Verification of Autonomous Vehicles: Scenario Generation based on Real World Accidents

James C. Holland
Department of Computer Science
Advanced Mobility Institute
Florida Polytechnic University
Lakeland, FL, USA
jholland4134@floridapoly.edu

Arman Sargolzaei
Department of Electrical and Computer Engineering
Advanced Mobility Institute
Florida Polytechnic University
Lakeland, FL, USA
a.sargolzaei@gmail.com

SoutheastCon 2020 | 978-1-7281-6861-6/20/$31.00 ©2020 IEEE | DOI: 10.1109/SoutheastCon44009.2020.9368284

***Abstract*—With the advent of technologies that allow for self-driving and autonomous vehicles, it is of the utmost importance to ensure the safety of occupants, pedestrians, and other motorists. Investigating when, why, and how these vehicles fail is integral to preventing future recurrences of these kinds of incidents. By gathering these accidents, their associated data, and simulating them, it is possible to identify the major reasons for the accident as well as allowing for the testing and verification of autonomous vehicles (AVs), before they encounter the real world. This knowledge can then be further refined for the purposes of establishing a set of standards for AV safety and capabilities. This paper proposes a novel system for crash scenario generation which works based on actual AV crashes. In addition, there does not yet exist a cloud based database for housing AV crashes, locations, and descriptions. Furthermore, there also does not exist an automated system that creates simulated testing scenarios based on real AV crashes. Our proposed algorithm checks the AV crash location and designs virtual roads from map data about the crash location, retrieved from Open Street Maps. Then it is planned to use natural language processing (NLP) to generate the crash scenario based on the crash description. The virtual scenario, which includes real features of roads – such as curvature, number of lanes, and speed limits – will be used to test AVs. Another portion of the proposed system will allow for important features to be extracted automatically from these crashes, which will be used for improving the road designs capable of addressing AV's needs.**

***Index Terms*—Accident Recreation, Car Crash Analysis, Automatic Scenario Generation, Road improvement and Testing, Autonomous Vehicles.**

I. Introduction

The world of today is one that, just a few decades ago, would have been the setting of a science fiction novel. Marvels such as artificial intelligence and robotics are rapidly becoming commonplace in everyday life. Technology is developing at an unprecedented pace, one that requires a set of rules or standards to maintain a direction and ensure the safety of new innovations, namely autonomous vehicles (AV). The number of AVs expected to be in operation by 2030 is over 20 million, nearly a tenth of the current total of registered vehicles in the US [1], [2]. Major automakers have made their interest in developing self-driving cars and technology quite evident through their investment in AV start-up companies [3].

While manufacturer optimism around AVs is on the rise, the growing majority of Americans are concerned about the driver-less revolution [4], [5], [6]. While an increased concern comes as a response to the fatal incident last year [7], polls show that 54% of participants had expressed concern over the future prevalence of AVs as far back as 2017 [8]. Even if AVs succeed in a legal and business sense, the public will not be accepting of technology that it feels is unsafe, emphasizing the importance of safety concerns surrounding AV development and testing methods. In the following subsections, some of the challenges facing AVs are discussed.

The purpose of this research effort is multifaceted with the end goal of connecting publicly accessible data with AV incidents to better train AV drive systems. In this paper, a novel framework to re-create AV related incidents from publicly accessible sources is presented and the methods used to make this possible discussed.

A. Edge Case Testing

Since 2012, governments at both the state and federal level began proposing and enacting legislation targeted at AV safety and operation [9], [10]. In addition, some automakers and tech companies [11], [12], [13] have began establishing private testing facilities to allow for the testing of driving scenarios deemed too dangerous for public roads, which are being referred to as "edge cases." The testing and research performed at these facilities will help shape the future of US safety regulations around AVs and, potentially, the auto industry as a whole.

Edge cases are a common challenge that involves input values that necessitate special handling by an algorithm behind a computer program. In the case of automating the process of driving, edge cases can be described as "the final 10%" of the AV challenge [14]. This "final 10%" is on display with each AV incident that occurs, pointing to an exciting bit of knowledge: AV incidents are an invaluable source of data. By equipping AVs with advanced data recorders, any aspect of an incident can be gathered and then fed to other AVs and their

978-1-7281-6861-6/20/$31.00 ©2020 IEEE

drive systems such that they can ”learn” from each other's mistakes.

B. Infrastructure in the Age of Autonomy

With the insertion of AVs into the roadway ecosystem, conventional automobiles and AVs will have to learn to coexist. During the first few years of this, there will likely be issues that arise and demand necessary changes [15]. Currently, roads are designed with human error and carelessness in mind; in an ecosystem with AVs, roads may have a smaller footprint due to the safety and efficiency of the technology [16]. Features of roadways like wide, spanning lanes may become distant memories of a primitive time when AVs weren't present [16]. The abundant signage to communicate crucial traffic information to drivers may cease to exist due to vehicle-to-vehicle (V2V) communication that allows for real-time information communication.

Features of highways, such as power lines and their electromagnetic fields, may prove disruptive to AV drive systems and to V2V communication. The vehicles that currently occupy roads are a huge concern as well, in many ways. Conventional vehicles won't be connected to or in communication with AVs, eliminating a valuable asset to AV drive systems. These vehicles, like power lines, also produce magnetic fields that are in much closer proximity to AVs and from many different origin points. Furthermore, vehicles controlled by humans prove to be unpredictable and enhance the task load of AV systems, increasing the probability of an incident. These issues alone may cause AVs to, initially, be relegated to an exclusive lane similarly to high occupancy vehicles (HOV) and express lanes [17]. This measure would prove to be effective and low cost during the initial introduction of AVs.

C. Learning from Aerospace Flow

The method in which aircraft crashes are managed and investigated may prove to be a solid foundation for an improved, AV-focused regulation system. In many ways, the trend of AV system development already mirrors that of aircraft. For example, many of the motivations for AV autopilot systems are mimics of early aircraft autopilot systems [18]. Even the progression of vehicle automation follows closely to that of aircraft automation, such as the adoption of human-centered automation[19]. This can be found in the various driver aids as the idea behind this approach is to encourage human-automation integration[20] rather than total automation of the system. The relationship between aircraft and AVs is one that has interested various professionals from a variety of fields [21], [22].

Following this similar progression, it seems natural to equip AVs with data logging systems such as those found in aircraft [23]. Currently, vehicles do have event data recorders (EDR) that collect, at minimum, 15 essential data points. The recorded parameters include vehicle speed, location, and time of the incident [24]. The EDRs equipped in AVs will likely monitor almost every aspect of the vehicle since fault could lie with the manufacturer, possibly creating a widespread, recall worthy issue. With these concerns in mind, nations like the United States and Germany are leading the push for defining what data is necessary to record and disclose to investigators. This decision is not one to be taken lightly as the more data gathered, the more there is to process. The EDRs used in aviation can record over 100,000 parameters, creating terabytes of data per flight. Like aviation, a system must be developed to discern what happened from the incident data.

The proposed system could be designed to make better use of the data. For example, accident data could be processed to recreate and simulate the event for analysis, something not currently performed. Additionally, incident data and simulations could be used as training data for the AV drive systems to ”teach” other AVs how to perform better in those situations. This would be similar to the third phase of vehicle connectivity. Phase 3 focuses on connecting vehicles for over the air (OTA) updating of software and driving behavior sharing. Phase 3 lays the foundation for phase 4: fully autonomous vehicles[25]. If such a system were to be implemented, it could drastically improve the development and verification time of AVs, namely those tested in the real-world.

D. Current Regulation Protocol

Currently, AVs are federally regulated in a manner similar to conventional, manned vehicles[26], which revolves around the assumption that vehicle operation and ownership will maintain the current course. The current safety regulations are established by the National Highway Traffic Safety Administration (NHTSA) [27] and referred to as the Federal Motor Vehicle Safety Standards (FMVSS) [26]. For a vehicle to be introduced into the market, the manufacturer must demonstrate that the vehicle meets or exceeds all the current requirements in the FMVSS. In regards to AVs, the issue lies in the lack of guidance for testing driver-less vehicles and technology. Traditionally, manufacturers would certify testing metrics on a private track with qualified officials [28]. This, however, does not work well in practice for AVs as the platform requires real-world testing of systems that allow for the car to operate independently from the occupant(s). Due to this, it seems apparent that the current system is not equipped for addressing safety issues related to AVs and their necessary field testing.

How vehicle recalls are handled may also prove to be lacking for the handling of AV related issues. Currently, there exist two methods to prompt a recall, both pertaining to conventional vehicles as well as AVs [29], [30]:

1) Manufacturer chooses to issue a recall voluntarily
2) NHTSA prompts the manufacturer to issue a recall

Regardless of the manner in which a recall is issued, most recalls are prompted by consumer complaints to the NHTSA's Office of Defects Investigation (ODI) via their online form [31]. If enough consumer complaints are issued or if several complaints indicate a severe issue, the NHTSA will take a series of steps to investigate the complaints and determine if a recall is to be issued [30].

E. State of and Importance of America's Roadways

According to the American Society of Civil Engineers' (ASCE) 2017 Infrastructure Report Card, the United States' roadways are crowded, underfunded, and becoming more and more dangerous to those who rely on them [32]. This has been due to the lack of federal funding over the last several years, resulting in a $836 billion backlog. The Federal Highway Administration (FHWA) estimated that each dollar invested would return $5 in the way of reduced vehicle wear and tear, fuel consumption, and improved traffic flow – which in turn results in less roadway maintenance in the future. A nation's infrastructure is an invaluable utility that not only enables commerce from coast to coast but also the mobility of businesses and individuals. In 2016 alone, more than $18 trillion of freight was shipped across the United States, trucks claiming a sizable 82% of total shipping [33]. Roadway utilization also captured 80% of the 5.3 trillion miles traveled by Americans in 2016, a quantity most likely to continue rising in the coming years. This only scratches the surface of roadway importance but illustrates the value of investing not only in the maintenance and construction of roads but also in methods that can improve the discovery of roadway flaws that lead to increased accident rates and roadway inefficiency.

II. Our Approach

Improving the manner in which AVs and road designs are tested, on and off public motorways, is essential to their continued development and future prevalence in everyday life. What is proposed in this paper is an automated management system of AV incident data to give insight as to when, why, and where these vehicles or systems fail for use in the development and verification of AVs. The proposed framework can also be used to extract essential features related to roadway design and infrastructures to address future issues with AVs. Studying of the current state of the arts suggests that there does not exist an automated crash analysis platform at this time, even for conventional vehicles.

By employing NLP, accident descriptions and reports can be analyzed to gather information necessary for recreating AV incidents. NLP is a field of computer science and artificial intelligence that handles how computers interact with human languages. While NLPs have been implemented in technology such as Siri and Cortana, the technology can also be used to mine the data stored in text documents to generate a set of automatic actions. This information can then be used to sync the events of the incident with additional information, such as weather and traffic data from databases such as the National Oceanic and Atmospheric Administration (NOAA) and the Department of Transportation (DOT). By including other, relevant data it is possible to gain more insight as to what exactly lead to the event.

A major hurdle impeding data analysis is the current method of handling accident reports and information due to the following:

- Decentralized storage
- Manually updated
- Challenging to obtain data

Accident data is compiled by each state's Department of Motor Vehicles (DMV) rather than a central, national database. When an incident occurs, it is manually inserted into its respective database, resulting in delays in information availability. Due to this, the establishment of an automated and centralized database is necessary. Thanks to the efforts of those at work in the Advanced Mobility Institute (AMI), there exists an online database of AV incidents from across the United States [34]. These crashes were compiled from various media outlets and the California Department of Motor Vehicles (DMV) and manually entered into the database. In the future, the AMI database would request and share information with the DMV offices of other states and regions to automatically update and log incidents in real-time.

One of the primary focuses of this proposed system is to automate how roadway design features are identified and analyzed as this is paramount in guiding future road design and construction that takes AVs into consideration. With the roadway and incident reconstructed, deriving a "signature" of the road in which the incident occurred is made possible. Future roads can be designed to avoid these features associated with higher crash rates using the proposed framework. The influence of roadway design and condition on accident frequency and severity has been investigated at length, pointing to several possible causes [35], [36]. Of these causes, this paper currently focuses on road curvature and governed speeds.

Roadway curvature is a contributing factor to crash rates, regardless of setting [37], [38]. One reason for this is the enhanced risk caused by long approach lengths and short approach sight distances associated with sharp curves [37]. The effects of curvature are further exacerbated by high super-elevations – "banking" of the road – and higher rates of speeds, such as those found on highway access ramps. This relationship can also be seen in the length of curvature, the greater the length resulting in lower rates of crashes [36]. By having lower levels of banking and wider curves, drivers are less likely to travel through with high rates of speed. The posted speed of a roadway has been shown to be one of the most significant influences on crash rate [39], [40], [41]. Higher vehicle speeds enhance the dangers associated with a roadway's design features such as curvature, elevation change, or surface type. Due to this, proper analysis of a roadway should include not only one factor or another but instead, investigate the relationships among the various design features.

The proposed system, illustrated in Fig. 1, requests from and updates databases in real-time. From the *AV Incident Database*, the *Generator* requests AV incident details that contain information like vehicle data and the descriptions, date, time, and location of the incident. To develop a more accurate reenactment of the events, the *Generator* also requests complementary information to aid the accuracy of the simulation. Information such as weather and traffic data can greatly influence the series of events that lead up to the end result. Requesting information from databases such as NOAA [42] would allow

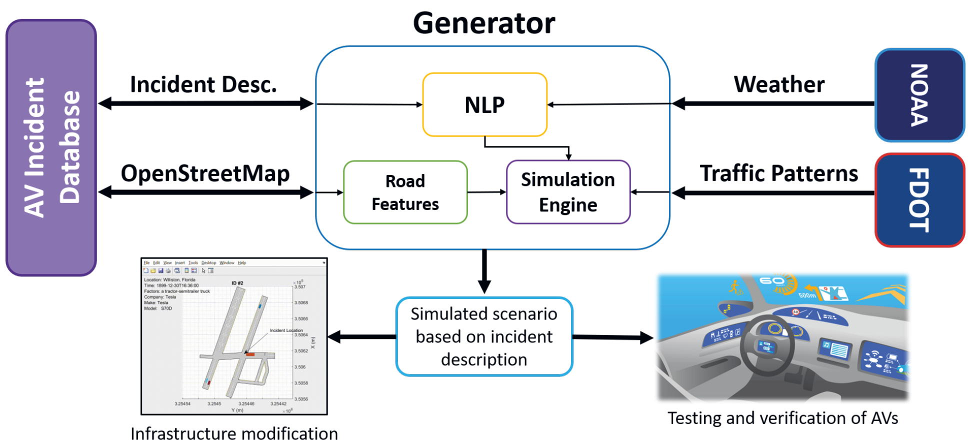

Fig. 1. Automated AV Incident Simulation Generator

for both real-time and historical weather data. Traffic databases such as the Florida Department of Transportation's (FDOT) Florida 511 and those from privately owned GPS providers, such as TomTom [**?**], and Google Maps [**?**], collect traffic data that would prove to be more than sufficient in determining a traffic congestion level. Another alternative would be to gather that information – if available – from the incident description or police report. Contemporary accident reports are quite structured and already contain relevant information – date, time, weather, and others. – but can easily be expanded to accommodate AVs. Using the incident details, namely the latitude and longitude of the event, the *Generator* requests a street map of the area from Open Street Map (OSM) [43].

With all the necessary data gathered, the *Generator* uses NLP to process the incident description and weather data to translate the oral retelling of events into a 'screenplay' of sorts that the *Simulation Engine* can use to reconstruct the incident into a simulation. Also necessary for the simulation are the other, anonymous 'actors' in the incident. By using traffic data, the *Simulation Engine* can add other vehicles as 'extras' to reflect any role that congestion may have played. With all details processed and roles filled, the map file from Open Street Map is reconstructed and populated with the vehicles directly involved in the incident and with other contributing factors represented. Once rendered, the simulation is uploaded to the *AV Incident Database* and added to that incident's documentation. From this simulation and the information used to create it, a full understanding of what occurred is possible.

A. Incident Simulation Generator Prototype

The prototype framework of the system created and tested in this paper can be simplified into three stages:

1) Retrieval of incident details and OSM file from Open Street Map.
2) Processing of details and OSM files.
3) Creation of incident simulation from AV incident data.

In order to retrieve the incident information, MATLAB [**?**] first obtains the incident reports from the Advanced Mobility Institute (AMI) database in the form of an XML file. Once downloaded, a function – called *crashDataStructParser()* – is called to parse the newly obtained XML file. The parser must first convert the XML to a MATLAB structure for searching through the elements. Once the parser finds an entry name matching the accident template, the parser will then iterate through that node to find the latitude, longitude, and description of the incident. Once the latitude and longitude are found, MATLAB checks if the coordinates are valid. If the coordinates are not usable, Florida Polytechnic University's location is used by default before moving on to the next scenario, as there is no way to properly recreate the current incident without the location of occurrence.

With coordinates logged, the parser then uses the coordinates as a center point to create a bounded box around. By estimating each coordinate degree as 111,111 meters, a border of approx $50 meters can be created. The calculations for dimensions can be found in the *crashDataStructParser()* documentation. The dimensions of this bounded box are then inserted into the export URL of Open Street Map and, using *websave()*, the OSM file is retrieved and saved into the current working folder.

Now with all the information for an incident retrieved, the puzzle can begin being pieced together. First, the OSM must be converted from an XML into a MATLAB struct to undergo processing to gather the features and connectivity for reconstructing the map. Once completed, a connectivity matrix is returned that will be used to plot roads and place cars upon. Road placement is determined from the shortest path through the connectivity matrix. Next, a driving scenario is created in MATLAB, using the plotted roads as paths to place the 'actors' of the incident. At this time, the task of description processing and simulation creation are done manually.

III. Components of System

In this section, the databases, functions, and software used during this research effort are explained and discussed.

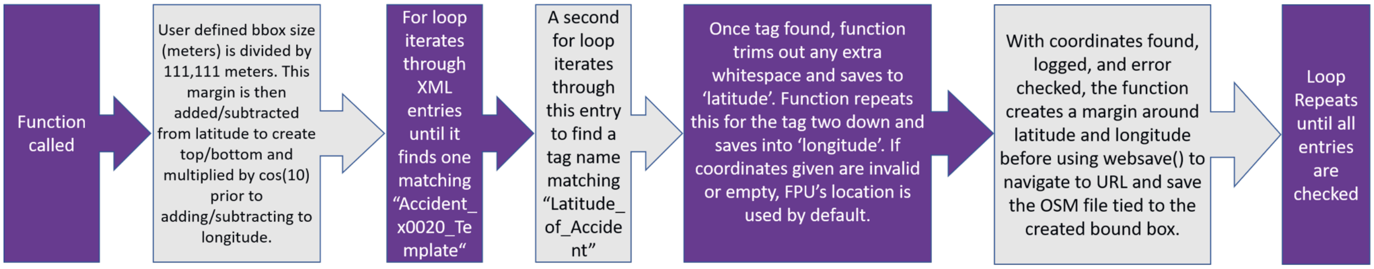

Fig. 2. Process flowchart of *crashDataStructParser()*

A. AMI AV Incident Database

The Advanced Mobility Institute (AMI) database is composed of accident details. From here, the incidents are retrieved and processed by a created MATLAB [**?**] function – called *crashDataStructParser()* – that parses out relevant data, such as locations and the accident description, from the XML file. As the locations are logged, the function retrieves the corresponding Open Street Map (OSM) file for that location from OpenStreetMap [43]. OSM files contain the geographic information of the area in a structured format, similar to an XML file [44]. Once the OSM is retrieved, a series of functions is run to process and reconstruct the map location. With the map recovered, simulated vehicle markers are placed onto the roads and geographic features that correspond with the incident description.

B. OpenStreetMap

OpenStreetMap (OSM) [43] is a collaborative project with the intent to create an editable world map. Map data is stored in various file formats [44] for ease of transport across the internet. For this endeavor, the .osm file format was primarily used. This file type contains raw road and geography information in a structured format. Files of this type require processing to reconstruct into a map but also allows for editing prior to reconstruction.

C. MATLAB

MATLAB was implemented as the *Generator* in demonstrating the automated system as data was retrieved, parsed, and simulated through functions created in this environment. In the following sections, the functions will be further explained.

D. Crash Data Parsing Function

The following description pertains to *crashDataStructParser()* and the diagram provided in Fig. 2. The crash data parser works by creating an XML struct from the AccidentTemplate.xml file found in the declared folder (stored in the xmlFolder variable). The parser loops through the entries, stopping at entries where the tag name is "Accident_x0020_Template". Once an entry matching this tag is found, another loop traverses that entry's tag names until "Latitude_of_Accident" is found. The data in this child is then saved under "latitude," and the entry+2 child is saved under "longitude," as this is the format of the database. An 'if' statement checks to ensure that the data is indeed numeric before continuing. If it is not a numeric value, then the coordinates are set to a default location. After the 'if' statement, the coordinates are used in a websave() function to go to the Open Street Maps export URL and retrieve the OSM file that matches the location, saving it as OSM_ followed by the filename, where filename is equivalent to the ID of the XML entry. Once all the entries have been traversed, a movefile() command moves all the OSM files to a specified folder for storage. The function can also be given an optional parameter to define the area, in meters, around the point of interest. If the parameter is left blank, the function uses a default value of 50 meters.

IV. Demonstration

A step-by-step walk-through is contained in this section to demonstrate the capabilities of the discussed framework. In the following, a section of road will be exported from Open Street Map, reconstructed as per accident description in MATLAB, and then scenario details are retrieved from the AMI database. From the AMI database, as seen in Fig. 3, the details and description of incident #1 can be found. On www.openstreetmap.org, the location corresponding to the incident is retrieved. Next, using the information from the description, the incident is recreated. In Fig. 3b, the map is being reconstructed from the OSM file into a raster map (Fig. 3c). Using this raster map, the roads and pathways of vehicles are determined. Following the description, vehicles, and pedestrians - if involved - are added, resulting in the final simulation shown in Fig. 3d. This final simulation is uploaded to the AMI database and present for viewing [34]. Located in each database entry is a link that allows for downloading a zip file of the simulation and other details of the incident.

A. Preliminary Observations

Currently, the AMI database is home to 96 total traffic incidents involving AVs, 34 of which have been processed through the proposed framework, and their scenarios are recreated [34]. The proposed, automated system will be built around the methods and elements established during this initial stage of research and development. Using the data gathered from the processed incidents, it was possible to conduct some small scale statistical analysis on various roadway elements.

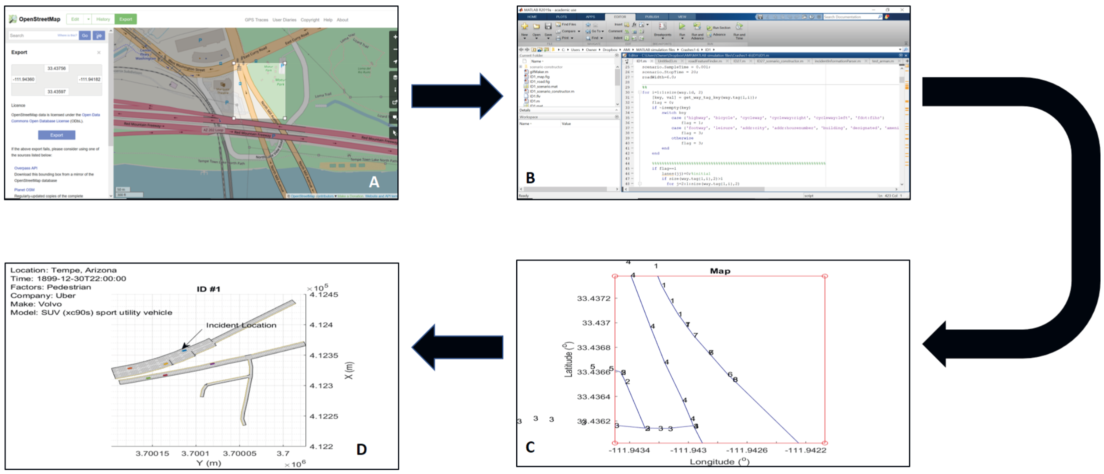

Fig. 3. Step-by-step of the process

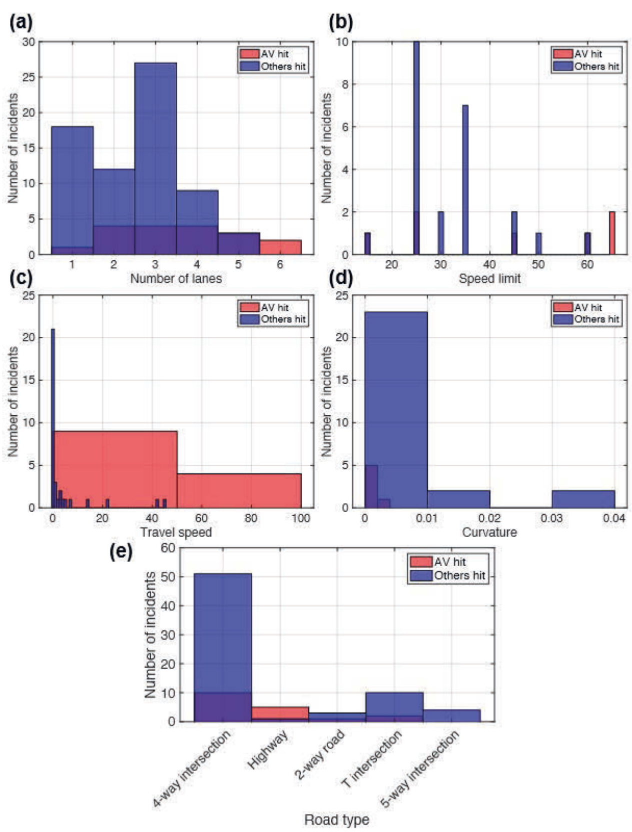

Fig. 4. Preliminary Observation from the AV Simulation

However, since the process and framework are automatic, as the number of incidents increases, the same framework can be used to get more meaningful results. Fig. 4 displays the results of this analysis and the potential insight that can be gleaned from the analysis of traffic accidents. In the pursuit of furthering AV technology and development, real-world traffic incidents possess invaluable data that doesn't occur in a lab. Being able to mine this data from incidents as they occur will allow autonomous drive systems to better respond to these scenarios when encountered. A more widespread use, perhaps, would be the analysis of the roads on which incidents occurred. By determining potentially dangerous features of current roads, future roads can be designed to avoid these elements, creating a safer driving experience for conventional vehicles and AVs alike.

V. Conclusion and Future Work

So far, many aspects of the proposed system have been achieved. This includes the simulation of AV incidents using incident descriptions and details hosted on the AMI database. From the web-page, a preview of the simulation is available as well as the downloadable zip file. This file contains the necessary data to reconstruct the scenario within the MATLAB environment. This will allow other researchers to investigate crash scenarios and analyze the design of roads to improve them for AVs. Using the simulation, it is also possible to derive the curvature of the roadway in which the accident occurred. Curvature, combined with the posted speed limit, help provide insight and potential areas of improvement.

One of the significant aspects of the system still to be developed would be that of an incident description processor. With this utility, a simulation 'script' could be automated. Developing an automated simulation process that uses the processed descriptions would also become a major focus as this would be the last major task currently being handled by an end-user. The way in which information is gathered and recorded from the scene of an incident is another area often pointed out for improvement. As technology progresses, the necessity of manual information gathering will become obsolete as event data recorders (EDR) begin to record more data. Another development would be the inclusion of police report information in the incident details. Collection of information such as the weather and traffic conditions are standard procedure and could be checked against databases for accuracy.

VI. Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. CNS-1919855. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. This work is also supported by Advanced Mobility Institute at Florida Polytechnic University. Authors would like to thank Dr. Saleem Sahawneh for the initial collection of autonomous vehicles crashes database. Authors also would like to thank Ms. Shirin Noei and Dr. Rahul Razdan for their valuable inputs.

References

[1] "Projected number of autonomous vehicles in operation in the united states in 2025 and 2030 (in millions)." https://www.statista.com/statistics/750149/us-autonomous-vehicles-in-operation-forecast/, 2017.

[2] "Us vio vehicle registration data 2018, fast quote on car data." https://hedgescompany.com/automotive-market-research-statistics/auto-mailing-lists-and-marketing/, 2018.

[3] J. Walker, "The self-driving car timeline predictions from the top 11 global automakers." https://emerj.com/ai-adoption-timelines/self-driving-car-timeline-themselves-top-11-automakers/, 2019.

[4] A. Walker, "Are self-driving cars safe for our cities?." https://www.curbed.com/2016/9/21/12991696/driverless-cars-safety-pros-cons, 2019.

[5] A. J. Hawkins, "Americans still deeply skeptical about driverless cars: poll." https://www.theverge.com/2018/1/12/16883510/self-driving-car-poll-congress-bill-safety, 2018.

[6] F. Richter, "Consumer concerns about self-driving cars." https://www.statista.com/chart/5950/concerns-about-self-driving-cars/, 2018.

[7] D. Wakabayashi, "Self-driving uber car kills pedestrian in arizona, where robots roam." https://www.nytimes.com/2018/03/19/technology/uber-driverless-fatality.html, 2018.

[8] J. Gramlich, "Americans had concerns about self-driving cars before fatal arizona accident." http://www.pewresearch.org/fact-tank/2018/03/21/americans-had-concerns-about-self-driving-cars-before-fatal-arizona-accident/, 2018.

[9] "Autonomous vehicles, self vehicles enacted legislation database." http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-legislation.aspx, 2019.

[10] "Automated vehicles for safety." https://www.nhtsa.gov/technology-innovation/automated-vehicles-safety, 2018.

[11] A. J. Hawkins, "Toyota will test self-driving car 'edge cases' at new proving ground in michigan." https://www.theverge.com/2018/5/3/17314778/toyota-self-driving-car-test-proving-ground-michigan, 2018.

[12] A. J. Hawkins, "Waymo gave me a ride in a car with no driver." https://www.theverge.com/2017/10/31/16579180/waymo-self-driving-test-facility-castle-google, 2017.

[13] D. Muoio, "Uber built a fake city in pittsburgh with roaming mannequins to test its self-driving cars." https://www.businessinsider.com/ubers-fake-city-pittsburgh-self-driving-cars-2017-10, 2017.

[14] M. Dempsey, "(h)edge cases in autonomous vehicles." https://medium.com/frontier-tech/h-edge-cases-in-autonomous-vehicles-37f75fe63b56, 2016.

[15] E. Gjerdingen and T. Sohrweide, "Driverless vehicles set to change the way we design our roadways?." http://www.sehinc.com/news/future-what-do-driverless-cars-mean-road-design, -07-30T12:35:13-05:00 2018.

[16] J. Lombardo, "How will autonomous vehicles impact how we build roads?." https://www.forconstructionpros.com/asphalt/article/20985026/how-will-autonomous-vehicles-impact-how-we-build-roads, Jan 17, 2018.

[17] D. Grossman, "Self-driving cars could soon have their own lane on the highway." https://www.popularmechanics.com/technology/infrastructure/a13615577/self-driving-cars-lane-wisconsin/, -11-14 09:47:18 2017.

[18] P. M. F. (Ed.), "Human engineering for an effective air-navigation and traffic-control system," *Washington, DC: National Research Council*, 1951.

[19] C. M. Mitchell, *Human-Centered Automation: A Philosophy, Some Design Tenets, and Related Research*, pp. 377–381. Boston, MA: Springer US, 1996.

[20] D. Romero, O. Noran, J. Stahre, P. Bernus, and Å. Fast-Berglund, "Towards a human-centred reference architecture for next generation balanced automation systems: Human-automation symbiosis," in *Advances in Production Management Systems: Innovative Production Management Towards Sustainable Growth* (S. Umeda, M. Nakano, H. Mizuyama, H. Hibino, D. Kiritsis, and G. von Cieminski, eds.), (Cham), pp. 556–566, Springer International Publishing, 2015.

[21] D. H. M. S. Young, N. A. Stanton, "Driving automation: Learning from aviation about design philosophies," 2007.

[22] N. A. Stanton and P. Marsden, "From fly-by-wire to drive-by-wire: Safety implications of automation in vehicles," *Safety Science*, vol. 24, no. 1, pp. 35 – 49, 1996.

[23] N. C. Kevin Bonsor, "How black boxes work." https://science.howstuffworks.com/transport/flight/modern/black-box.htm, 2019.

[24] R. Schneiderman, "United states, germany take the lead in requiring black boxes for self-driving vehicles." http://theinstitute.ieee.org/ieee-roundup/blogs/blog/united-states-germany-take-the-lead-in-requiring-black-boxes-for-selfdriving-vehicles, 2017.

[25] K. Moinzadeh, "Vehicle connectivity: Paving the road to the future of transportation.." https://www.entrepreneur.com/article/298321, 2017.

[26] "Nhtsa issued federal motor vehicle safety standards." https://www.nhtsa.gov/laws-regulations/fmvss, 2018.

[27] "National highway traffic safety administration." https://www.nhtsa.gov/, 2019.

[28] "Test procedures." https://www.nhtsa.gov/vehicle-manufacturers/test-procedures, *N/A*.

[29] J. O'Dell, "How nhtsa gets cars recalled." https://www.edmunds.com/car-safety/how-nhtsa-gets-cars-recalled.html, 2015.

[30] "Safety issues and recalls." https://www.nhtsa.gov/recalls, *N/A*.

[31] "Nhtsa office of defects investigation." https://www-odi.nhtsa.dot.gov/, *N/A*.

[32] "Infrastructure report card." https://www.infrastructurereportcard.org/cat-item/roads/, 2017.

[33] J. Russell, "Frequently asked questions." https://www.artba.org/about/faq/, 2019.

[34] M. C. Holland, James and A. Sargolzaei, "Rancs research group-autonomous vehicle incident database." https://www.rancs-lab.com/AVcrashes/, 2018.

[35] S. Othman, "Influence of road characteristics on traffic safety," 01 2007.

[36] S. Othman, R. Thomson, and G. Lannér, "Identifying critical road geometry parameters affecting crash rate and crash type," *Annals of advances in automotive medicine. Association for the Advancement of Automotive Medicine. Annual Scientific Conference*, vol. 53, pp. 155–165, Oct 2009.

[37] K. L. Fink and R. A. Krammes, "Tangent length and sight distance effects on accident rates at horizontal curves on rural two-lane highways," *Transportation Research Record*, no. 1500, 1995.

[38] D. C. Watson, A. Al-Kaisy, and N. D. Anderson, "Examining the effect of speed, roadside features, and roadway geometry on crash experience along a rural corridor," *Journal of Modern Transportation*, vol. 22, pp. 84–95, Jun 2014.

[39] N. J. Garber and A. A. Ehrhart, "Effect of speed, flow, and geometric characteristics on crash frequency for two-lane highways," *Transportation Research Record*, vol. 1717, no. 1, pp. 76–83, 2000.

[40] H. Isebrands, "Crash analysis of roundabouts at high-speed rural intersections," *Transportation research record*, vol. 2096, no. 1, pp. 1–7, 2009.

[41] L. Aarts and I. Van Schagen, "Driving speed and the risk of road crashes: A review," *Accident Analysis & Prevention*, vol. 38, no. 2, pp. 215–224, 2006.

[42] "National oceanic and atmospheric administration (noaa) website." https://www.noaa.gov/, *N/A*.

[43] O. S. M. Foundation, "Openstreetmap homepage." https://www.openstreetmap.org, 2004.

[44] "Learn osm." https://learnosm.org/en/osm-data/file-formats/, 2016.