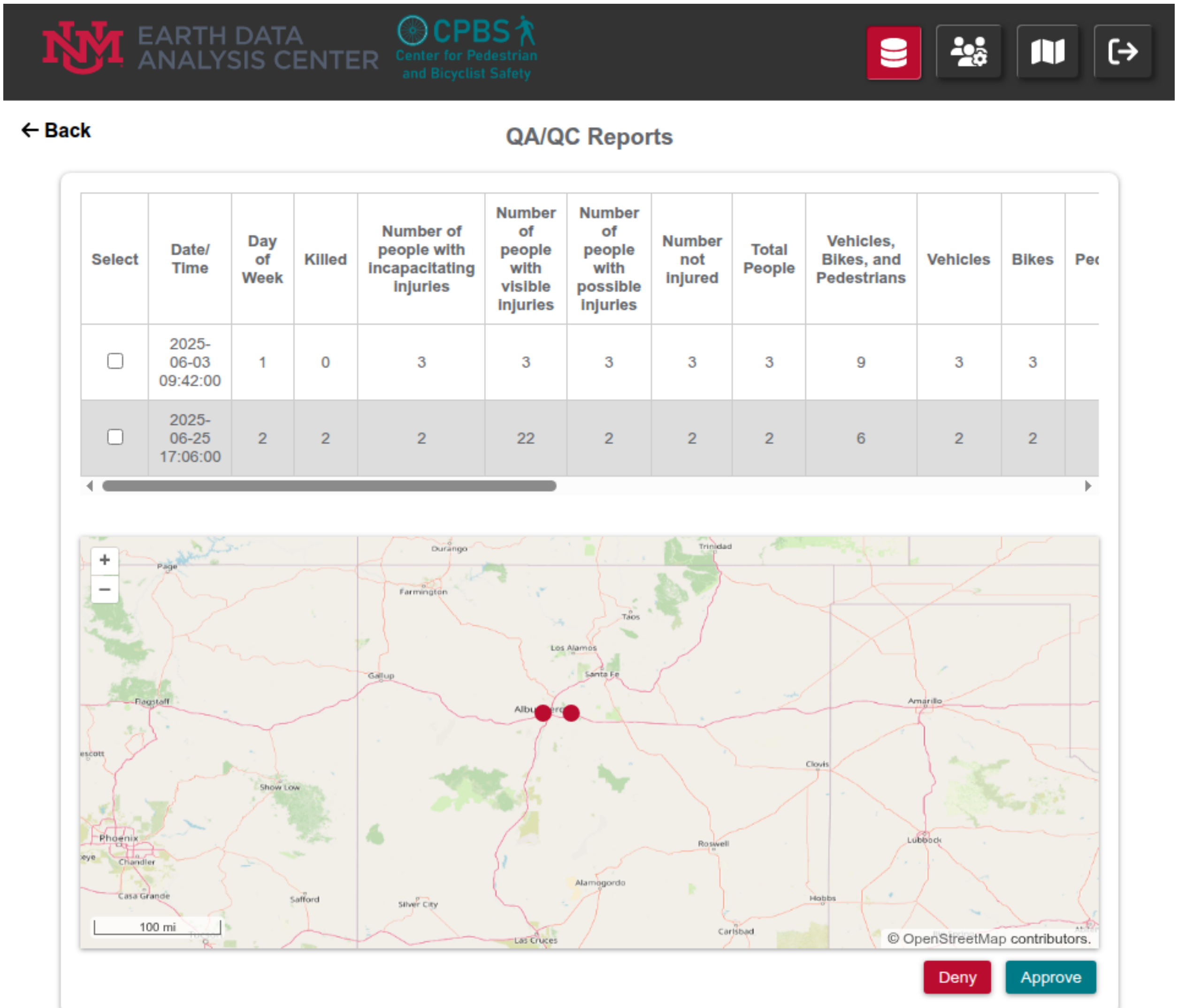

Figure 5. Crash reporting review page. The QA/QC page is the final step in reporting a crash and determines if a data point should be kept or discarded.

Site Access Information and Scheduling

The Site Access Information section of the web application was developed to provide administrators with an overview of user activity, including the number of visitors and the specific tools being utilized within the platform. An AccessInformation table was created in the database to store this information and includes the following fields: *date_time*, *ip*, *status*, *message*, *country*, *countryCode*, *region*, *regionName*, *city*, *zip*, *timezone*, *isp*, *org*, *as_num_org*, *route_accessed*, and *geom.* A custom route decorator was also implemented to wrap the functions triggered when specific routes are accessed. This decorator takes a function as input and enables the addition of supplementary functionality without modifying the original function, enhancing modularity and code reuse. In this case, the decorator was used to add logging functionality to the map tool routes and the main map, allowing the system to track user interactions with these components without altering the core logic of the route handlers. When a user accesses any of the tools or map, the logging decorator collects the user's IP address, the time at which it was accessed and the web route accessed. This information is then stored in the AccessInformation table as a partially complete entry. In order to get information about the IP address, including the general location and geometry, a batch of requests is made nightly to ip-api.com. These requests are made nightly due to limitations set on the volume of requests that can be made per day by the api. Since the requests needed to be automated, it was imperative to implement a cron job to handle the requests. A cron job is a time-based scheduler for linux systems that enables scheduling tasks to run at specific times or intervals. The APScheduler python module was chosen as it has been shown to work well with Flask applications.

Gamification

Gamification was incorporated into the web application to encourage user interaction and increase report submissions, ultimately promote traffic safety in the general public. This feature was implemented using a straightforward ranking system, which tracks and displays the number of reports submitted by each user on a leaderboard. To enable this functionality, all reports submitted by a user are queried from the database, retrieving both the total submission count and the number of approved reports. A second query aggregates the total number of approved reports across all users, generating a ranked list based on approval count. The user's individual approval count and rank are then returned to the front end of the web application and displayed on the leaderboard, providing real-time feedback and motivating continued participation.

The leaderboard interface was designed to be simple, informative, and visually engaging, ensuring a seamless user experience. It displays each user's current rank relative to the total number of participants, along with the total number of crash report they have submitted. It also highlights the number of reports that have been accepted after passing QA/QC validation, providing insight into the quality of their submission. Additionally, the interface displays system-wide statistics, including the total number of reports submitted by all participants and the total number of reports submitted by all participants and the total number of reports accepted after QA/QC validation, providing a comprehensive view of both individual and overall performance.

Figure 6 below illustrates the layout of the leaderboard displayed on the main page following user sign-in. This leaderboard provides users an immediate overview of their ranking relative to other contributors, presenting a visual snapshot of their standing within the community. Such a ranking system function as a form of positive reinforcement, providing users with recognition for their contributions, which in turn fosters continued participation. Moreover, the leaderboard serves as a competition mechanism, encouraging users to improve their performance through friendly form of competition. Even within a relatively small user base, the real-time feedback loop inherent in this design promotes a sense of accomplishment and drives sustained engagement. By continuously updating users ton their relative progress, the leaderboard cultivates a sense of achievement, thereby incentivizing users to contribute more actively to the community. This approach, underpinned by principles of gamification, not only enhances user motivation but also strengthens community interaction and collaboration.

Additionally, the gamification framework has been designed with scalability as a core consideration. To ensure optimal performance even as the user base grows, the system leverages a series of best practices, such as the implementation of database indexing and query optimization techniques. These strategies allow the backend of efficiently handle increasingly complex ranking calculations and large volumes of user data, minimizing the impact of system load during peak usage. As a result, even with a significant increase in participants, the system is able to deliver prompt and responsive load times, ensuring a seamless user experience.

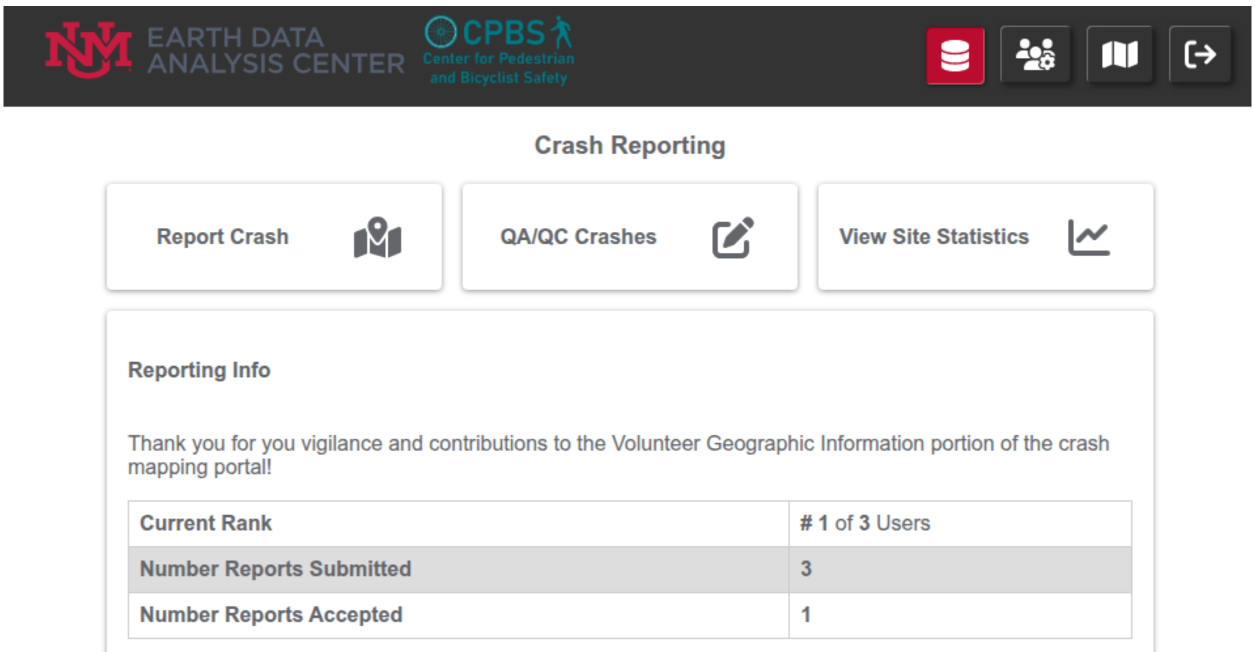

Figure 6. Website landing page and leaderboard after sign-in. The landing page is where users can see the status of their interaction with the website and current standing in the community reporting.

Furthermore, the system's architecture is designed to accommodate further enhancements and feature expansions. For instance, the potential addition of ranking period – such as weekly or monthly leaderboards highlighting top contributors – has been factored into the design from the outset. The foresight allows for the integration of time-based ranking features without requiring significant reengineering of the underlying infrastructure. Additionally, provisions have been made for potential adjustments in the database schema, ensuring that the structure can scale horizontally as the platform grows and new features are introduced. On the front-end side, the user interface has been built with flexibility in mind, ensuring that future expansions, such as personalized achievement tracking or new gamification elements, can be smoothly integrated.

Overall, the gamification strategy serves to enhance user engagement and improve data quality by rewarding users for accepted reports rather than just the volume of submissions. This strategy encourages users to focus on accuracy and thoroughness, thus helping maintain the integrity of the volunteer-sourced crash dataset. By recognizing quality contributions, the system promotes a collaborative, community-driven approach to traffic crash data collection, motivating users to contribute data that are more reliable and fostering a stronger sense of collective responsibility. The result is a more trustworthy dataset and a more engaged and motivated user base.

Results

The existing crash mapping tool was successfully modified to support the integration of **VGI** contributed by local community members. Key updates included the development of a user management system, the implementation of a crash-reporting interface, the addition of web analytics for monitoring site access, and the creation of a **QC** workflow for reviewing submitted reports.

The user management system now supports multiple user roles, allowing individuals to register, manage their accounts, and submit reports, while providing administrators with insight into user activity and submission history. Secure authentication protocols were implemented using industry best practices, including a hash-and-salt method for storing user credentials.
The crash reporting form was designed to capture all relevant information needed for geostatistical analyses and aligns with the fields used in the official NMDOT dataset. Submitted data is stored in a PostgreSQL database and becomes immediately available for visualization and analysis through the web platform. In parallel, user IP addresses are logged and geolocated, contributing additional context for QC reviewers and enabling access pattern monitoring via an administrative dashboard.

A dedicated QC interface was developed to ensure data quality, allowing trained reviewers to approve or deny VGI submissions based on content validity. This process helps mitigate concerns about malicious or low-quality entries, supporting the reliability of the integrated dataset.

To enhance community engagement, gamification features were incorporated, including a ranking system that displays users' submission counts and approval rates. These elements foster internal motivation and promote continued participation. The platform is now equipped to serve local communities, particularly those with disproportionately high traffic collision rates, by encouraging civic involvement in data reporting. The inclusion of VGI is designed not only to increase community awareness and ownership of local traffic safety but also to inform infrastructure improvements by providing decision-makers with more comprehensive and localized crash data.

Discussion

This study sought to explore two primary questions: how the issue of under-reported traffic collisions might be addressed through the use of VGI, and how the implementation of an online crash-mapping portal could support traffic safety engagement and decision-making within Native American communities. By integrating a VGI reporting tool into an existing web application, the project enabled the inclusion of community-sourced data in tools that may ultimately influence infrastructure planning and resource allocation. In doing so, the study not only facilitated community participation in traffic safety monitoring but also promoted trust in the research process and encouraged the adoption of safer driving practices.

One of the central contributions of this research is the use of VGI to supplement traditionally under-reported crash datasets (Younes & Noland, 2025). A key advantage of VGI is its ability to rapidly generate large volumes of data at minimal cost. However, this benefit is counterbalanced by concerns over data quality, including the risk of erroneous or malicious submissions. To address this, the study implemented two mitigation strategies: IP address logging and a structured quality control (QC) process. IP-based filtering helped limit automated or bot-driven submissions, although the decision to maintain an open-source framework meant that more advanced, proprietary filtering technologies were not utilized. The QC workflow provided an additional safeguard by enabling trained reviewers to evaluate the validity of each submission, ensuring a higher standard of data integrity. Together, these measures enhanced the reliability of VGI inputs and expanded the volume of actionable data available to decision-makers.

Beyond improving data quality, the platform provides a valuable avenue for public engagement. Community members can use the tool to report traffic collisions, examine dynamic crash maps, and identify local high-risk areas. This empowers residents to make safer travel choices and become active participants in traffic safety solutions. At the same time, decision-makers gain access to near-real-time, community-informed data that can inform targeted infrastructure interventions. This localized, participatory approach to traffic monitoring fosters stronger alignment between community needs and public resource allocation, ultimately contributing to more responsive and equitable transportation planning.

Conclusions and Recommendations

This research successfully developed a web-based tool for geovisualization and geostatistical analysis of traffic collisions in New Mexico, with added functionality to collect and integrate VGI. By enabling community members to submit crash data, the platform addresses the persistent issue of under-reported collisions and creates a channel for public participation in transportation planning.

The inclusion of VGI not only enriches the available dataset but also fosters stronger connections between communities and decision-makers. This engagement has the potential to promote safer driving behaviors by increasing spatial awareness of high-risk areas and empowering individuals to contribute to traffic safety initiatives.

Future development should focus on expanding the reach and impact of the tool through targeted outreach and marketing strategies to raise public awareness of its reporting capabilities. Additionally, further research is recommended to evaluate the statistical differences between VGI-submitted reports and official datasets, which may provide insight into reporting gaps and opportunities for improving crash documentation practices statewide.

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