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Microscopic Traffic Simulation Modeling and Communication Tool for Post-Disaster Evacuation Routing

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MICROSCOPIC TRAFFIC SIMULATION MODELING AND COMMUNICATION

TOOLS FOR POST-DISASTER EVACUATION ROUTING

by

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This thesis consists of the following two articles, formatted in the style used by the Missouri University of Science and Technology:

Paper I: Deep Learning Models and Tools for Disaster Evacuation and Routing, found on pages 14-26, has been published in the proceedings of the American Society for Engineering Management 2022 International Annual Conference in Tampa, LA, in October 2022.

Paper II: Identification of a Response and Rescue Network for the St. Louis Region, found on pages 27-38, is intended for submission to the Institute of Industrial and Systems Engineers Annual Conference in New Orleans, LA, in May 2023.

ABSTRACT

This research evaluated the effectiveness of conducting traffic simulation models and developing a mobile application to serve as a communication channel for emergency evacuation preparation and routing. An iOS and Android app was developed to display emergency events to users with suggested routes for evacuation and a microscopic traffic simulation model was conducted for the St. Louis (MO) metropolitan region that analyzed various road networks with projected evacuation demand.

A mobile application coded in Swift (Apple) and Kotlin (Android) featured an emergency notification screen that displayed the type of emergency warning (e.g., earthquake, flood, or no warnings) with provided routes for evacuation. Upon selecting an evacuation route, the user can view the desired route to evacuate with and commence the turn-by-turn directions within the app.

Microscopic traffic simulations were conducted for the St. Louis (MO) metropolitan region with projected evacuation demand in SUMO (Simulation of Urban MObility) software. The microscopic approach simulated individual vehicles moving along the desired routes and generated operational performance measures such as delays, noise, speed, and overall travel times.

The microscopic traffic simulation modeling and mobile app both contributed to the efforts by the Missouri Department of Transportation for effective evacuation preparation. Engineering managers can utilize this research for continued efforts in developing communication and routing tools for emergency evacuation planning. This research was partially sponsored by the Missouri Department of Transportation.

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1. INTRODUCTION

The importance of emergency management and traffic management systems are critical for evaluating evacuation efforts for post-disaster events including earthquakes, flooding, and tornados. The Missouri Department of Natural Resources states that Missouri is known for having small earthquakes and tremors frequently where about 200 shocks are detected annually in the New Madrid Seismic Zone. About once or twice a year southeast Missouri is disturbed by earthquakes strong enough to crack plaster in buildings. The United States Geological Survey (USGS) agency lists ten earthquakes of Magnitude 2.5+ that affected the United States on March 13, 2023. With there being evidence of frequent earthquakes affecting Missouri, and the rest of the United States, it is important for emergency management and traffic management systems to be established for residents to have effective evacuation procedures and for emergency personnel to prepare for earthquake aftershocks.

1.1. IMPORTANCE OF EMERGENCY MANAGEMENT

Emergency management is defined as the managerial function charged with creating the framework within which communities reduce vulnerability to hazards and cope with disaster by the Federal Emergency Management Agency (FEMA). While natural disasters, such as earthquakes, are just a subsection of emergency management, they too require adequate and effective preparation and communication tools. Smartphones serve as a highly effective communication tool that could benefit disaster response efforts. Lack of collaboration is the chief culprit in major failures in disaster response and takes the form of a lack of available crisis information or poorly manage information flow (Wang et al., 2020). With this, information and communication technology encompassed within mobile phones could be considered as critical means to enhance the flow of information to residents and emergency personnel. This research creates a communication tool in the form of a mobile app for residents and state emergency personnel to prepare for earthquake related events.

1.2. IMPORTANCE OF TRAFFIC MANAGEMENT SYSTEMS

Traffic management systems can provide insights into traffic conditions on various road networks in response to an earthquake event that encompass three different traffic models: Macroscopic, Microscopic and Mesoscopic. The microscopic approach simulates individual vehicles, traffic signals, and generates performance metrics such as delays and travel times. A macroscopic approach uses traffic flow theory relationships to generate operational metrics. A mesoscopic approach encompasses both microscopic and macroscopic approaches with fast simulation times and the ability to model groups of individual vehicles and traffic control. Traffic simulation frameworks provide a helpful tool to answer complex research questions, to evaluate or to test traffic management strategies and their impacts (Lopez et al., 2018). These traffic simulation models can be applied to obtain a better understanding of the evacuation conditions and the effect of traffic regulations and control measures (Pel et al., 2012). For this research, microscopic traffic simulation models were conducted inside SUMO for the St. Louis (MO) metropolitan area to examine the performance of various road networks against projected evacuation demand.

2. LITERATURE REVIEW

Mobile applications have become more robust over the past decade and 85% of adults in the U.S. own a smartphone (Laricchia, 2022) as of 2021. With this, there are multiple opportunities for emergency management to enter the mobile app industry with robust tools for users to prepare for emergency events including natural disasters such as earthquakes, floods, and tornados. The Federal Emergency Management Agency (FEMA) of the U.S. released their Improving Public Messaging for Evacuation and Shelter-in-Place literature review that highlighted the importance of warning messages. Specifically noting how messages that clearly describe the tangible personal impact of the hazard motivates protective action and adding visuals, such as maps, improves message comprehension and decision-making. While also promoting attention-getting language and describing storm impacts are effective measures for citizens to take effective action prior to an earthquake event. With this in mind, the mobile application presented in this research, on page 20, houses a compelling warning message of the natural disaster with a simplistic design and a map for users to plan for evacuation. Mobile emergency applications, feasibility factors for emergency planning apps, natural disaster warning apps, and an emergency routing mobile app for an indoor fire are described below.

2.1. MOBILE EMERGENCY APPLICATIONS

A form of emergency planning on mobile devices are mobile emergency applications and features such as the Emergency SOS feature on Apple iPhones. A study was conducted by Repanovici and Nedelcu (2021) on the implementation of mobile emergency alert apps to support Emergency Management systems all over the world. A portion of this study involved the use of mobile applications to provide essential data to the emergency teams by providing instant identification of users and event information with the user's location. This could be a potential additional feature applied to the mobile app introduced later in this research paper. The European Emergency Number Association is in the process of implementing a Pan-European Mobile Emergency Apps (PEMEA) policy that provides a mobile emergency app that is user-friendly and meets customers' perception in terms of usability, functionality, utility and costs, with strong security (Repanovici and Nedelcu, 2021). All of these characteristics of their application fall in line with the characteristics for the app introduced in this thesis paper. The decision-making criteria established for this study based on social, economic, and technological factors included: manufacturing and maintenance cost, utility, quantities of information, accuracy of information, data monitoring, user perception, usability and time of response. This study concluded that successful implementation of mobile emergency apps would entail designing international standards and regulations, integrate mobile solution into the emergency system, and promote mobile emergency apps. While the emergency evacuation routing application proposed in this thesis is tailored towards providing evacuation routes for end users, later iterations of the app could incorporate some of the mobile emergency app offerings.

2.2. FEASIBILITY FACTORS FOR EMERGENCY PLANNING APPS

While there are many methods to implement emergency planning mobile apps onto the market, a study was done by Chien et al. (2020) that evaluated the feasibility of an emergency and mutual-aid app. This research incorporated the technology acceptance model (TAM) that is a set of theories to explain the determinants of information technology acceptance. The feasible factors that were assessed for the impact of an emergency app were perceived ease of use, perceived usefulness, and use willingness and frequency. A structed questionnaire was developed as a research tool for in-depth interviews from experts in medical, legal, and mobile app departments with a statical analysis from a Statistical Package for the Social Sciences (SPSS version 19; IBM Corp, Armonk, New York). The findings of this study concluded that the perceived ease of use, perceived usefulness, and use willingness are important factors for users' behavioral intention of using the app. Perceived usefulness had a strong relationship with use willingness (Chien et al., 2020). This research reinforces the idea that users want a useful and ease-of-use mobile app for their emergency planning. The availability and acceptability of an emergency and mutual-aid app model might make it an effective tool to assist people in managing emergencies and reducing mortality (Chien et al., 2020). This research thesis proposes a mobile app that has high perceived usage potential from individuals and emergency personnel to plan for an early warning of an earthquake accordingly with a simple user interface and process flow.

2.3. NATURAL DISASTER WARNING MOBILE APPS

Research proposed by Pamuji et al. (2020) the development of a mobile application for earthquake and tsunami early warning system to support community-based disaster risk reduction efforts. Savings lives and also reducing devasted infrastructures is the highest priority in Early Warning Systems (EWS) in earthquake and tsunami prone areas (Pamuji et al., 2020). This study developed a two-stage approach that included designing and building the mobile application as well as delivering a questionnaire to some respondents to test the mobile app. The following screens were incorporated into the mobile application: Mitigation menu for information about earthquakes, tsunamis, and disaster risk reduction (DRR), an emergency number to call local emergency personnel, an early warning system as a menu providing links to official websites of government weather-related agencies, evacuation signs and their meaning, an evacuation route screen with various points of evacuation that are divided into three zones, and a post-earthquake menu to provide education on what to do after the event of an earthquake. This study concluded that the application is effective to give alerts and knowledge as an early warning system.

A mobile application that provides information about the intensity, time and whereabouts of a recent earthquake are discussed in a study conducted by Kirci et al. (2023). This application also contains emergency phone numbers and can provide general information about an earthquake which users can benefit from before and after an earthquake. Information about an earthquake kit is given to users in the application and the earthquake kit should be prepared before the earthquake (Kirci et al., 2023). This feature could be an additional add-on to the mobile app proposed in this thesis paper. Smartphones are ideal tools for the dissemination of earthquake alerts to inform a large number of users about the potential damage of an impending earthquake (Kirci et al., 2023).

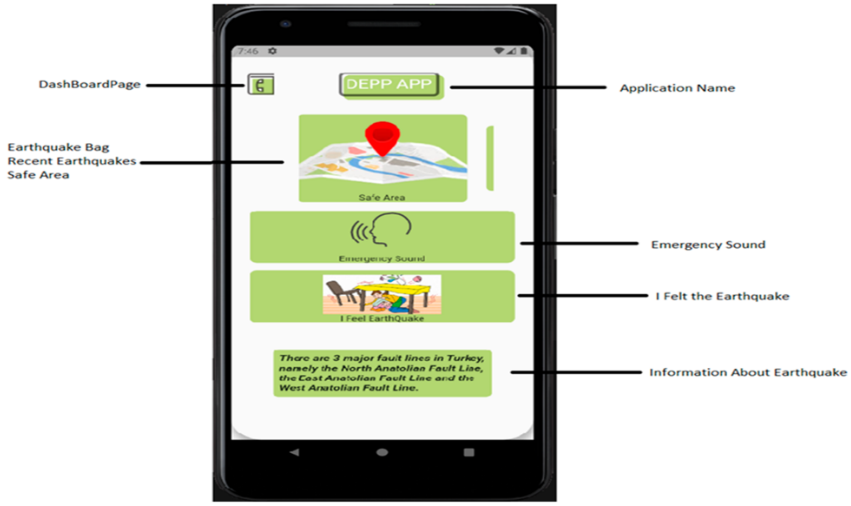

Figure 1.1. Main page of mobile app (Kirci et al., 2023)

As shown in Figure 1.1., the main menu consists of the earthquake badge and first aid kit, a notification system, a earthquake questionnaire system, safe areas for gathering after an earthquake, an emergency sound that will enable people to report their location, and a list of recent earthquakes. This study concluded a mobile application aimed to minimize the damages of earthquakes that takes place. While this app provides similar offerings compared to the mobile app introduced in this thesis paper, this app does not offer routing options for end users to view for earthquake preparation.

Disaster Management consists of four fundamental steps such as mitigation, preparedness, response, and recovery (Rahman et al., 2012). These steps can be transferrable into the offering of the mobile app discussed in this thesis paper as the app is tailored towards preparing the response and recovery rates of individuals within an effected area from an earthquake event. If the user is in any disaster zone, the application will automatically track the user so that the authority can rescue him from probable disaster affected area where the user is identified with stored national id in the application

(Rahman et al., 2012). This feature could later be applied to the mobile app discussed in this thesis paper. OpenStreetMaps (OSM) is the rendered map for the application that displays two points of interest with different icons that is served through CloudMade. CloudMade is a geographic related service provider that provides necessary data for the application to draw the shortest path around the area of the user's current location and shelter.

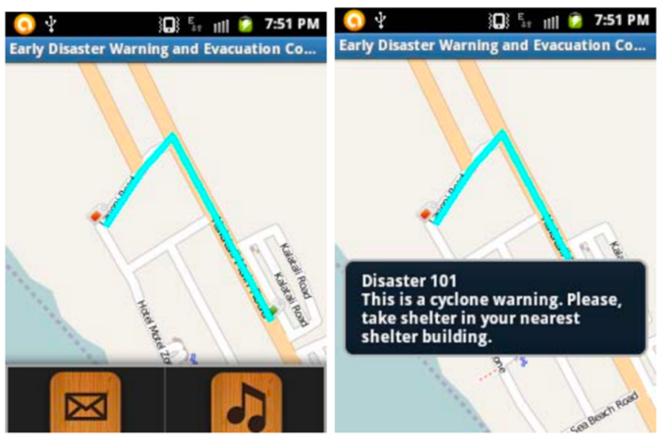

Figure 1.2. User interface displaying highlighted route, audio directions, event warning message, and menu options (Rahman et al., 2012)

As shown in Figure 1.2., this app does show the evacuation route for the end user with audio directions, however, step-by-step visual navigation is not present.

2.4. EMERGENCY ROUTING MOBILE APP FOR AN INDOOR FIRE

An additional use-case for an evacuation mobile application consists of indoor fire emergencies. A study conducted by Zhang et al. (2019), proses a fire evacuation management framework with utilized Bluetooth low energy (BLE)-based indoor real-time location system (RTLS) to push personalized evacuation route recommendations and turn-by-turn guidance to the smartphone of a building occupant. The development and application of mobile Internet provides smartphones with a number of potential uses, including emergency evacuation and management (Zhang et al., 2019). As the first mobile app to provide step-by-step navigation for end users, in case of a fire, BLE capabilities could be explored for the app proposed in this thesis in case of an event where cellular towers are offline following an earthquake event. From there, the app could utilize the BLE technology to track the user's phone during evacuation along the recommended route. Building information from the BIM (building information model) model, information about the fire situation, and the real-time location of the smartphone of a building occupant are the most important inputs needed for the calculation of a possible evacuation route for a given occupant (Zhang et al., 2019). While the agenda for the provided mobile app in this thesis is built for emergency evacuations related to earthquake events, the app discussed above for indoor fire evacuation provides additional insight on how BLE technology could be potentially incorporated into future studies relating to evacuation routing due to an earthquake event.

2.5. MICROSCOPIC TRAFFIC SIMULATION MODELING

A study on microscopic simulation modelling (MITSIMLab) was conducted by Jha et al. (2004) to evaluate emergency evacuation plans for the Los Alamos National Laboratory (LANL). In comparison, microscopic traffic simulation modelling was conducted in SUMO for this thesis paper to evaluate emergency evacuation plans for St. Louis (MO) metropolitan area. Performance measures for evaluating an evacuation plan included the total time to achieve a complete evacuation, the time needed for a partial evacuation in which the population within certain areas are at risk, and the percentage of the population in affected zones as a function of time (Jha et al., 2004). This thesis paper utilized the projected evacuation demand from a previous earthquake evacuation study on the New Madrid Seismic zone in southeast Missouri that was then implemented into the traffic model over a certain amount of time. Network coding, O-D Matrix, background traffic, and route assignment were all contributing elements to the evacuation scenarios. These characteristics aligned with the proposed microscopic traffic simulation model in this thesis paper. The following modeling requirements for evacuation planning were used: time-dependent path processing, modeling of individual vehicles, and development of an O-D table. The results from this analysis indicated that detailed modeling of traffic operations, including signal control, was necessary to appropriately model the evacuation scenarios (Jha et al., 2004). The microscopic traffic simulation model conducted in this thesis paper allowed for detailed modeling of traffic operations.

2.6. MICRO VS MESO TRAFFIC SIMULATION MODELING

A comparison of Microscopic and Mesoscopic traffic modeling tools for evacuation was conducted by Aljamal et al. (2018). The microscopic traffic simulation tool produces logical results with trip durations increasing with increased traffic demand levels and decreasing road capacity scenarios (Aljamal et al., 2018). The results for this study reflect the results for the microscopic traffic model conducted in this thesis paper. Whereas the average trip duration using the mesoscopic simulation tool decreases with increasing demand levels and increasing road capacity (Aljamal et al., 2018). The estimated evacuation time values for both models were very close to each other since the O-D file generates a long tail for trips (Aljamal et al., 2018). This meaning that the departure time is distributed over a long period of time that ensures the network is not congested. The microscopic traffic model conducted for this thesis paper also generated a long tail for trips. Although, two of the road networks were severely congested even with a long tail as shown later in this paper. The average trip duration was computed by taking the total travel time of all vehicles that needed to finish their trips and dividing by the total number of vehicles (Aljamal et al., 2018). The results of the study indicated that the estimated evacuation times for both models were similar due to the input demand was a common variable in both simulations.

2.7. SUMO MICROSCOPIC TRAFFIC SIMULATION MODELING

Modeling the flow of road traffic with SUMO software was conducted in the study by Haddouch et al. (2018). The methodology of this analysis consisted of flow: progression of vehicles on tracks (queues, flows, speeds) and assignment: distribution of vehicles on the network. SUMO consists of a series of tools covering road network imports and enrichment, generation and allocation of demand, and a state-of-the-art microscopic traffic simulation capable of simulating private and public transport modes, and also personal travel channel (Haddouch et al., 2018). With is, SUMO houses many tools for microscopic traffic simulations that were utilized during the microscopic traffic modeling for this thesis paper. It can be concluded from this study that SUMO allows situating network congestion at severe levels in position, in shorter paths and in importance. When developing a traffic model analysis, the end goal being which road networks would be most ideal for the intended evacuee, SUMO offers the capabilities in order to fulfill these goals and prompt safe evacuation behavior.

2.8. EVACUATION PLANNING AGAINST AN EARTHQUAKE

A research study conducted by Ye et al. (2012) focused on methodology and its application for evacuation planning against an earthquake disaster. Pre-disaster emergency evacuation zoning has become a significant topic of disaster prevention and mitigation research (Ye et al., 2012). A systematical methodology utilized in this research was based on the present layout of evacuation facilities and shelters as well as the evacuation demands in urban communities. The methodology for occupant evacuation against earthquakes on a community scale was developed by employing spatial analysis techniques of Geographical Information System (GIS). The methodology included the distribution analysis of emergency evacuation demands, the calculation of shelter space accessibility, and the optimization of evacuation destinations (Ye et al., 2012). An evacuation destination optimization formula was introduced that houses evacuation zoning equations within the constraints of the shortest path, the population assigned to one shelter does not exceed its carrying capacity, and one household unit shall correspond to one shelter. This paper concludes that the above algorithm was able to achieve the dual objectives of space accessibility and capacity accommodation. This research provided a feasible way for supporting emergency management in terms of shelter construction, pre-disaster evacuation drills, and rescue operations (Ye et al., 2012). While the main agendas for this thesis paper included traffic simulation to evaluate road networks against evacuation demand due to an earthquake event and the mobile app to display and provide step-by-step directions for users to evacuate with, the research discussed above could lead to potential opportunities for this thesis to focus on the destination (shelter) requirements for users that could impact the evacuation demand on certain road networks and overall destination locations within the app.

PAPER

I. DEEP LEARNING MODELS AND TOOLS FOR DISASTER EVACUATION AND ROUTING

ABSTRACT

Engineering managers and transportations planners need robust tools to communicate evacuation routing plans following disruptions from natural hazards. This research considers the New Madrid Seismic Zone, uses machine learning algorithms to determine best routes, and disseminates these routes via a phone application to manage evacuation capacity on surface roadways. Effective communication of impacted routes and safest options are a vital part of these planning efforts. The phone application developed here interfaces with state department of transportation travel maps to notify the user of an earthquake in progress or aftershocks. After the initial notification, the application will display a detailed warning message and indicate the quickest and safest route options to nearby shelters. Once a route is selected, the user will be presented with guided directions. The route selection will be determined from machine learning algorithms developed in this research group that are integrated with geographic information shapefiles. The notifications will display impaired or unusable roadways, nearest shelter, and best options for safe egress from the seismic zone. The results of this study can be used to improve safety following a major earthquake through the creation and use of a real-time communications application.

1. INTRODUCTION

This research extends previous research in disaster restoration and flood prediction (Ramachandran, et al, 2015a; Ramachandran, et al, 2015b; Ramachandran, et al, 2016; Corns, et al, 2016; Ojha et al, 2018; Gude, et al, 2020) to address a gap in communications tools and protocols. This proposed research uses deep learning and other computational intelligence techniques to predict road conditions at identified locations. The results of these algorithms are used as inputs to determine safe and effective routing schemas and communications processes surrounding natural hazard events. Machine/deep learning and data mining algorithms provide an opportunity to significantly improve the performance of automated tasks in seismology because they allow for more complex inference approaches that mimic the behavior of the human mind (Ross et al., 2018). A deep learning neural network will be implemented with state-driven evolutionary algorithms on selected test sites to predict potential earthquake damage using geospatial features along with roadway capacity and general demographic data. It can be noted that by using deep learning, the elimination of being biased to events that were previously quiet regions or for very large-magnitude events, without sacrificing detection sensitivity can be achieved (Ross et al., 2018).

This research focuses on the use of proper evacuation plans in response to a disaster to end users through an application. Following an earthquake, road conditions for individuals to reach necessary facilities and for emergency personnel to travel throughout the region may not be known and cause delays. The delays could entail a delay in life saving activities for people injured in an earthquake. Restoring water, electricity, telecommunication facilities, as well as maintaining operations at health facilities, are top priority in a post-earthquake situation where accurate and up-to-date information about various road conditions/outages are crucial. Having an accurate and up-to-date disaster response, routing, and communication mechanism via an application in response to earthquake and aftershocks is of the highest priority. These three entities combined will provide the base work for communication during the event, emergency response, and network restoration. Designing and validating a scalable GIS-model that considers projected levels of damage from an extreme event while also creating routing and scheduling protocols as part of a publicly available application is the target for this project. A survey instrument was developed and deployed to Missouri State Highway Patrol members and other first responders to identify locations and rank risk factors (of earthquake impact) for identified locations. Survey instruments were utilized for gathering information and then focus groups would be organized for additional information if needed. The code for both iOS and Android platforms is detailed in this paper along with their abilities to provide information and conclusions for full-scale implementation of the applications. Overall, the functionality of this application is to provide earthquake warnings and suggested routes for a region dealing with earthquake aftershocks for the end user to navigate safely to a shelter and to allow for community planners and first responders to plan accordingly.

2. METHODOLOGY

This study integrates visualization, prioritization, and simulation tools. Visualization tools harness data from heterogeneous multi-mode sources, fuse them as needed, and apply big data analytics and data management tools to provide geospatial and physical context for disaster response mapping. Prioritization tools integrate graph theory, capacity models, and impact models to design routing and resource allocation tools. Simulation tools were used to generate operational performance measures such as delays and clearance times for different traffic control scenarios during an evacuation. In particular, a traffic simulation model was developed to evaluate the performance of road network under different evacuation traffic control measures. Performance measures such as delays, clearance times, and travel times were extracted from the model for various demand and traffic control scenarios. The effect of different traffic control scenarios and network configurations were assessed using mesoscopic traffic simulation tools. From there, the simulation model provided the route(s) of choice following an earthquake for end users to use during evacuation in the New Madrid Seismic region (MO).

These data were exported as an excel file that was then read into the native app programs. The provided data encompassed the end points in the test region and the recommended route for the end user during evacuation was generated. The application was developed in three stages: user-interface & flow, Google Map integration and Mapbox integration. This application was developed in both iOS and Android native languages for Missouri Department of Transportation (MoDOT) to have full customization capabilities and functions. In earthquake disasters, the leading causes of death are directly related both to build collapses and fatalities during the following evacuation phase (Bernardini et all., 2017). In order to increase the safety of the end user, the following APIs (application programming interfaes) were introduced into this application to aid in the evacuation process.

Google Firebase, Google Database, Google Cloud Messaging, Google Maps, and Mapbox were the APIs utilized within the application. Mapbox handled the step-by-step navigation for the end user with their user-interface. Google Maps was utilized to display the desired route to the end user. Google Firebase/Database/Cloud Messaging services provided all the backend development to allow customized push notifications, potential user authentication and account creation, as well as allowing MoDOT to quickly provide updates to end users. All the incorporated APIs allow a seamless flow throughout the app without the user having to have an external app installed. When designing the app from the beginning it was important that the app was not complex but could get the desired information across to the end user. The heart of the application rests on the main page after the user has granted current location access and enabled notifications. Having Google Maps and Mapbox integrated into the application allows MoDOT to have further customization. Both APIs have their internal functions for generating the routes and displaying the navigation to the end user that can be retrieved with a few functional calls in the code. The California Integrated Seismic Network (CISN) provides continuous alerts for earthquake activity within the area for towns people through texts and/or emails. The system aims to provide warnings in seconds to tens of seconds prior to the occurrence of ground shaking at a site; since the system broadcasts the location and time of the earthquake, user software can estimate the arrival time and intensity of the expected S-wave (Cheng et all., 2014). This app would provide further functionality by providing mapping capabilities for the user to plan their evacuation ahead of time.

3. RESULTS AND DISCUSSION

The user experience was heavily considered throughout the design of the app to ensure a clean design that presents all necessary information with easy flow between screens. This includes incorporating MoDOT's current color scheme with easily accessible buttons and having text being clearly visible. When the user opens the application on an Android or iOS device, the loading screens displays the MoDOT logo with a prompt to allow location access to the device as shown in Figure 1. If location access is not granted, the user is prompted to go into settings to allow location access to use the application. The application will also ask to have notifications enabled for the application to send time sensitive alerts to the end user. Upon allowing device location access, the user can view upcoming possible warnings for their area, the route that the MoDOT team recommends for the user to take during evacuation, and the step-by-step navigation. As show in Figure 3 (for iOS) and Figure 4 (for Android). When the user does have possible earthquake aftershocks in their area in the near future, they are shown a screen that displays a warning overview, details about the warning, and the preferred route selection by MoDOT. Two locations were chosen as shelter locations for the end user to safely navigate to post-earthquake. The simulation data that was read into the program will only allow the non-affected roads to be determined in the route formulation process. This will ensure that the end user does not run into any issues while navigating to these shelters post-earthquake aftershocks. Once the user taps the “View Route” button in the application, they are brought to the next screen that displays the route that MoDOT recommends that they take via Google Maps. The app will have the current user location be the starting point of the route with the shelter being the destination point. When tapped, the “Start Navigation” button will bring the user to the final screen that displays step-by-step route instructions. The navigation feature has voice turn-by-turn instructions with projected arrival time. All of these features were incorporated into the app via Mapbox Navigation APIs. The flow of the app has a back button for the Map screen and a cancel button during navigation to allow seamless flow. If there is not a warning where the user resides, the phone will display “There are no earthquake warnings in your area at this time”. The target operating system for Apple is iOS 15.4 and the minimum API level for Android is API 27 for the MoDOT application to run.

Figure 1. iOS View of MoDOT Evacuation Application Onboarding Process

Dynamic notifications are also enabled within the applications where MoDOT can send customized notifications to end users. These notifications could encompass messages regarding last-minute warnings about an earthquake, the current development of an earthquake in the area, and the potential for earthquake aftershocks in the near future. An example message setup is shown in Figure 2. An apple certificate was generated through an Apple Developer account to allow push notifications on all Apple devices.

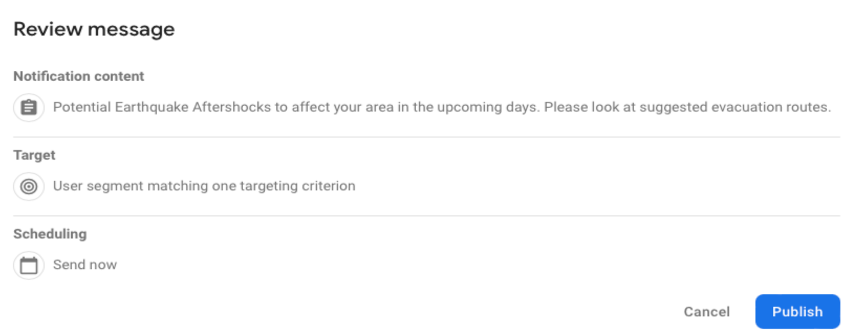

Figure 2. Google Notification Message Preview

The application currently is implemented with Google services for the dynamic messaging where notifications can be prewritten into a que. From there, depending on the region of potential earthquake aftershocks, MoDOT has the ability to push certain notifications from the que to reach the end user in a timely manner. Additional code will be necessary for full-scale production to target location specific notifications. As of now, notifications can be pushed to the device with the select warning message desired by MoDOT. As mentioned in this paper, this application could mirror the notification system built by CISN but provide additional mapping capabilities for safely evacuating individuals within a specific region being affected by earthquake aftershocks.

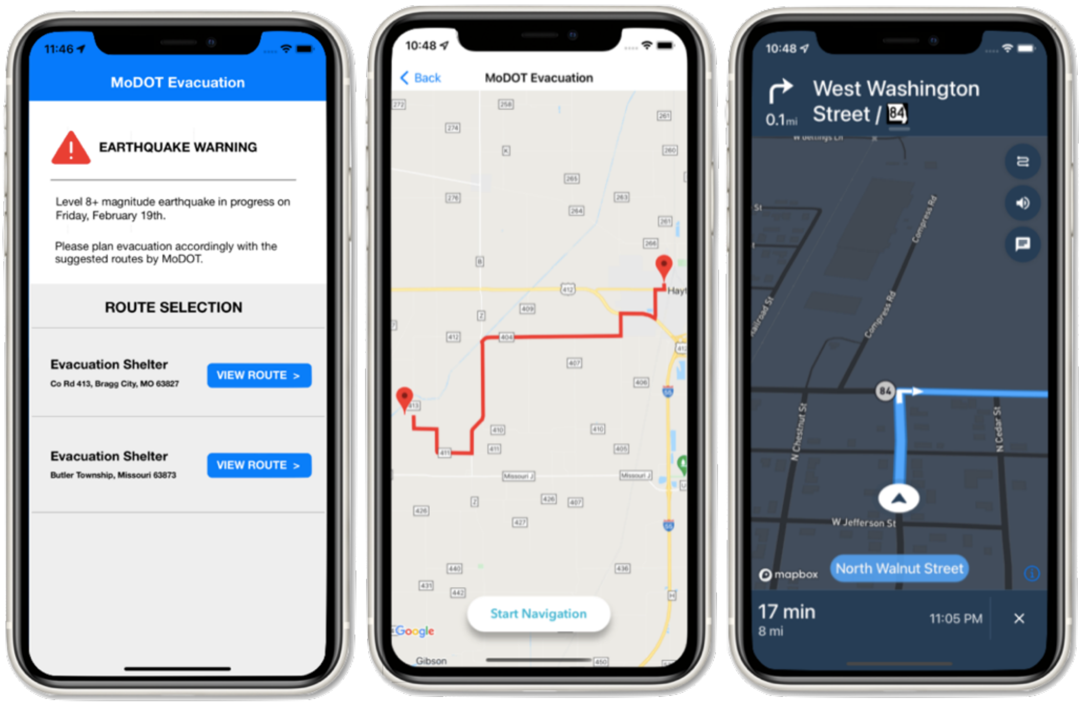

Figure 3. iOS view of MoDOT Evacuation Application Flow

Extending further into the application, Figure 3 displays three phone screens to showcase the functionality of the app. The left screen depicts the main warning screen followed by the Google Map, map preview screen. With the click of the “Start Navigation” button, the user is able to initiate step-by-step navigation. The “View Route” button allows the user to reach the second screen to view the suggested route on a map. Additional functionality of this application could extend into allowing the user to type in a specific address and adding an outlet for the user to report road damage to MoDOT with a message and possibly a picture. Google Firebase Authentication procedures would need to be implemented into the code to allow the incorporation of these features. The application flow of the Android version is shown in Figure 4. Both applications allow parallel functionality to the end user with both having the same potential for future add-on features. The navigation between screens has altered a little bit with the Android app for the navigation bar is at the bottom of the screen. An iPhone 11 and Android Nexus 5X were the devices chosen for simulation.

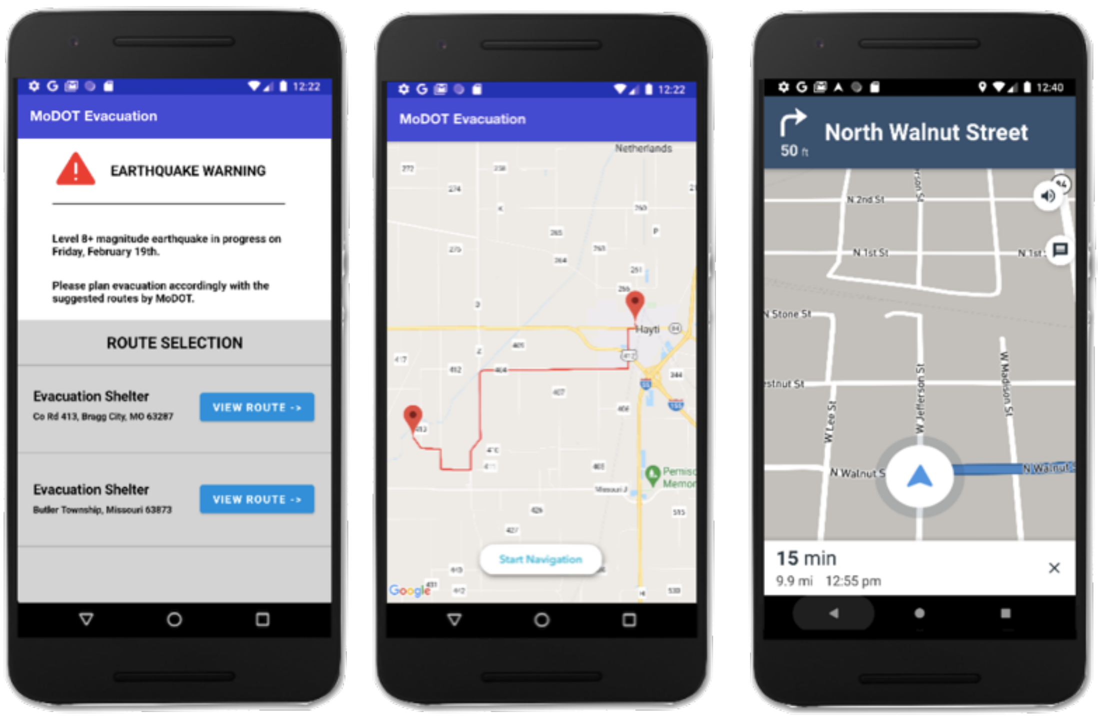

Figure 4. Android view of MoDOT Evacuation Application Flow

The app was presented to MoDOT and community first responders for guidance and updates as part of a pilot projects. The work presented in this paper reflects those suggested changes.

4. CONCLUSIONS AND FUTURE WORK

Stakeholders have requested an easily used, seamless communications tools as part of emergency response and preparedness. This project provides that capability, with the application development focused on the New Madrid Seismic Zone with two shelters resembling the destination locations for the user. The phone location was set to a specific point for both tests. While the app can read the data coming into the program, it cannot draw the route. Currently the program creates an array of all the elements from the excel that can be individually assigned a value. That value can then be used to determine the end location and/or help with determining which route to display to the user in the app. The app is currently programmed only for the New Madrid Seismic Zone. For full scall production, additional classes of waypoints will be needed. This will allow MoDOT to "override" the current Google Map and Mapbox direction and navigation algorithm. One is unable to explicitly tell Google Maps or Mapbox to only display a certain route. Depending on where the user's current location is, additional functionality will be needed to determine which waypoints need to be called into the directions and navigation functions. Notifications are enabled on the app and can be simulated with various messages and warnings. However, additional code to create location specific notifications will also be needed. This encompasses recording and storing the user's current location ID and checking if that location point is within the range of the affected area.

Google Cloud Messaging provides the notifications and can be managed by MoDOT through Google Console. Potentially, the React Native framework could also be implemented with this application to combine two versions of the code into one single version. Another point of interest to consider is whether cellular towers will still be functioning after the earthquake shocks. This will have a dramatic effect on the usability of the phone/device for the application requires GPS location and internet to navigate the user to a shelter. Further research can be conducted on whether the APIs offer off-line map capabilities for the user to download the route ahead of time. One final note to consider would be offering more than one route suggestion for a location to the user. Whether a main road is predicted to be not usable post-earthquake aftershocks, having all users take the same alternate road may lead to congestion for the route does not sync with real time traffic data. Traffic congestion can be shown on the map in Google Maps. The initial prospect of being able to notify a user ahead of time of potential earthquake aftershocks and provide a route suggestion for the user to evacuate safely for a specific region was accomplished. With this application, engineering managers, transportation planners, and civilians can utilize this app for effective emergency evacuation planning. Future work will include more robust usability studies, along with greater mechanisms for integration into Missouri state emergency preparedness networks.

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II. IDENTIFCATION OF A RESPONSE AND RESCUE NETWORK FOR THE ST. LOUIS REGION

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ABSTRACT

This research focuses on the planning and responses to earthquakes affecting the St. Louis (MO) metropolitan region. The team will analyze and develop egress and ingress routes followed by identifying structures prone to fail due to an earthquake in neighboring zones. A traffic simulation model for assessing the evacuation procedure will be created as well as a communication plan for evacuation directions to residents of the region. There are three traffic simulation models that will be explored by the team: microscopic, mesoscopic, and macroscopic models. Each model has its' own advantages and disadvantages that will be evaluated and the option most suitable will be selected. A traffic simulation model for the St. Louis metropolitan region will be developed to simulate the evacuation demand and generate key performance measures. Travel demand models will be utilized to generate evacuee demand for use in the simulation and the demand will be the input of the origin-destination (OD) matrices. A total of six road networks were tested with an evacuation demand to determine the noise, speed, and waiting periods for the simulated vehicles. Eclipse SUMO (Simulation of Urban MObility) software was utilized to conduct the microscopic traffic simulations in the St.

Louis metropolitan area. The results of this study will improve the emergency preparedness for earthquake events in the St. Louis metropolitan region.

1. INTRODUCTION

This research extends previous research in deep learning models and tools for disaster evacuation and routing (Corns et al., 2022) to provide routes to end users before and during earthquake after-shock warnings for evacuation. This research was coupled with disaster restoration and flood prediction (Ramachandran et al., 2015a; Ramachandran et al., 2015b; Ramachandran et al., 2016; Akhilesh et al., 2018; Gude et al., 2020) that addressed a gap in communication tools and protocol through the incorporation of deep learning models to predict road conditions at identified locations. This proposed research will identify vulnerable links in a roadway network based on their structural integrity in the St. Louis metropolitan area. USGS earthquake hazard mapping reports for St. Louis will allow the team to overlay the severity of earthquake ground shaking to correlate the shaking intensity to the state of the bridge. Alternative routes for each origin-destination pairs in the region will be determined and operational strategies such as communicating the detour information will be provided. A household survey will be conducted to obtain information on evacuee behavior in the region. The survey responses will identify populations likely threatened by an earthquake and will provide insight for the simulation model. The information collected will include decisions made by evacuees regarding their evacuation decision, departure times, personal vehicle use, route choice, and destination choice. This data will be used to develop evacuation travel demand data. For this research, the evacuation survey data obtained from the New Madrid Seismic Zone (Corns et al., 2022) was utilized for the traffic simulation models. Microscopic, mesoscopic, and macroscopic traffic simulation approaches were analyzed where each had their own advantages and disadvantages. This research focused on microscopic traffic simulations utilizing SUMO simulation software. The traffic simulation modeled the evacuation demand and generated key performance measures for use by emergency management stakeholders. The following steps were performed for the traffic simulations; relevant data was generated on evacuee behavior; a transportation network was coded in the simulation model using publicly available datasets such as open street maps; travel demand models will be used to generate evacuee demand for use in the simulation; traffic control data such as signal timing and phasing information and ramp closures will be inputted into the final simulation model; various scenarios will then be generated in the simulation model; and lastly, each scenario will be simulated at least 5 times to account for randomness in the simulation parameters. The key performance measures will include delays, vehicle volume by route, clearance times, and location of bottlenecks. The results of the different scenarios will be compared with the baseline that will allow the team to identify which network strategies perform the best at alleviating congestion and quickly getting evacuees to safety. Lastly, a tabletop exercise to replicate an earthquake will be designed and implemented to identify road and bridge closures, address evacuation and response strategies, and establish a communication plan for the public.

2. METHODOLOGY

This study integrated microscopic simulation tools to generate performance measures such as delays and clearance times for different traffic control scenarios during an evacuation. The performance of the road network under different evacuation traffic measures provided insight into delays, clearance times, vehicle speed, and overall travel times. From there, the data could be extracted to determine which route(s) in the region would be able to best withstand the estimated evacuation demand. Multi-vehicle tracking using microscopic traffic models proposed a multi-vehicle tracking algorithm from a leading vehicle passing slower vehicles (Song et al., 2019). This is an example of how microscopic traffic simulations can address vehicles moving independently of one another due to traffic volume and traffic heterogeneity. This research incorporated the evacuation demand generation from the household survey and the time and length of the traffic simulations from the New Madrid Seismic Zone project (Corns et al., 2022). With this data, the creation of the transportation network for the St. Louis County region was created with Open Street Maps (OSM) that is shown in Figure 1.

To extract the road network from OSM, a netconvert command was utilized that generated the network.xml file. Next, the origin-to-destination (OD) to trip destination file generated trips and routes within the road network given the OD matrix pair. This file encompassed the following: a TAZ (traffic analysis zone) file, an OD (origin-destination) matrix file, an od2trips configuration file, a duarouter configuration file, and a configuration file for the SUMO simulation. The TAZ file encompasses the edges from the road network and a numerical id associated with each edge.

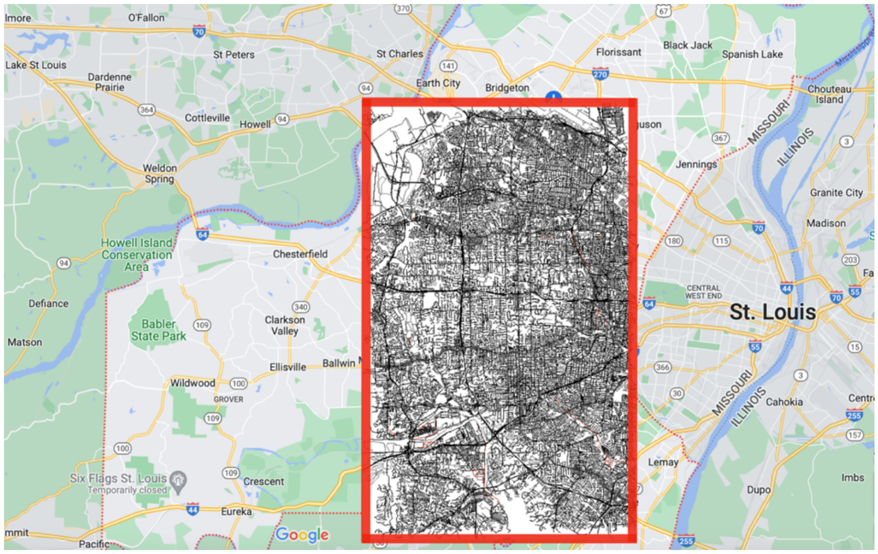

Figure 1. OSM to SUMO Network of St. Louis County Region (highlighted in red box)

The OD file encompasses the beginning and end times of the simulation, the number of vehicles for the simulation, and the vehicle directions from taz 1-to-2, 2-to-3, and so on. The od2trips file outputs the od_route_file.odtrips.xml with the network and od_route file as inputs. And the configuration file sets up the simulation.

From there, the NedEdit software (left image in Figure 2) was utilized to assign the desired route for the SUMO simulation. The road network consists of multiple edges (in red) that can be selected inside the NetEdit software. The selected edge was then imported into the TAZ file and assigned a numerical value (e.g., 1,2,3). This allowed the OD file to generate the desired path by statically coding the vehicles to move from edge 1 to 2, 2 to 3, and so on. Once the entire route was generated in the OD and TAZ file, the following command was executed to generate the trips file: od2trips -c PATH\od2trips.config.xml -n PATH\taz_file.taz.xml -d PATH\OD_file.od -o PATH\od_file.odtrips.xml. From there, the following command was executed to generate the route assignment that calculated the shortest path for each trip: duarrouter -c PATH\duarcfg_file.trips2routes.duarcfg -o od_route_file.odt. Once the simulation was generated, the following command was executed to view the run time of the simulation: sumo-gui -c config_file.sumocfg. The SUMO graphical user interface (gui) was then opened where the traffic simulation could be run to collect the overall simulation time (right image in Figure 2).

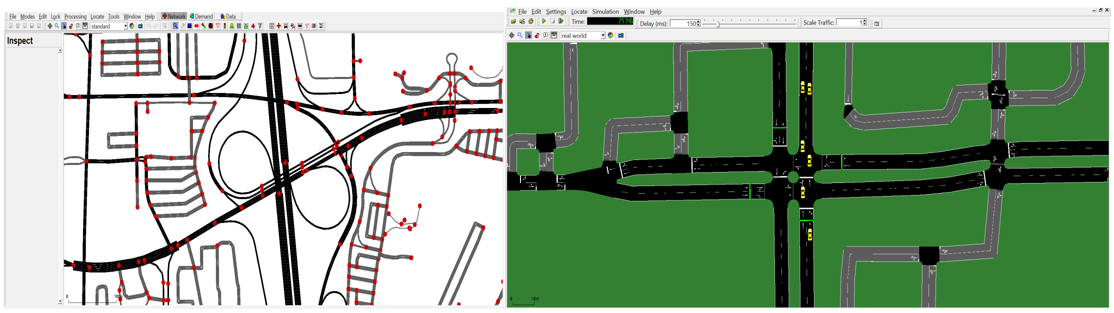

Figure 2. NetEdit Software (left image) and SUMO Software (right image)

To gather the results of the SUMO simulation, the following command was executed: sumo -c config_file.sumocfg –emission-output emission_file.csv. The emission output file contained the average speed of each vehicle, the average waiting times for each vehicle, and the average noise for each vehicle on the road network. This file also encompassed multiple types of emission data (e.g., CO2, CO, HC, NOx) that was not needed for this research. Validated road segments (Figure 3) were used to compare the simulated and free-flow travel times as shown in the third and fourth columns of Table 1.

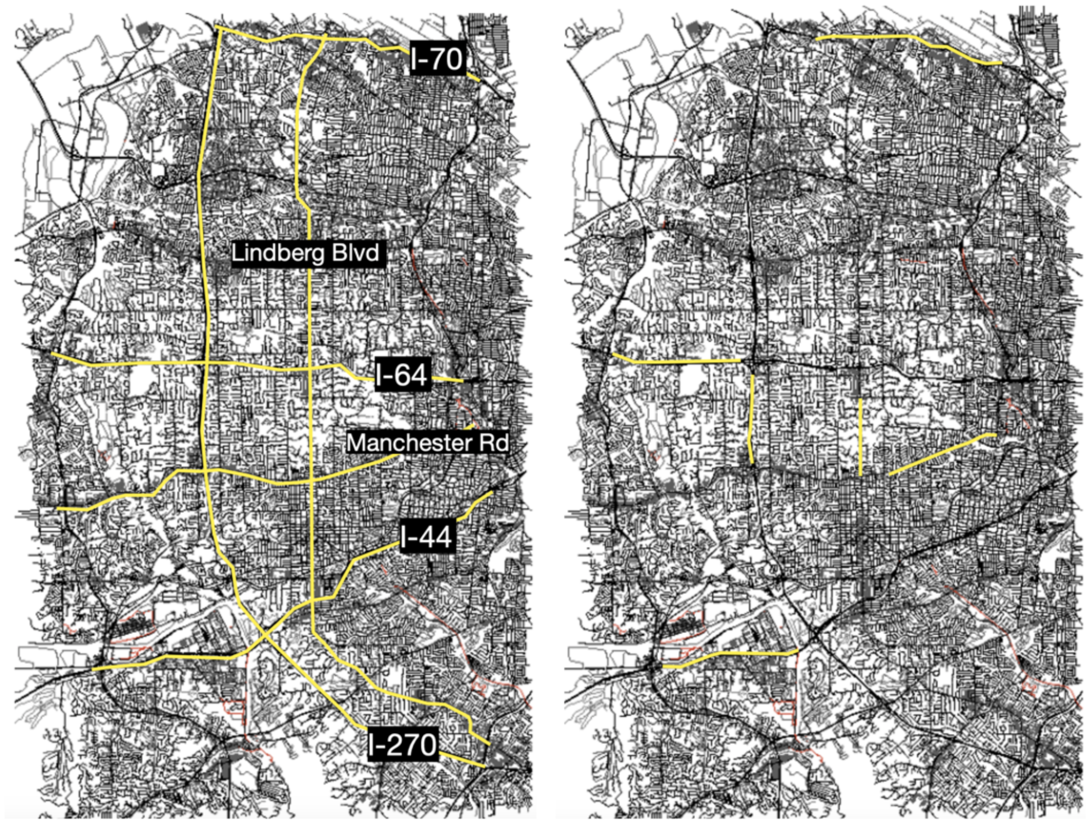

Figure 3. Simulated Road Network (left) and Verification Road Network (right) in yellow

Table 1. Travel Time Validation Results

Number	**Route**	**Travel time in SUMO (min)**	**Travel time in Google Maps (min)**
1	Lindberg Blvd (LB)	2.52	3
2	Manchester Rd (MN)	7.31	7
3	I-44	2.51	3
4	I-64	2.51	3
5	I-70	5.08	5
6	I-270	2.14	2

As shown in Table 1, the simulated travel times were close to the free-flow travel times using posted speed limits.

3. RESULTS AND DISCUSSION

In this study, the evacuation demand, a total of 47,100 vehicles, was loaded onto the road network in over 6-hour or 12-hour periods. The evacuation was assumed to begin at 7:00am for all the scenarios. Average Speed per hour, Average Noise per hour, and Average Delay per hour for the 6-hour period is shown in Figure 4 and for the 12-hour period in Figure 5.

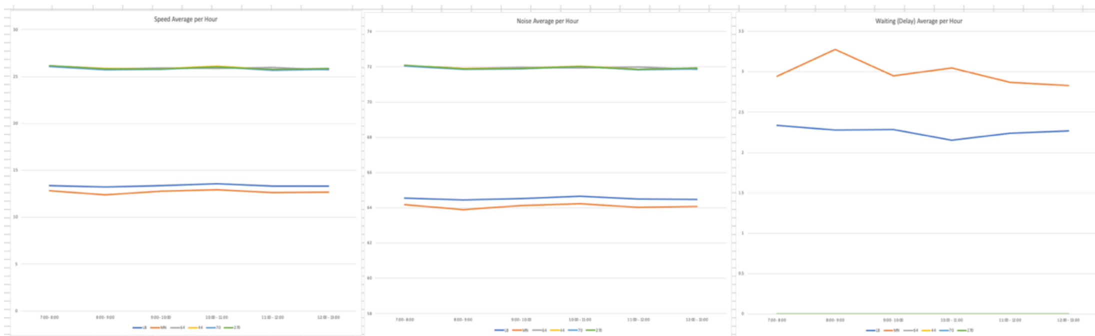

Figure 4. Traffic Simulation Results for 6-hour Period

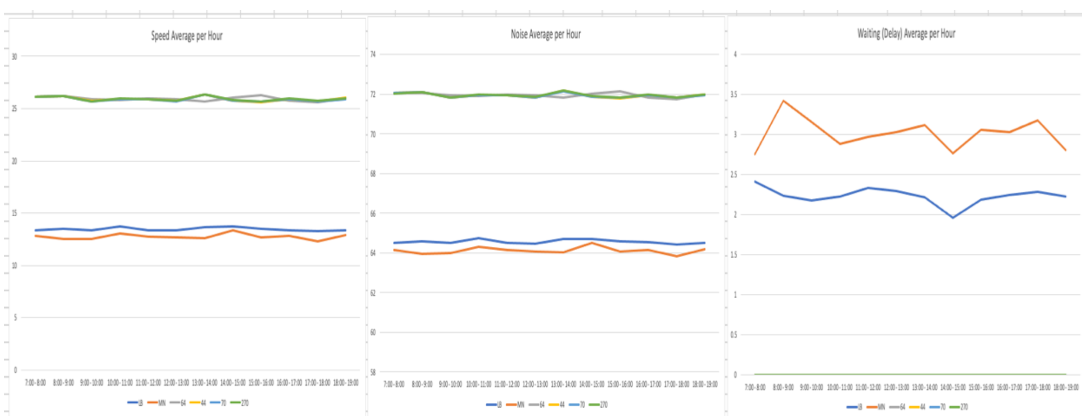

Figure 5. Traffic Simulation Results for 12-hour Period

The SUMO environment simulated the road network in seconds that then needed to be converted to hours. The output file type, Emission file, was selected for it encompassed the key performance measures to aid in the process of evacuation. The emission file was a CSV file type that then had to be split into smaller CSV files with Microsoft PowerShell for Excel to open and extract the data. For Figures 4 and 5, each hour resembles the average of all vehicles traveling at that point in time. The speed, noise, and delay, encompass the average of a tenth of all 47,100 vehicles. This was due to the size of the emission file being too large to extract for all 47,100 vehicles. The speed average reflects the speed of each vehicle travelling at that moment in time. The noise average reflects how compact the road network is which is a good indicator of the level of service (LOS) in the road network. And finally, the waiting (delay) average reflects how long a vehicle must be stationary at that period. Ideally, the speed average should be high, and the noise and delay averages should be low to ensure an efficient evacuation.

It can be noted that all six routes reflected the same outputs for the 6-hour and 12-hour period. Manchester Rd (MN) had the lowest speed and noise average for both periods. This could be due to the size of the road and the number of traffic lights. Lindberg Blvd (LB) had the second lowest speed and noise average due to the road being similar to Manchester Rd. The interstates (I-44, I-64, I-70, I-270) had the highest speed and noise average and the lowest delay average. Essentially the vehicles were able to travel at high speeds with little to no wait time. However, the roads were more compact with vehicles in each time step. In Table 2, the time results for the 6-hour and 12-hour period reflect all 47,100 vehicles. There were three waves of simulations that were conducted: wave one being the road network verification, wave two for the simulation time analysis, and wave three for the average speed, noise, and waiting time analysis. Table 2 houses the simulation time results for all scenarios.

Table 2. Simulation Times for 6-hour and 12-hour period

Number	**Route**	**Simulation time – 6-hour period**	**Simulation time – 12-hour period**
1	Lindberg Blvd (LB)	8.24 hours	12.16 hours
2	Manchester Rd (MN)	6.12 hours	12.10 hours
3	I-44	6.06 hours	12.06 hours
4	I-64	6.07 hours	12.07 hours
5	I-70	10.44 hours	12.11 hours
6	I-270	6.12 hours	12.11 hours

From the simulation time results, it can be noted that the roads that did not manage the high volume of evacuation demand for the 6-hour period were Lindberg Blvd and I-70. This could be due to the fact that Lindberg Blvd has many stoplights and is mostly a 2-lane road. And I-70 lays right next to St. Louis Lambert International Airport. All other routes for the 6-hour period scenario reflected close to the actual simulation time in SUMO. All 12-hour period scenarios had a simulation completion time that was relatively close to the 12-hour mark.

4. CONCLUSIONS AND FUTURE WORK

From the research on this project, a SUMO microscopic traffic simulation was conducted for the evacuation demand of 47,100 vehicles in the St. Louis County Region.

This provides a good benchmark for future projects as it displayed the capabilities of SUMO's traffic simulation modeling. The results indicated that the six road networks completed their simulation times close to the 12-hour period and four of the road networks completed their simulation times close to the 6-hour period. The speed average, noise average, and delay (waiting) average graphs were all extracted from the emissions output file from SUMO. These graphs entailed which roads in the St. Louis County region would be most suited for an evacuation. Further research into the following points is recommended; selecting only certain road networks (e.g., Manchester, I-44) from OSM to convert to SUMO for the entire St. Louis County region was too big to be extracted. Implementing the visualization plot commands of SUMO's output emissions file for graphs of the desired output categories (e.g., speed, noise, delay). And lastly, implementing bottlenecks in the road networks that are identified in earthquake hazard mapping and bridge seismic screening tools. This research encompasses a foundation for microscopic traffic simulation modeling in SUMO that can further incorporate earthquake-related inputs for a region of choice in future work. The engineering manager can use this research as a guide to develop additional microscopic traffic simulations in SUMO for effective emergency evacuation planning.

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SECTION

3. CONCLUSIONS AND RECOMMENDATIONS

3.1. CONCLUSIONS

A mobile application for post-disaster evacuation planning was developed for the New Madrid, MO region that served the purpose of sharing emergency event handling to end users. With the application open, users can view the type of emergency event, the recommended routes to evacuate with, and commence step-by-step navigation all with an easy-to-use user interface.

Microscopic traffic simulations were conducted for the St. Louis (MO) metropolitan area to assess which road networks would be impacted by the projected evacuation demand. The following metrics were used to determine which roads would be able to handle the demand most effectively: delays, noise, speed, and overall travel times.

3.2. RECOMMENDATIONS

The mobile app satisfied stakeholder's requirements that provided a communication tool for post-disaster evacuation planning tailored to emergency personnel and residents of the area. However, the application has several additional measures to be taken for full-scale implementation. Such as, implementing further waypoints for additional route customization, establishing location-specific push notifications, and integrating offline mapping capabilities.

The microscopic traffic simulations enable engineering managers to determine which road networks in the St. Louis (MO) metropolitan region are able to withstand the projected evacuation demand following an emergency event and pursue further simulation modeling in SUMO. Additional simulation modeling can be concluded for the St. Louis metropolitan area that entail implementing visualization plot commands and bottlenecks specific to the area.

This research focused on emergency evacuation planning tools to promote additional safety measures for residents in multiple cities in Missouri.

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VITA

Nicholas Alexander Kutheis was raised in St. Louis, MO, USA where he attended Kirkwood Senior High School, graduating in May of 2017. He went on to graduate magna cum laude from Missouri University of Science and Technology in December of 2021 with a B.S. in Electrical Engineering. Immediately following graduation, Nicholas began his master's studies at Missouri University of Science and Technology, receiving an M.S. degree in Engineering Management in May of 2023. During master's studies, his research interests included mobile app development for Android and Apple devices and microscopic traffic simulation modeling for post-disaster evacuation preparation and routing. Nicholas also served as a teacher's assistant during the first semester of his graduate program.