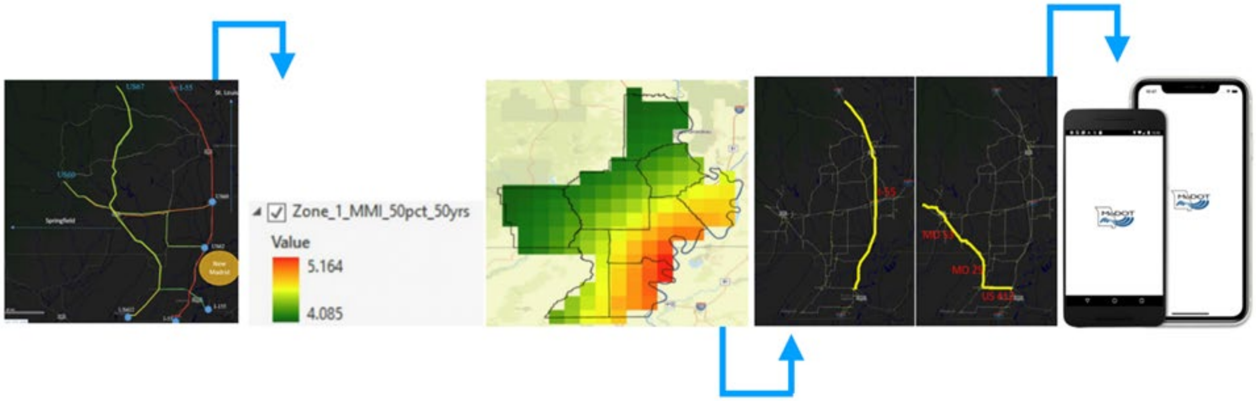
Deep Learning Models and Tools for Disaster Evacuation and Routing



December 2022
Final Report

Project number TR202202
MoDOT Research Report number cmr 22-014

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TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.
cmr 22-014

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Deep Learning Models and Tools for Disaster Evacuation and Routing

5. Report Date
December 2022
Published: December 2022

6. Performing Organization Code

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9. Performing Organization Name and Address
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10. Work Unit No.

11. Contract or Grant No.
MoDOT project # TR202202

12. Sponsoring Agency Name and Address
Missouri Department of Transportation (SPR-B)
Construction and Materials Division
P.O. Box 270
Jefferson City, MO 65102

13. Type of Report and Period Covered
Final Report (January 2022-October 2022)

14. Sponsoring Agency Code

15. Supplementary Notes
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. MoDOT research reports are available in the Innovation Library at https://www.modot.org/research-publications.

16. Abstract

Engineering managers and transportations planners need robust tools to communicate evacuation routing plans following disruptions from earthquake events. The project will use the New Madrid Seismic Zone in South-East Missouri as a testbed for modeling the response to an earthquake and aftershocks at Magnitude 8+. This area was chosen as it allows solutions to specific regions with inadequate road networks, limited communications protocols, and high likelihood of structural damage for the proposed scenario. Research tasks include identifying road structure damage based on the Mercalli Intensity Scale, running traffic simulations for post-earthquake evacuation to determine the desired routes out of the area. This research will then be able to display the warning of the earthquake event along with the desired route for the end user. Effectively providing the safest navigation routes are a vital part of these planning efforts.

17. Key Words
Disasters; Earthquakes; Emergencies; Evacuation; Mercalli Intensity Scale; Seismic prospecting

18. Distribution Statement
No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)
Unclassified.

20. Security Classif. (of this page)
Unclassified.

21. No. of Pages
56

22. Price

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

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A Report on Research Sponsored by

Missouri Department of Transportation

December 2022

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Acknowledgments

This project builds upon previous work done by the United States Geological Survey (USGS) and National Weather Service (NWS). The geospatial data is gathered by the United States Geological Survey (USGS) and the rainfall data is collected by the National Weather Service (NWS). The test location identification data was gathered by the Missouri State Emergency Management System (SEMA).

Table of Contents

List of Figures

List of Tables

Abstract

Engineering managers and transportations planners need robust tools to communicate evacuation routing plans following disruptions from earthquake events. The project will use the New Madrid Seismic Zone in South-East Missouri as a testbed for modeling the response to an earthquake and aftershocks at Magnitude 8+. This area was chosen as it allows solutions to specific regions with inadequate road networks, limited communications protocols, and high likelihood of structural damage for the proposed scenario. Research tasks include identifying road structure damage based on the Mercalli Intensity Scale, running traffic simulations for post-earthquake evacuation to determine the desired routes out of the area. This research will then be able to display the warning of the earthquake event along with the desired route for the end user. Effectively providing the safest navigation routes are a vital part of these planning efforts.

Executive Summary

This research project used historic data collection, a first responders survey instrument, and determined road structure damage from the Modified Mercalli Intensity scale as the inputs into the traffic simulation models that encompassed the safest route for end users to take after an earthquake event. The route was then passed into the mobile application via a CSV file that could display the route to the user. This study integrates visualization, prioritization, and simulation tools. Visualization tools harness the data from heterogeneous multi-mode sources and apply big data analytics and data management tools to provide geospatial and physical context for disaster response mapping. Prioritization tools integrate graph theory, impact models, and capacity 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 situations during an evacuation. In particular, a traffic simulation model was developed to evaluate the performance of road networks 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 events. 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).

Region Selection **Post-Disaster Road Impact Analysis** **Traffic Simulations** **Mobile App**

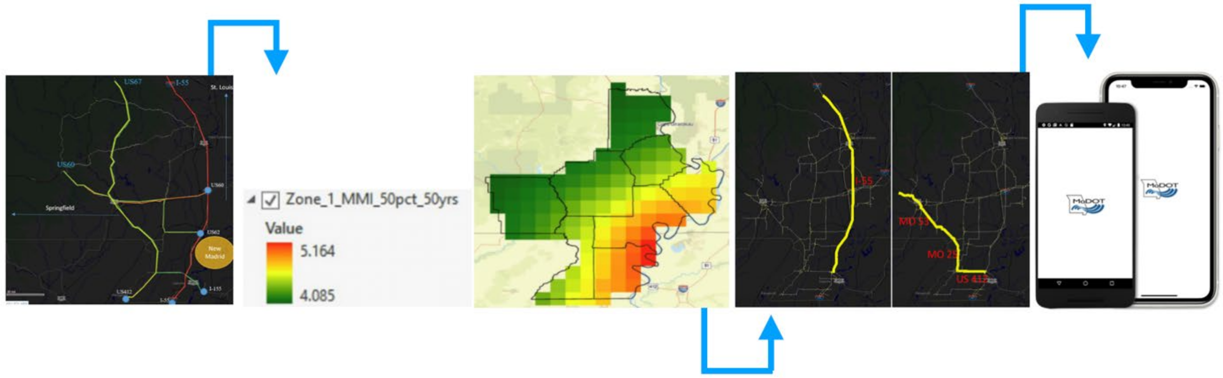


Figure 1. Project Task Overview

This project began with determining the location of interest that encompassed tasks one and two. Which included gathering data from public data sources and completing a survey sent to first responders identifying roads of impairment post-earthquake. From there, the Modified Mercalli Intensity scale provided further in-depth readings of structural damage from the area of interest, the New Madrid Seismic Region. The traffic simulations determined the safest route for evacuation which was then fed into a mobile application for the end user to safely evacuate out of the region. With this application, emergency personnel and civilians can use this app for effective emergency evacuation planning.

1. Literature Review

Earthquake events cause economic and personal damages to people living in the earthquake-prone areas of Missouri. While there have been multiple studies done to analyze the impact level of an earthquake in various regions throughout the state, there is a lack between the connection of earthquake damage and providing accurate warnings to individuals of an earthquake event with suggested routes to evacuate safely. In order to create the connection, this project focuses on determining the level of impact from an earthquake in a selected region within Missouri. As well as providing the safest routes for individuals to evacuate the affected area or for emergency personnel to plan accordingly.

Research Methodology

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. Originally, this proposed research was to incorporate deep learning and other computational intelligence techniques to predict road conditions at identified locations. 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). Where the results of these algorithms are used as inputs to determine safe and effective routing schemas and communications processes surrounding natural hazard events 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). A deep learning neural network was to be coupled with state- driven algorithms on selected test sites to predict potential earthquake damage using geospatial features along with roadway capacity and general demographic data.

Research Implementation

In earthquake disasters, the leading causes of death are directly related both to building collapses and fatalities during the evacuation phase (Bernardini et all., 2017). With this in mind, it is important and necessary to have effective warning and evacuation mechanisms for civilians and emergency personnel to decrease the number of fatalities. This research proposed an alternative method for determining the routes for evacuation by analyzing and extracting the data from the Modified Mercalli Intensity scale that indicates the level of structural damage due to an earthquake. That was then infused with traffic simulations to determine the roads that were able to handle high evacuation volumes while still being intact post-earthquake. Lastly, a phone application displayed the warning message to the end user and allowed the user to view the selected routes for evacuation and being the navigation process. Overall, this research is a proposed method to provide the next level of safety to civilians and emergency personnel.

2. Methodology

TASK 1: Historic Data Analysis

1.1 Background

The research team used historic seismic data from MoDOT, USGS, and other public data sources to identify areas of concern in the New Madrid Seismic Region. This information will be utilized in the preparation of the survey instrument (task 2) for first responders and to isolate data sources that would be linked to these areas. The data sources will be used as inputs for the First Responder Application.

1.2 United States Geological Survey (USGS)

The U.S. Geological Survey provides programs for monitoring, reporting, and researching earthquake and earthquake hazards. These tools provide documentation regarding earthquakes that are accessible for data analysis.

1.3 Missouri Department of Transportation (MoDOT)

The Missouri Department of Transportation provides tools to gather public roadway information that can be utilized in the survey instrumentation.

1.4 Missouri State Emergency Management Agency (SEMA)

The Missouri State Emergency Management Agency promotes disaster mitigation with a first responder group that will identify the test locations.

Summary of Task 1

This task focused on data collection from various sources regarding earthquake events. With the data from MoDOT, USGS, and SEMA, the team was able to prepare the survey instrument for first responders and isolate the data sources linked to this area.

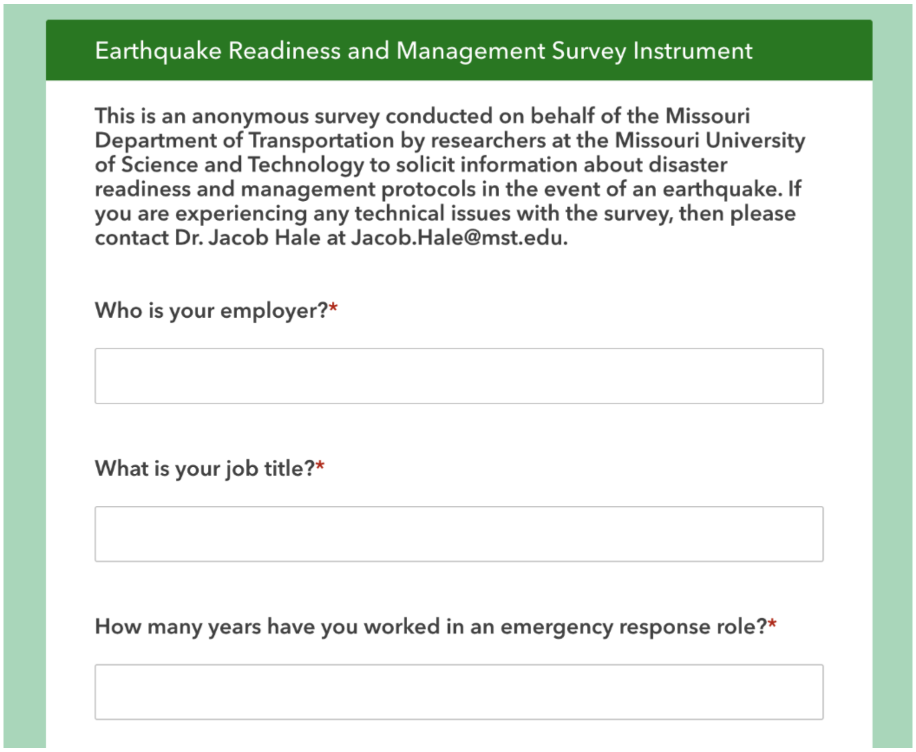
TASK 2: First Responders Survey Instrument

2.1 Background

A survey instrument will be created and sent to a sample of multiple first responder groups including the Missouri State Highway Patrol. Those selected will be in groups that must travel in Missouri as part of their job duties and be part of first responder efforts following a large-scale seismic event. The survey instrument solicits information on areas that are susceptible to high levels of damage due to a large-scale seismic event.

2.2 Survey Instrument Questions

The questions below were a part of the survey to determine which areas in Missouri would be susceptible to structural road damage following an earthquake.



Earthquake Readiness and Management Survey Instrument

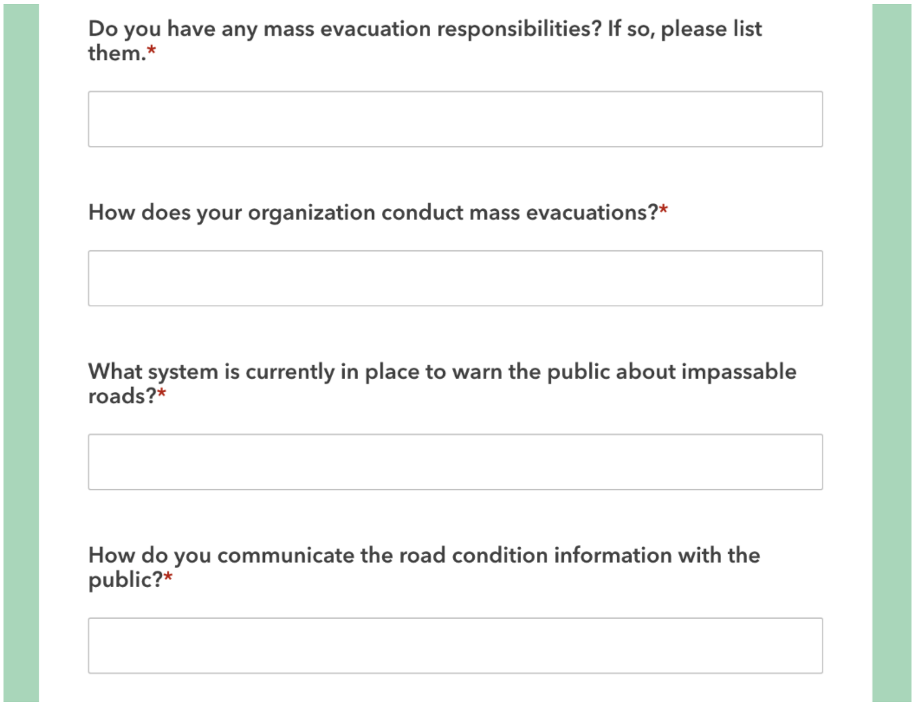
This is an anonymous survey conducted on behalf of the Missouri Department of Transportation by researchers at the Missouri University of Science and Technology to solicit information about disaster readiness and management protocols in the event of an earthquake. If you are experiencing any technical issues with the survey, then please contact Dr. Jacob Hale at Jacob.Hale@mst.edu.

Who is your employer?*

What is your job title?*

How many years have you worked in an emergency response role?*

Figure 2. Survey Questions 1-3



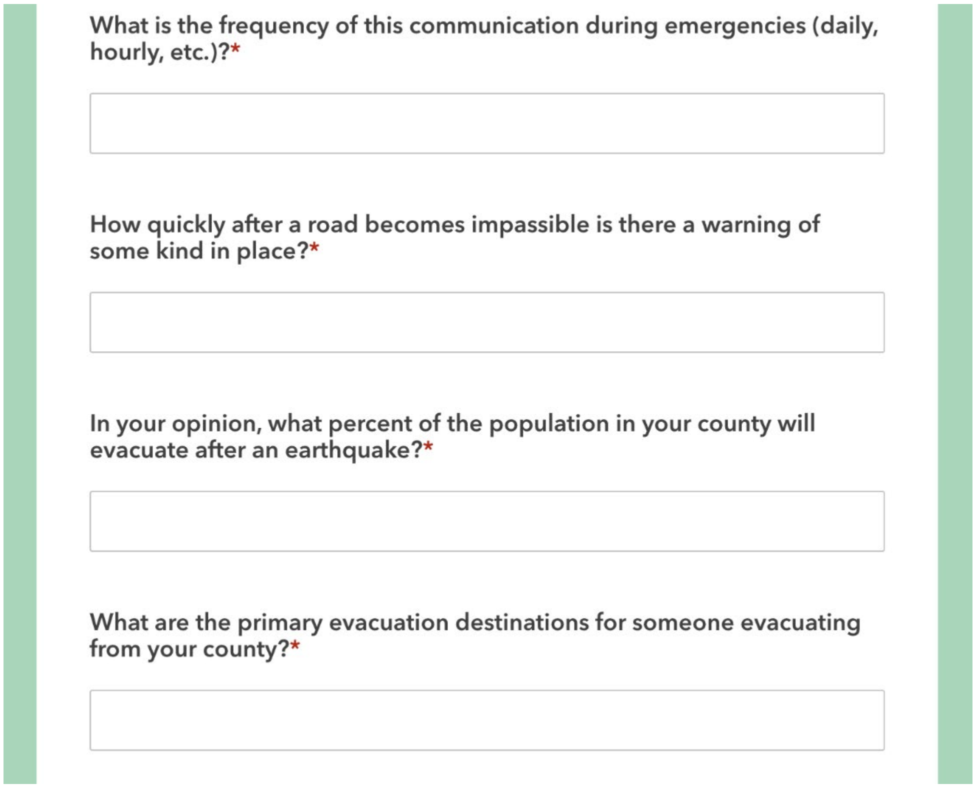
Do you have any mass evacuation responsibilities? If so, please list them.*

How does your organization conduct mass evacuations?*

What system is currently in place to warn the public about impassable roads?*

How do you communicate the road condition information with the public?*

Figure 3. Survey Questions 4-7



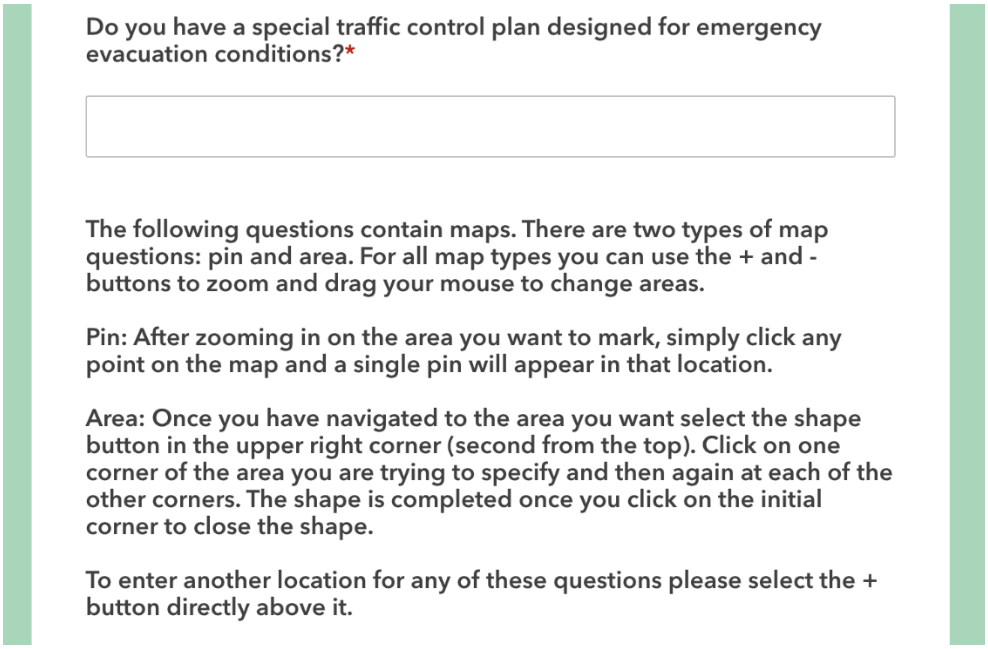
What is the frequency of this communication during emergencies (daily, hourly, etc.)?*

How quickly after a road becomes impassible is there a warning of some kind in place?*

In your opinion, what percent of the population in your county will evacuate after an earthquake?*

What are the primary evacuation destinations for someone evacuating from your county?*

Figure 4. Survey Questions 8-11



Do you have a special traffic control plan designed for emergency evacuation conditions?*

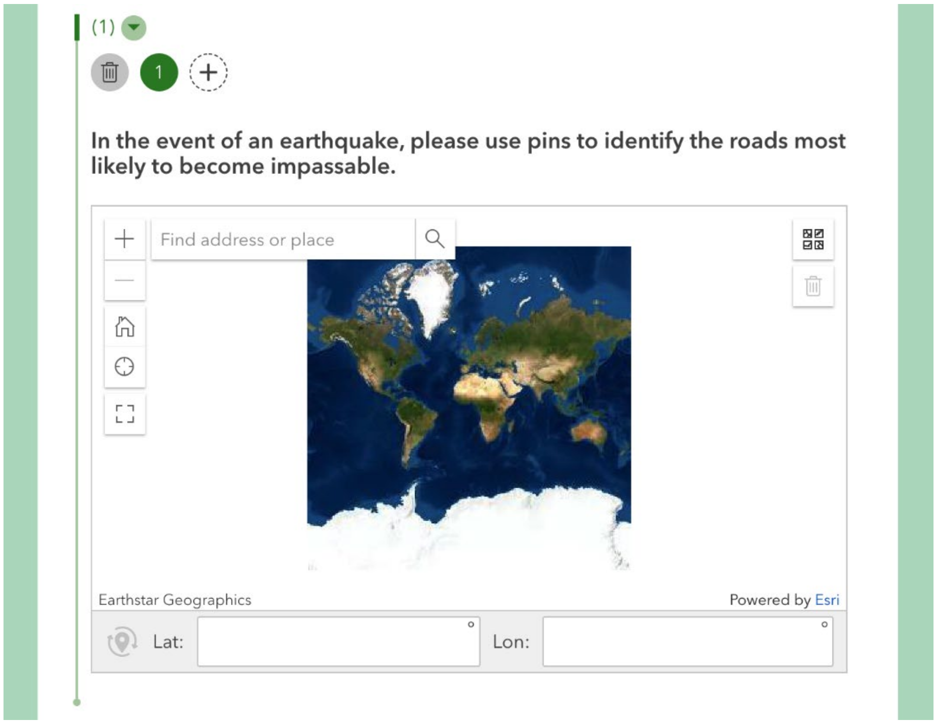
The following questions contain maps. There are two types of map questions: pin and area. For all map types you can use the + and - buttons to zoom and drag your mouse to change areas.

Pin: After zooming in on the area you want to mark, simply click any point on the map and a single pin will appear in that location.

Area: Once you have navigated to the area you want select the shape button in the upper right corner (second from the top). Click on one corner of the area you are trying to specify and then again at each of the other corners. The shape is completed once you click on the initial corner to close the shape.

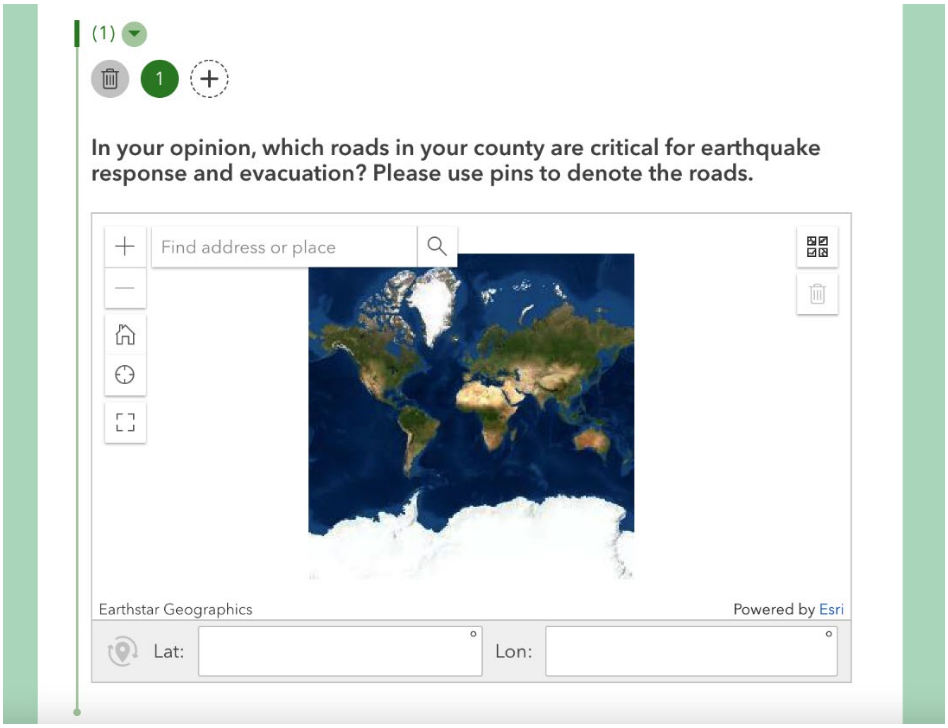
To enter another location for any of these questions please select the + button directly above it.

Figure 5. Survey Question 12 and Instructions


(1)

In the event of an earthquake, please use pins to identify the roads most likely to become impassable.

Figure 6. Survey Question 13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In your opinion, which roads in your county are critical for earthquake response and evacuation? Please use pins to denote the roads.

Figure 7. Survey Question 14

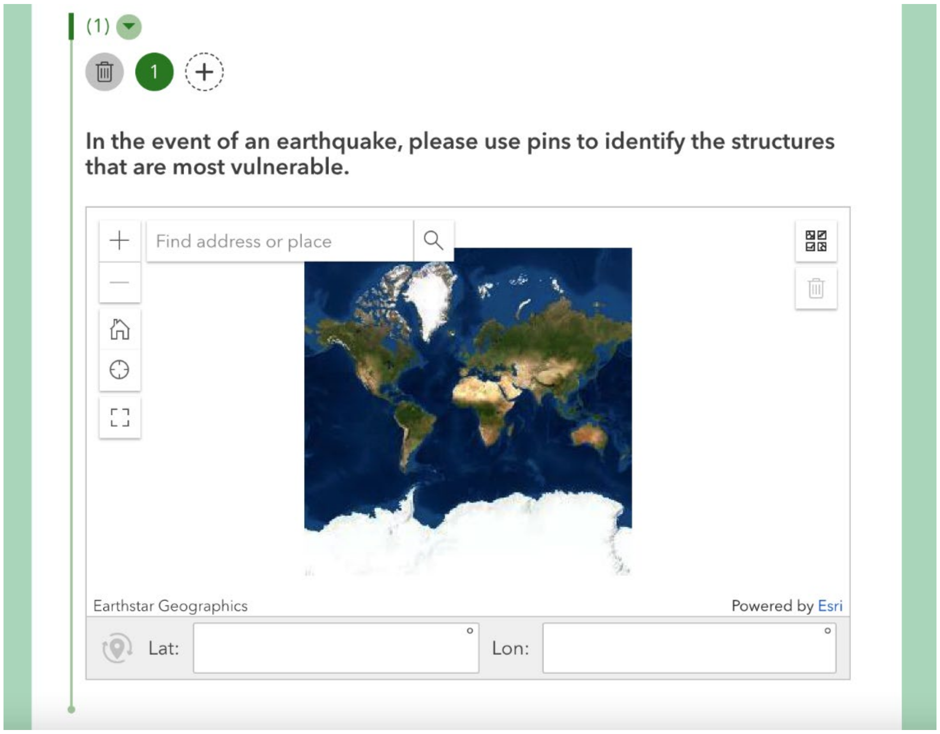

In the event of an earthquake, please use pins to identify the structures that are most vulnerable.

Figure 8. Survey Question 15

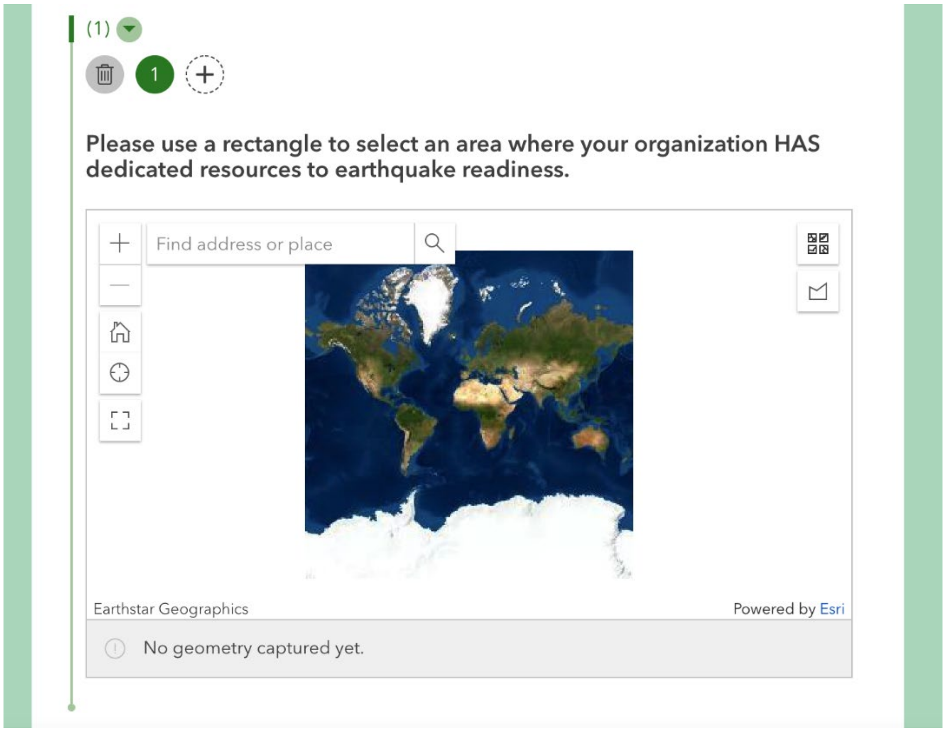
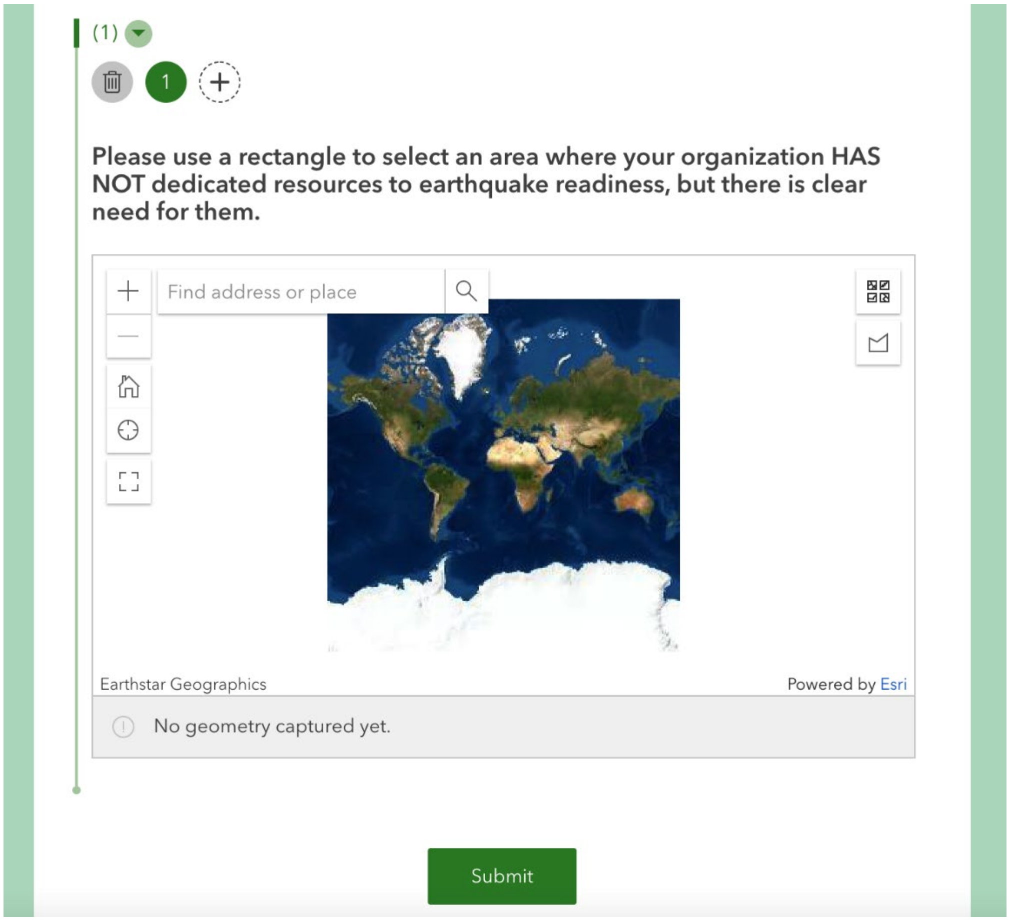

Please use a rectangle to select an area where your organization HAS dedicated resources to earthquake readiness.

Figure 9. Survey Question 16



(1)

Please use a rectangle to select an area where your organization HAS NOT dedicated resources to earthquake readiness, but there is clear need for them.

No geometry captured yet.

Figure 10. Survey Question 17 and Submission

2.3 Survey Instrument Results

This section discusses the survey responses in regard to the mapping questions. Figure 11 provides a state-level view of map-based survey results across Missouri. Notable areas of responses include Zone 1 counties and areas near STL. Additionally, Kansas City, NE Missouri, and Lake of the Ozarks are also present in the figure. The following figures zoom into each of these areas to provide greater context of the infrastructure elements and areas identified.

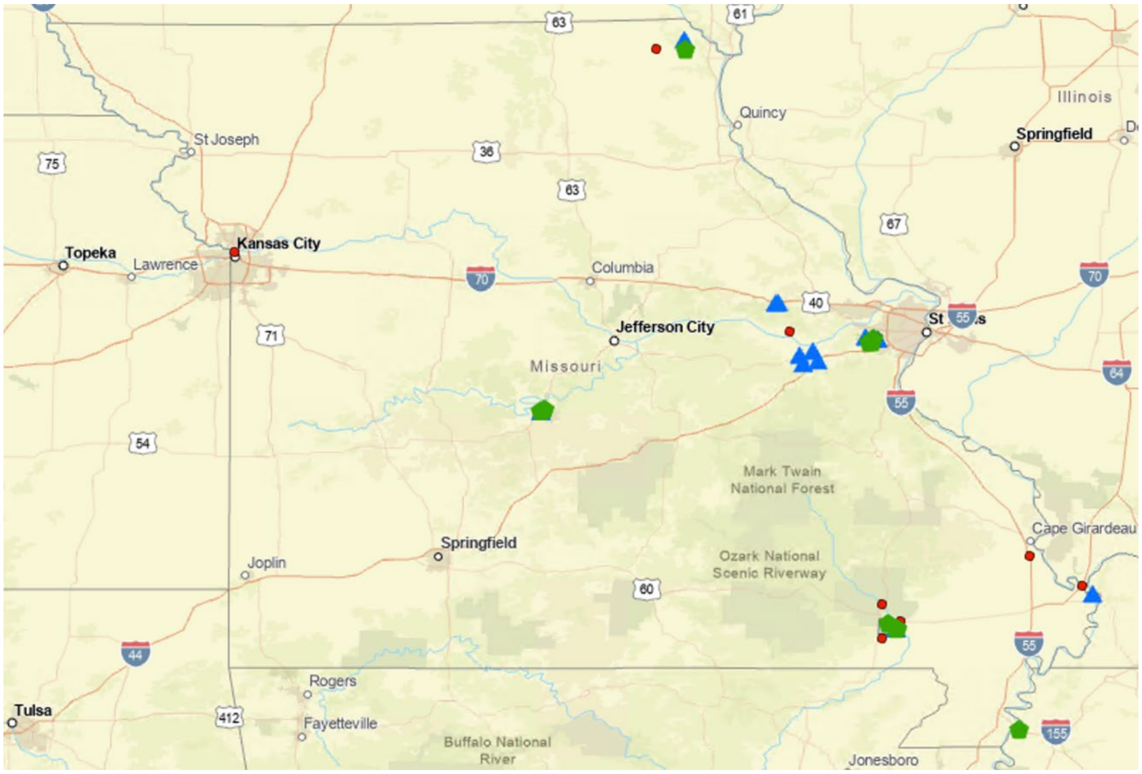


Figure 11. State-level View for Map=based Survey Questions

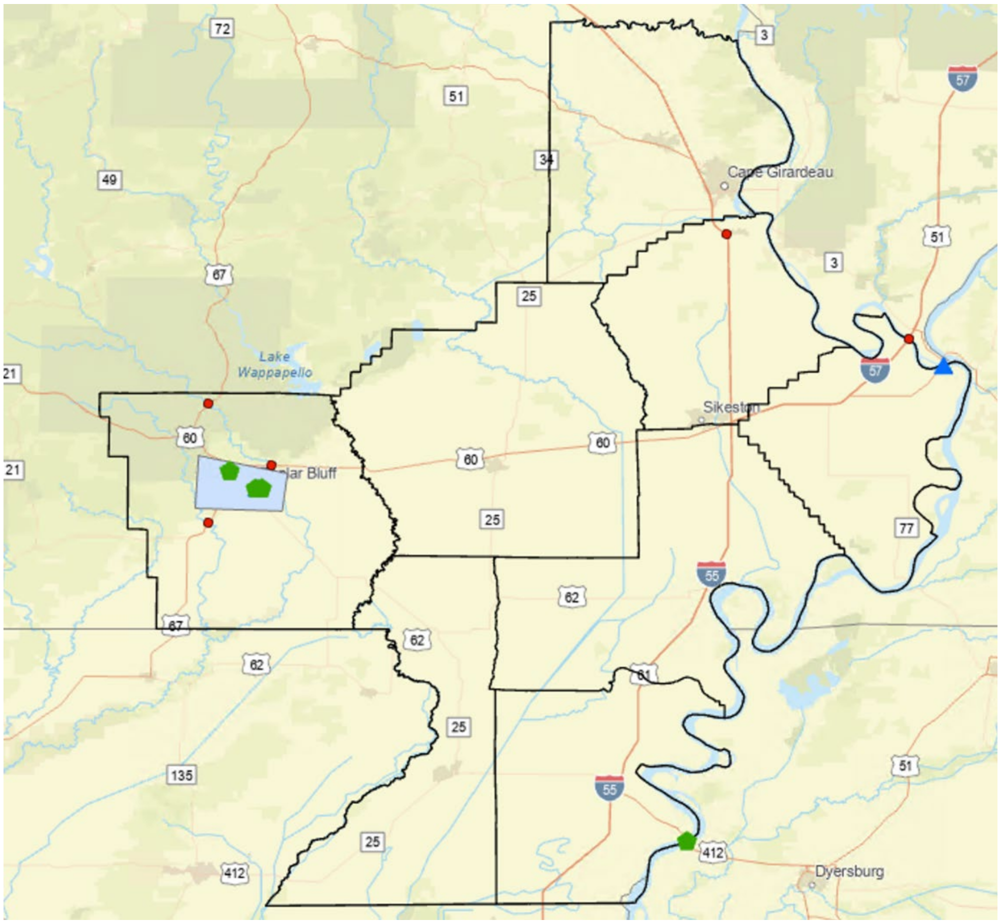


Figure 12. Map-based Survey Results for Zone 1

The area around Poplar Bluff currently has the largest number of specific data points provided. Some critical bridges and interstates are also identified.

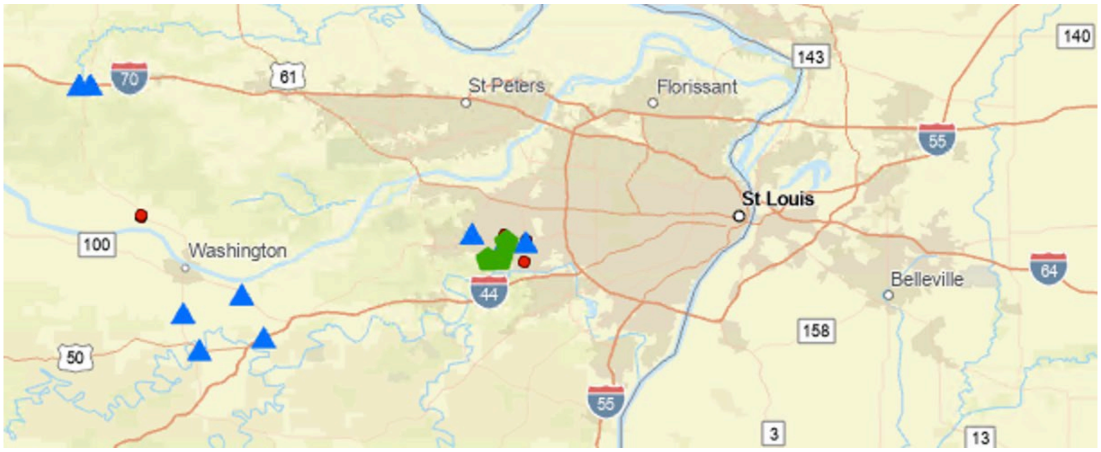


Figure 13. Map-based Survey Results for STL, MO Area

Figures 13-16 provide similar information for different parts of the state. Surprisingly, areas far from the NMSZ are present in the form of NE Missouri, Lake of the Ozarks, and Kansas City.

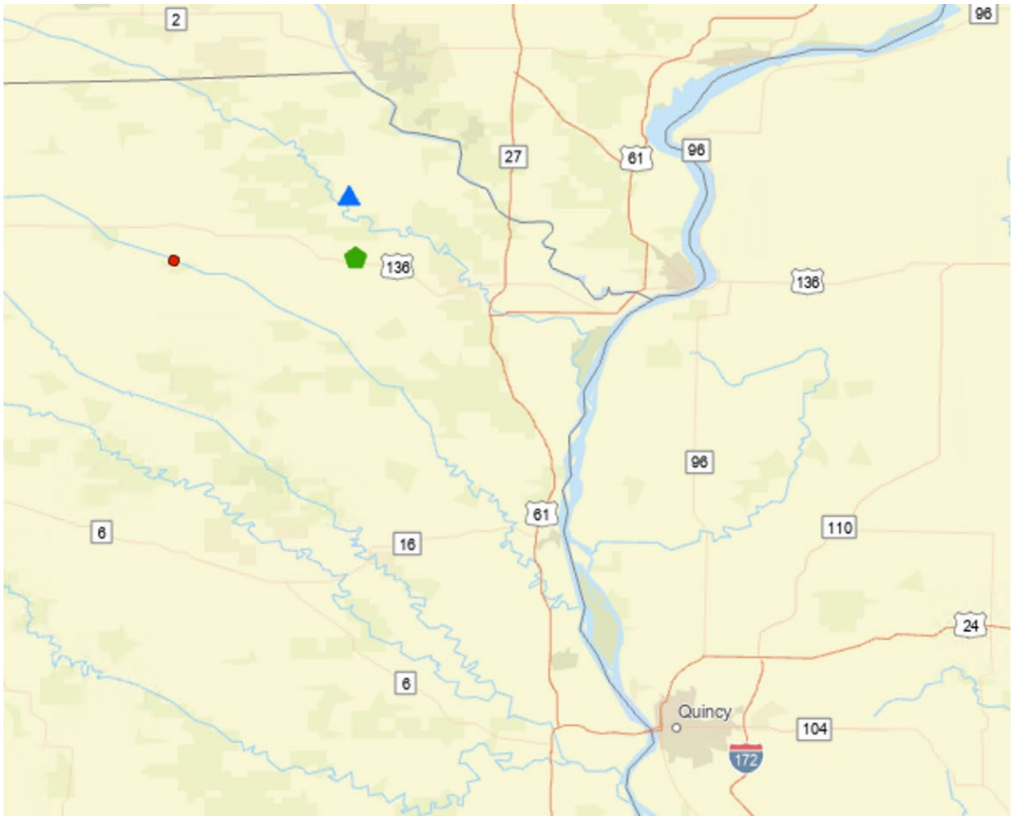


Figure 14. Map-based Survey Results for NE Missouri

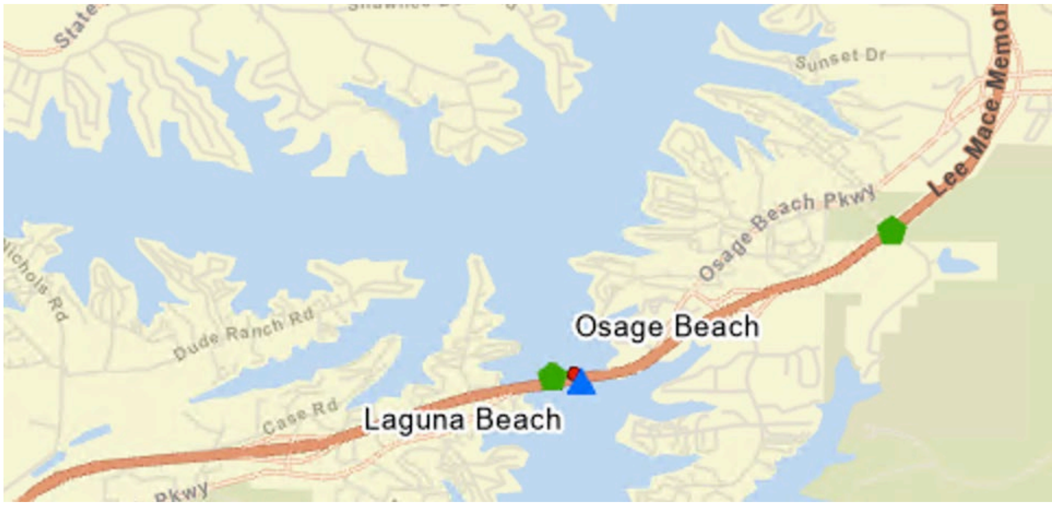


Figure 15. Map-based Survey Results for Osage Beach at the Lake of the Ozarks, MO

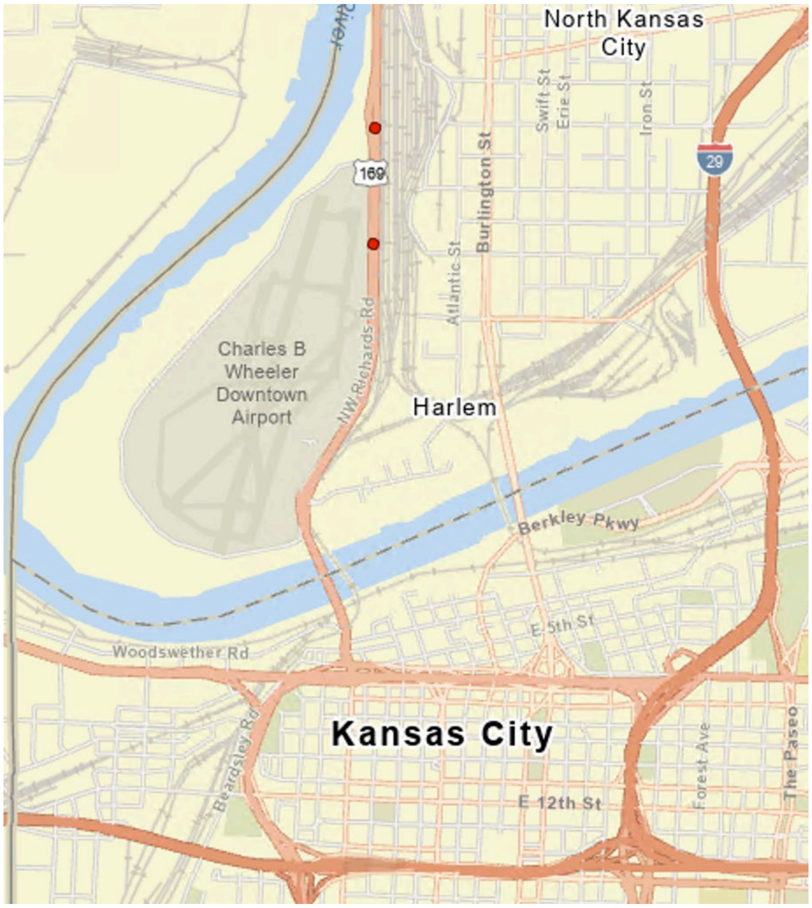


Figure 16. Map-based Survey Results for Kansas City, MO

Summary of Task 2

The results from task 2 indicate that from the information provided about areas that are suspectable to high levels of damage due to a large-scale seismic event, the New Madrid Seismic Zone would be the area for the study. This was because the zone has inadequate road networks, limited communication patrols, and a high likelihood of destruction for the simulated scenario of an earthquake at magnitude 8+.

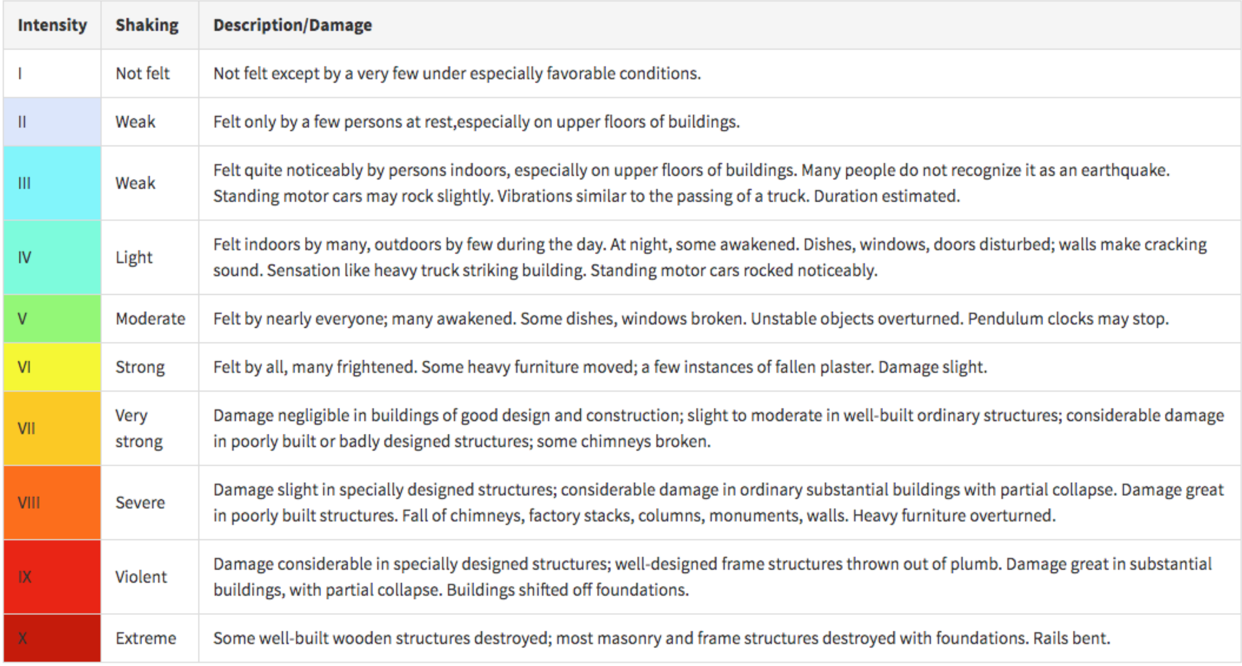
TASK 3: Analyzing the Modified Mercalli Intensity Scale for Structural Damage

3.1 Background

The Modified Mercalli Intensity scale is a seismic intensity scale used for measuring the intensity of shaking produced by an earthquake. The measurements include intensity, shaking and damage. The MMI scale was used in the New Madrid Seismic Zone to evaluate the probability of an earthquake (as a percent) from appearing. This information could be accessed as a CSV file to determine the structure damage inside the region.

3.2 The Modified Mercalli Intensity (MMI) Scale

The Modified Mercalli Intensity (MMI) maps provided the following three scenarios: 50% probability of exceedance (PE) in 50 years (likely), 10% PE in 50 years (infrequent), and 2% PE in 50 years (rare). Figure 17 provides a roman numeral rating system, shaking description, and description/damage for the MMI scale.



Intensity	Shaking	Description/Damage
I	Not felt	Not felt except by a very few under especially favorable conditions.
II	Weak	Felt only by a few persons at rest,especially on upper floors of buildings.
III	Weak	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibrations similar to the passing of a truck. Duration estimated.
IV	Light	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
V	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
VI	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
VII	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
VIII	Severe	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
IX	Violent	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
X	Extreme	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rails bent.

Figure 17. Modified Mercalli Intensity (MMI) Scale Explanation

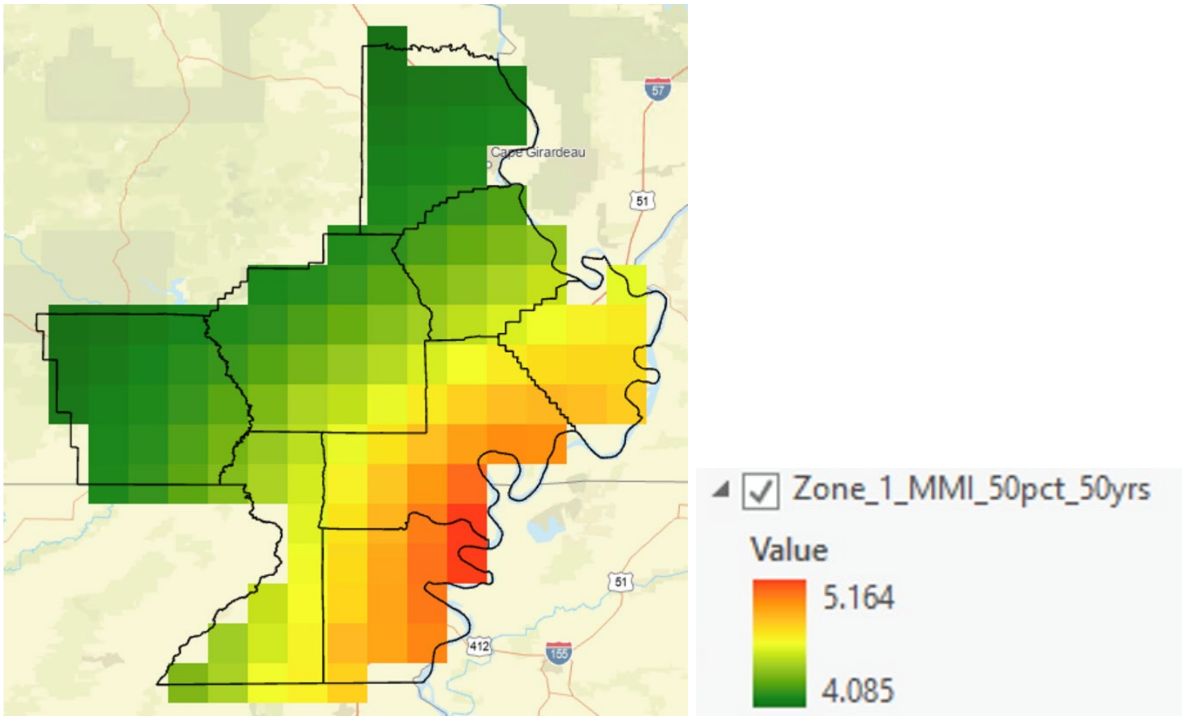


Figure 18. MMI 50% PE in the next 50 years

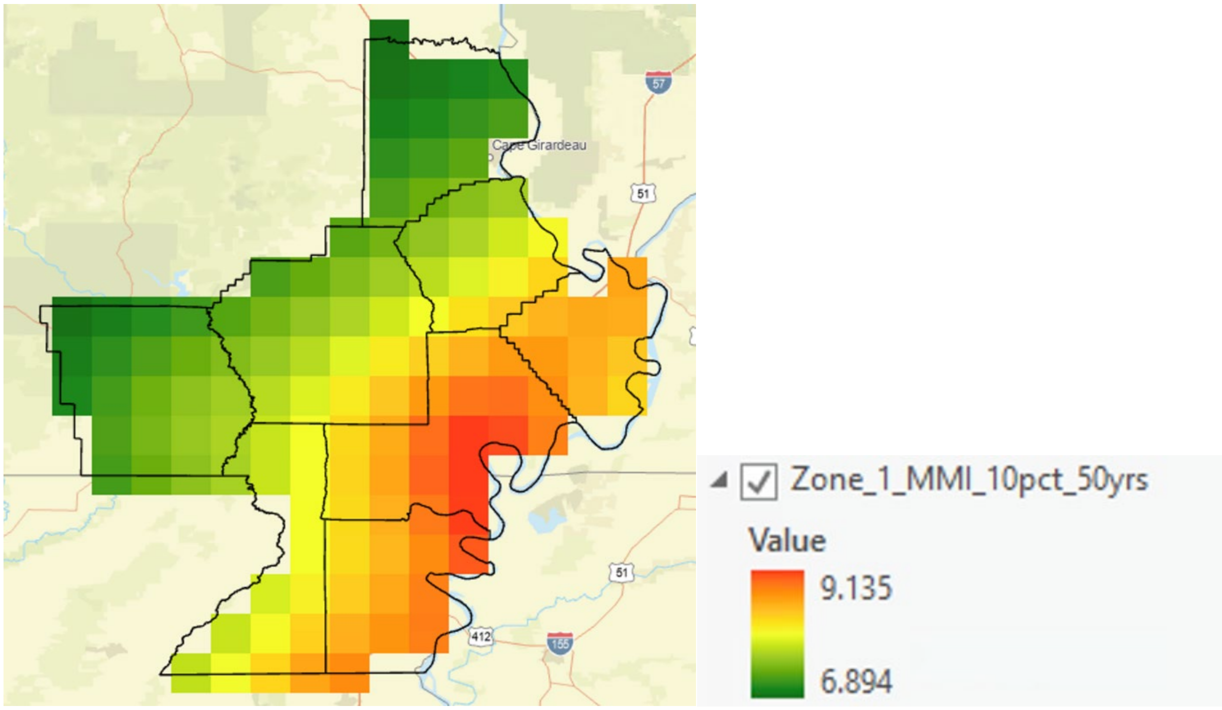


Figure 19. MMI 10% PE in the next 50 years

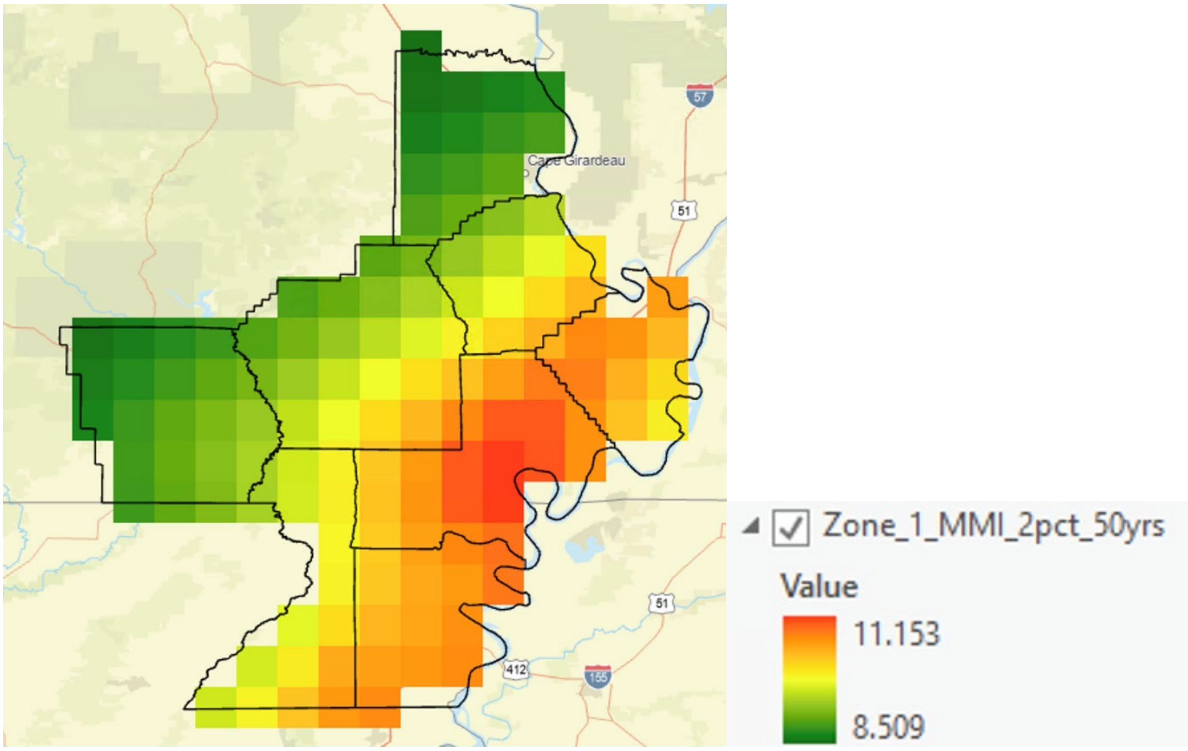


Figure 20. MMI 2% PE in the next 50 years

Summary of Task 3

This task focused on utilizing the Modified Mercalli Intensity scale to measure the shaking produced by an 8+ earthquake in the New Madrid Seismic Region. From this, the team was able to extract the CSV file that contained the structural damage report for the region. The amount of damage that impacted road infrastructure was accounted for and evaluated during the traffic simulations (task 4) to provide the safest route for evacuation outside of the region.

TASK 4: Assessing Evacuation Performance Using Simulation Models

4.1 Background

The research team applied a three-step process to assess the performance of earthquake evacuation in the New Madrid region. The process shown in Figure 21 starts with the development of a traffic simulation model of the study region. The second step involves the generation of evacuation demand for use in the traffic simulation model. The final step consists of utilizing the simulation model to compare several earthquake evacuation scenarios. Each of these steps will be discussed in detail in this chapter.

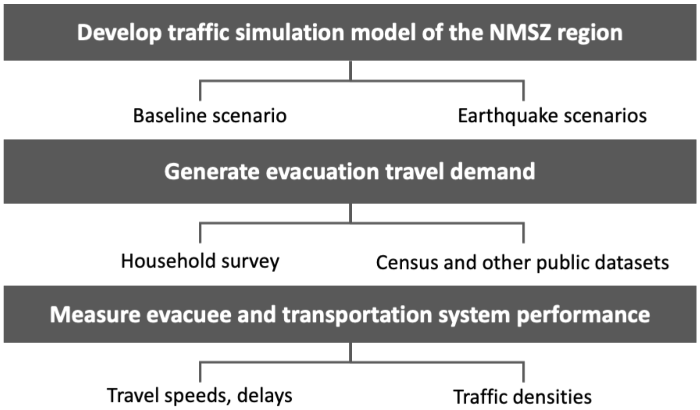


Figure 21. Three-step process for the evacuation assessment

4.2 Development of Evacuation Traffic Simulation Model

4.2.1 Study Region and Network Creation

The development of simulation model starts with the creation of the road network. Open-source mapping data from Open Street Maps was obtained and manipulated using GIS software. The study region consists of the following eight counties in the New Madrid region: Cape Girardeau, Scott, Butler, Stoddard, Mississippi, New Madrid, Dunklin, and Pemiscot. A map of the study region is shown in Figure 22.

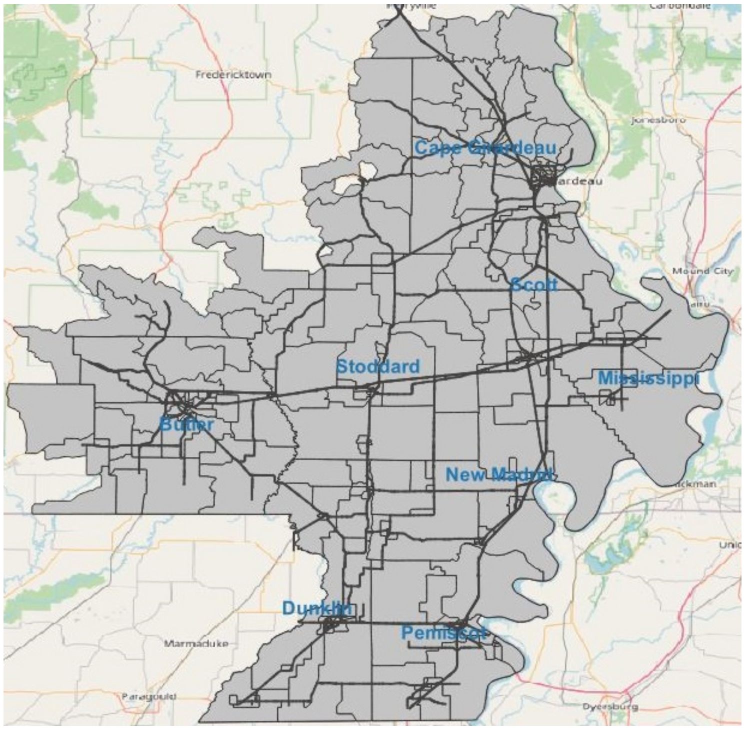


Figure 22. Study region consisting of eight counties in the New Madrid region

The prepared GIS mapping data was imported into VISSIM simulation software as the base road network. Figure 23 shows a screenshot of the road network in VISSIM. Several characteristics, such as the number of lanes, speed limit, capacity, and traffic control on major routes were checked manually to ensure the imported data was accurate. Additional network validation was performed using travel times. Figure 24 represents the validation segments that were used to compare the simulated and free-flow travel times. As shown in the third and fourth columns of Table 1, the simulated travel times were close to the free-flow travel times computed using posted speed limits.

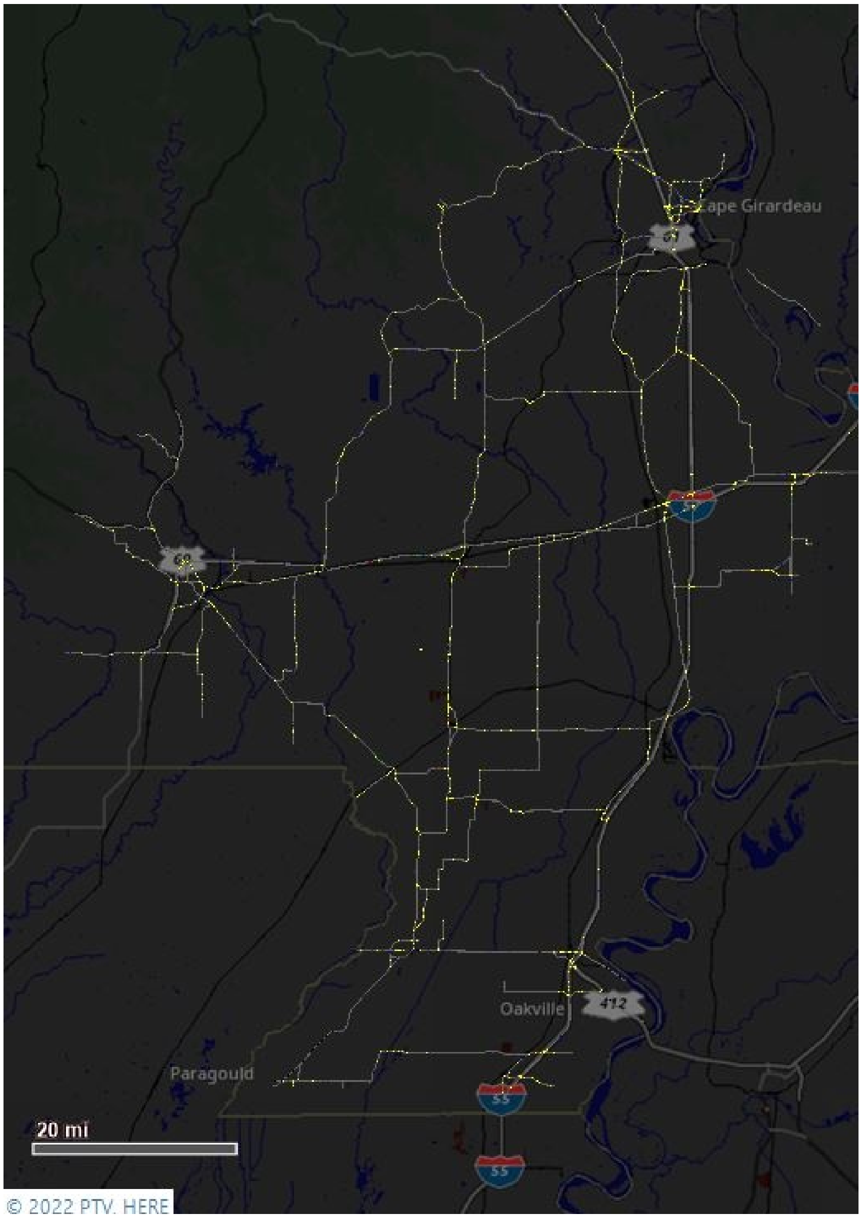


Figure 23. Road network in VISSIM software

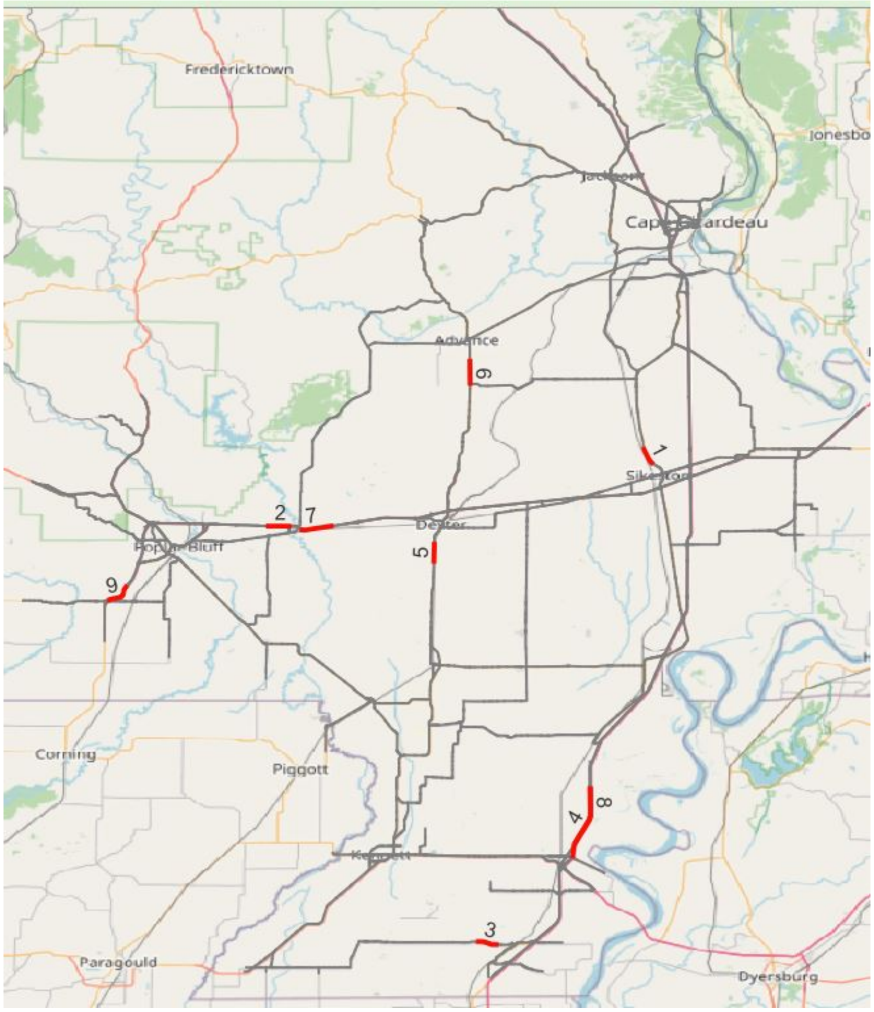


Figure 24. Road segments used for validation

Table 1. Travel time validation results

Number	Route	Travel time in VISSIM (min)	Travel time in Google maps (min)
1	US 61 N	2.17	2.00
2	US 60 E	2.06	2.00
3	MO 164 E	1.94	2.00
4	I 55 S	7.46	7.00
5	MO 25 S	2.15	2.00
6	MO 25 N	2.88	3.00
7	US 60 W	2.66	2.00
8	I 55 N	6.91	7.00
9	US 67 S	2.45	2.00

4.3 Evacuation Demand Generation

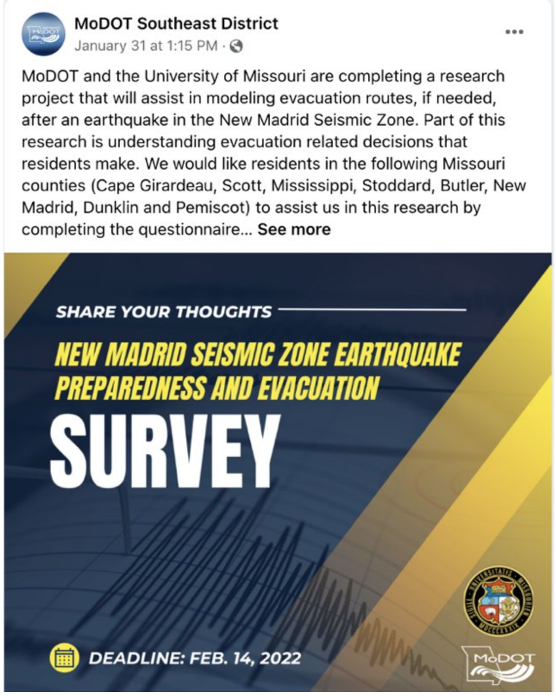
The simulation model uses demand as an input to simulate traffic flow on the road network. Two types of travel demand are relevant for this project, evacuation demand and background trip demand. Census data and a household evacuation survey were used to estimate the demand. This section first describes the household survey and then explains how the survey responses were used in conjunction with Census data to develop the evacuation and background demand.

4.3.1 Household Survey of the New Madrid Region

An online survey was conducted to obtain information on evacuee behavior. The survey sought responses from individuals living in any of the eight counties in the New Madrid region. The survey was approved by MU's Institutional Review Board (IRB) and deployed via Qualtrics software. The survey consisted of 41 questions including the following questions about evacuation decision making by households:

1) How likely is that you and your family will be impacted by an earthquake in the next five years?
2) Have you ever experienced an earthquake?
3) If an earthquake was going to impact your neighborhood, what would you be most likely to do? Evacuate, shelter in home, etc.
4) If you evacuate, where would you go, what road would you take?
5) How many personal vehicles does your household have available for use in an evacuation?

The survey was advertised primarily using MoDOT and FEMA social media and local news media. Figure 25 shows a screenshot of the social media post by the MoDOT Southeast District.



MoDOT Southeast District
January 31 at 1:15 PM ·

MoDOT and the University of Missouri are completing a research project that will assist in modeling evacuation routes, if needed, after an earthquake in the New Madrid Seismic Zone. Part of this research is understanding evacuation related decisions that residents make. We would like residents in the following Missouri counties (Cape Girardeau, Scott, Mississippi, Stoddard, Butler, New Madrid, Dunklin and Pemiscot) to assist us in this research by completing the questionnaire... **See more**

Figure 25. Survey distribution via social media

The survey was available for a two-week period during which 891 responses were received. Table 2 shows the Census 2010 population for each county, the percentage of county population in the region and the number (and percentage) of survey responses received from each county. The responses received were proportional to the population living in each county.

Table 2. Survey Responses by County

County Name	Population (Census 2010)	Percentage of Total Population	Sample Size in Survey	Percentage of Total Responses
Butler	42,794	16%	166	19%
Cape Girardeau	75,674	28%	187	21%
Dunklin	31,953	12%	98	11%
Mississippi	14,358	5%	54	6%
New Madrid	18,956	7%	53	6%
Pemiscot	18,296	7%	56	6%
Scott	39,191	14%	100	11%
Stoddard	29,968	11%	98	11%
Other			79	9%
Total	271,190	100.0%	891	100%

A summary of responses to the survey questions are presented next. When asked about the likelihood of being impacted by an earthquake in the next five years, 34% of respondents said likely or very likely, 55% were unsure, and 11% said unlikely or very unlikely (Figure 26).

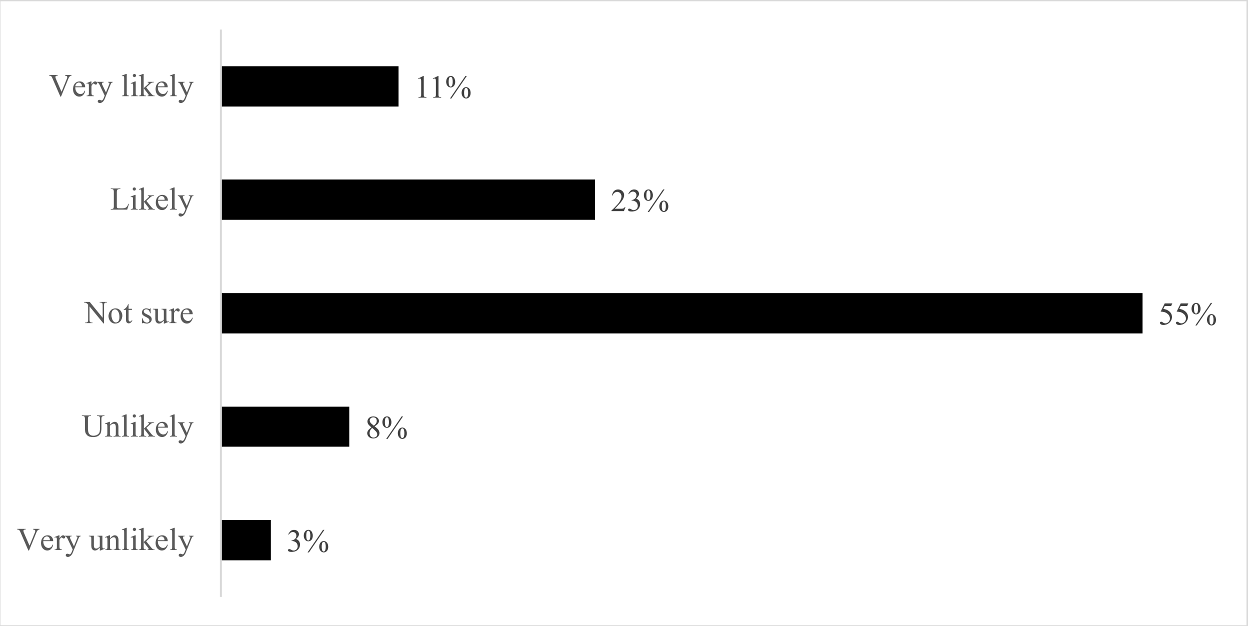


Figure 26. Likelihood of being impacted by an earthquake in the next five years (N=880)

Seventy nine percent of the respondents said that they had previously experienced an earthquake. Figure 27 shows the earthquake impacts on these respondents with eight percent indicating experiencing disruption to daily life, six percent experiencing property damage, and two percent experiencing injury.

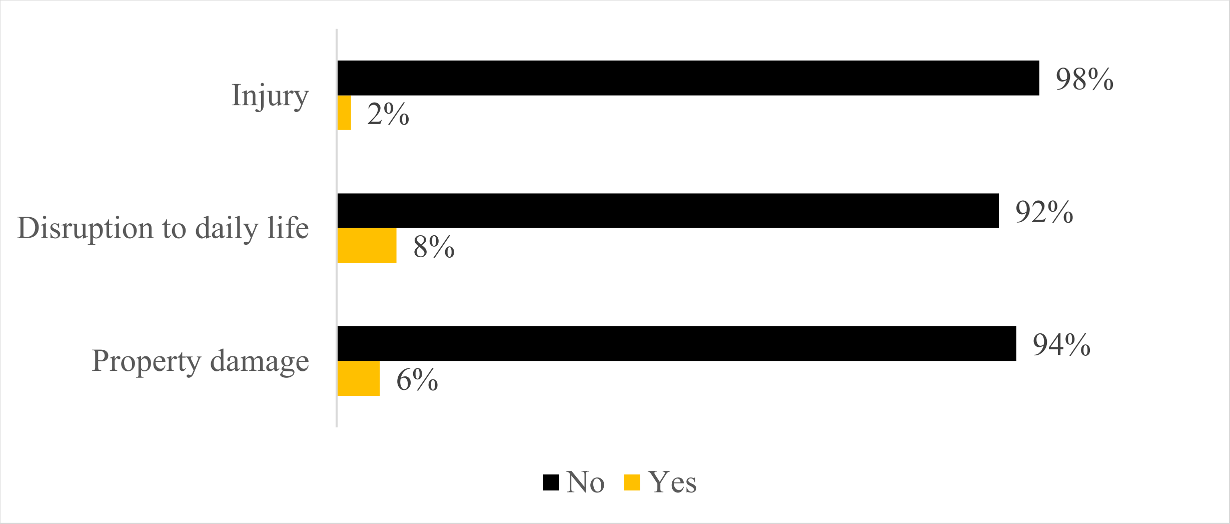


Figure 27. Impacted during any prior earthquake experience (N=790)

When asked about their most likely action when impacted by an earthquake (see Figure 28), the vast majority (45%) said they would shelter in place, 24% said they would evacuate, and the 31% were unsure or took other actions.

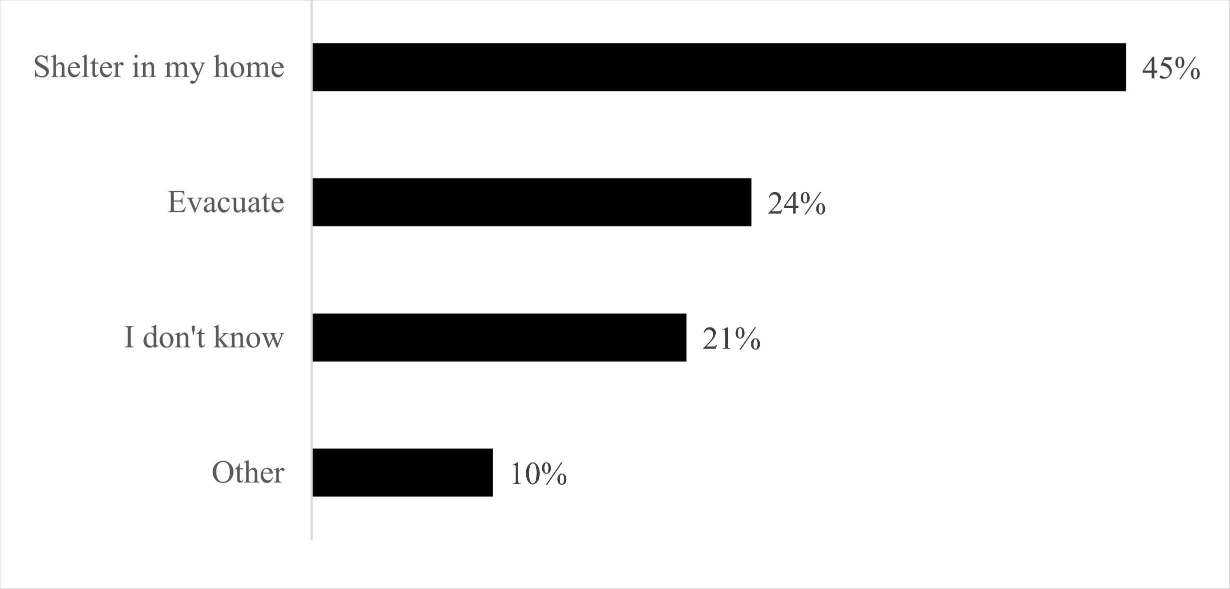


Figure 28. Most likely action when impacted by an earthquake in your neighborhood (N=880)

Of those choosing to evacuate (see Figure 29), 52% said they would go to a relative's home, 11% to a hotel/motel, 6% to a second home, 5% to a friend's home, and 2% to a public shelter.

Thirteen percent of the respondents said they were unsure where they would go while 7% stated that they had no place to go.

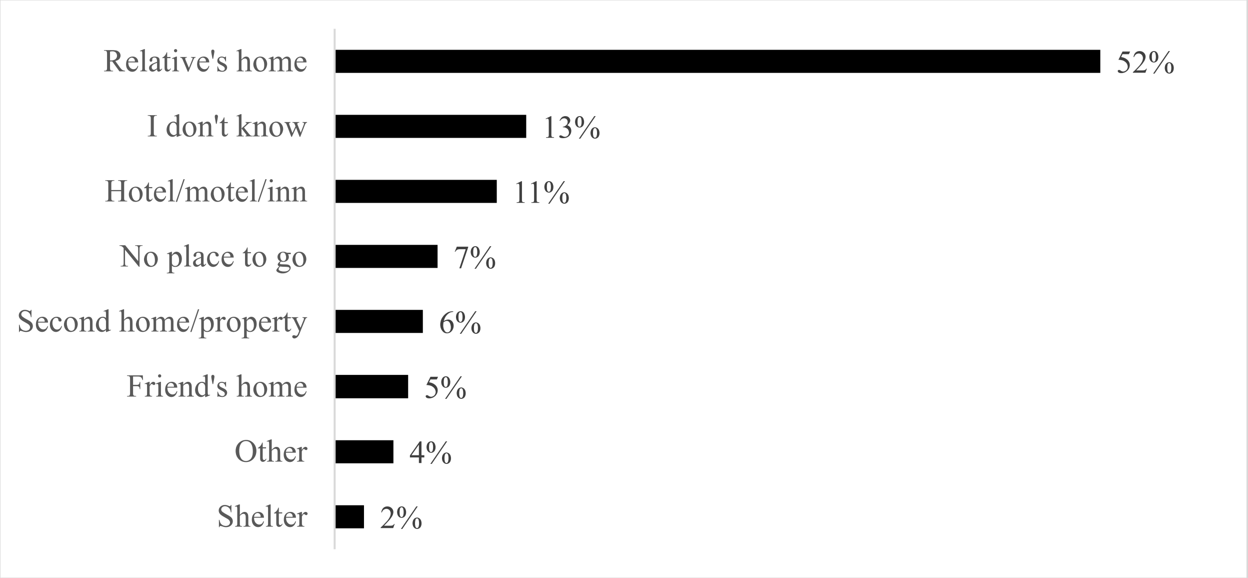


Figure 29. Preferred destination type for evacuation (N=655)

Figure 30 shows the percentage responses for when evacuees said they would depart to their preferred destinations. Thirty five percent said they would evacuate within one day, 32% said they would evacuate within one to three days, 15% stated evacuating between three days to a week, and 18% said they would evacuate after a week.

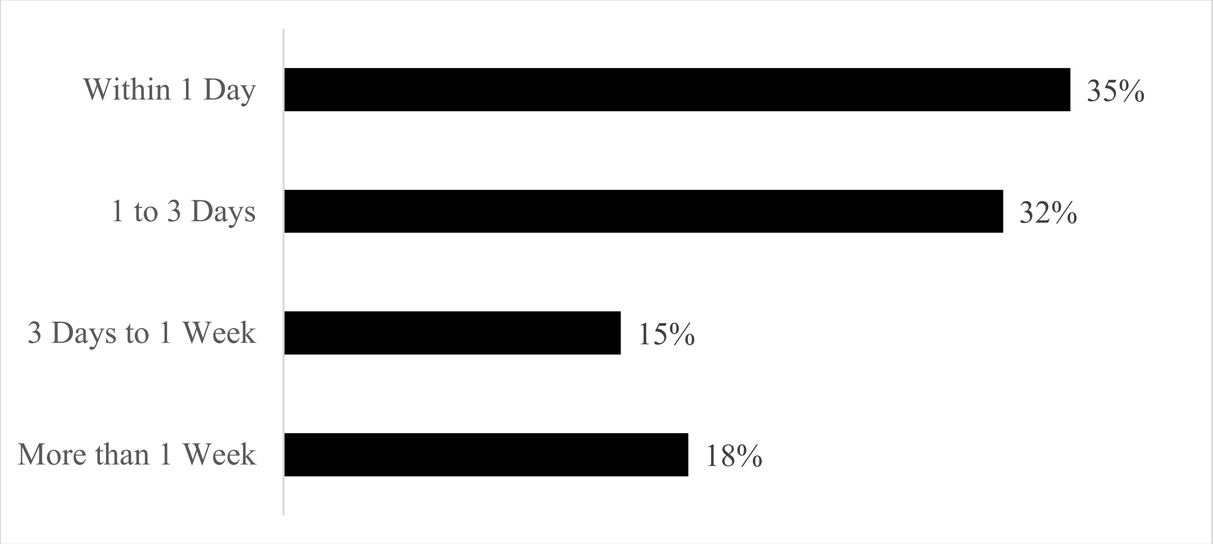


Figure 30. Preferred departure time of evacuation (N=636)

When asked what type of roadway they preferred to travel on, 33% preferred freeway, 27% selected major roads with traffic signals, 25% said local roads, and 15% were unsure (see Figure 31).

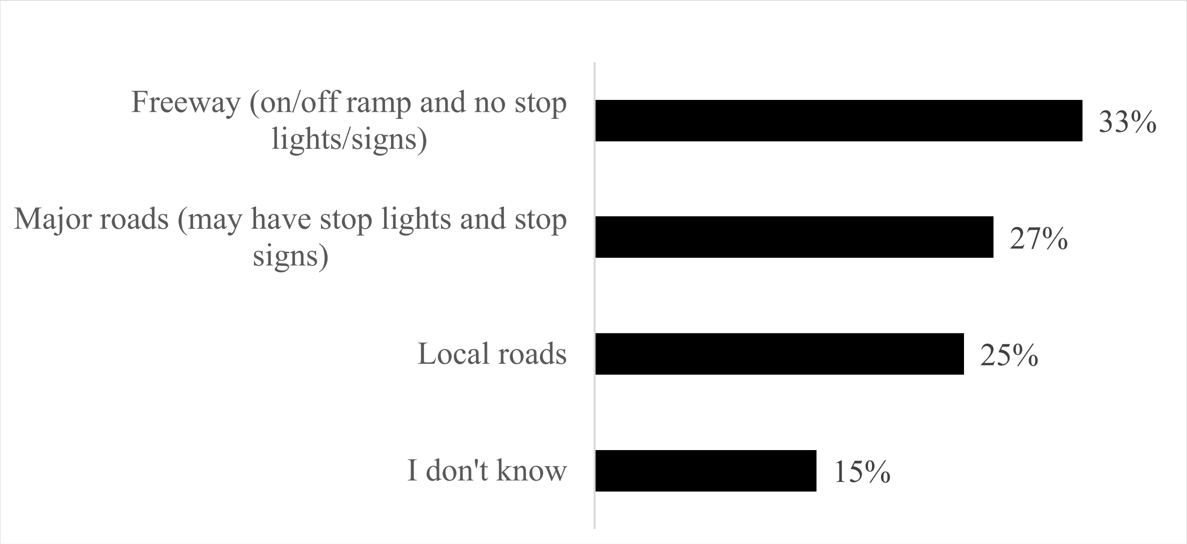


Figure 31. Preferred roadway type for evacuation (N=647)

Figure 32 shows the response to compliance with official evacuation routes recommended by government agencies. Eighty-four percent of the respondents said they would definitely or probably use the recommended route while 10% said they would probably not or definitely not use the recommended route.

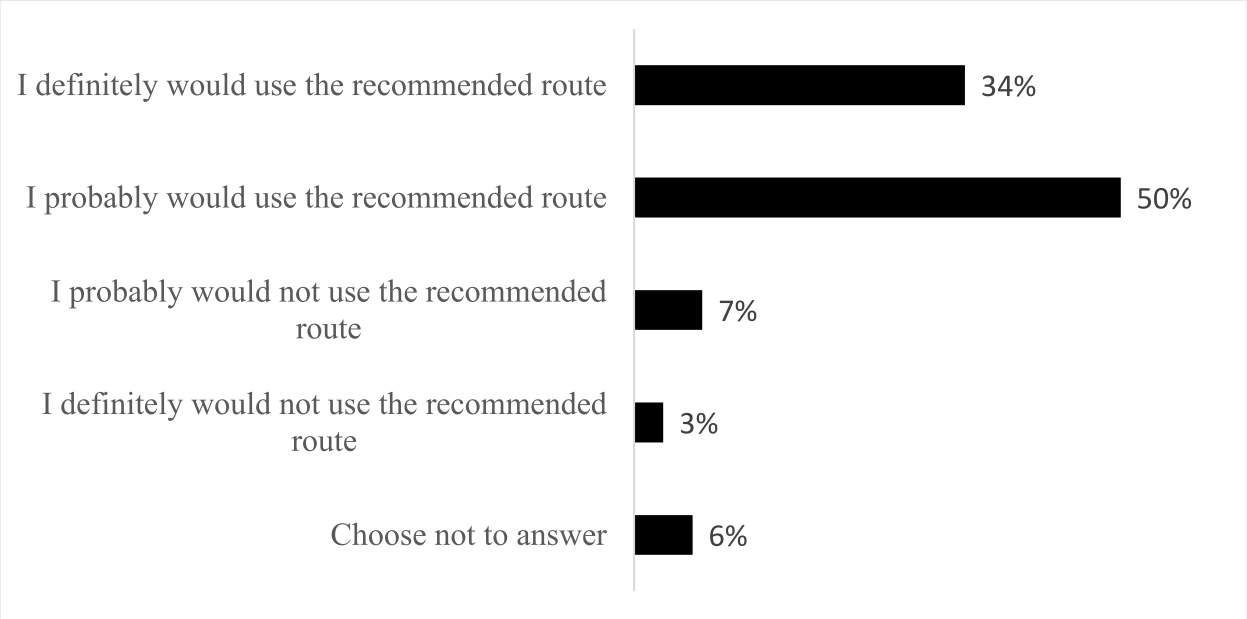


Figure 32. Compliance with official recommended routes for evacuation (N=649)

Vehicle ownership and availability play an important variable in determining the number of evacuation trips taken by a household. Figure 33 shows that majority of the respondents (42%) have two vehicles available for evacuation. Twenty five percent said they had one vehicle while 31% said they had three or more vehicles available for evacuation.

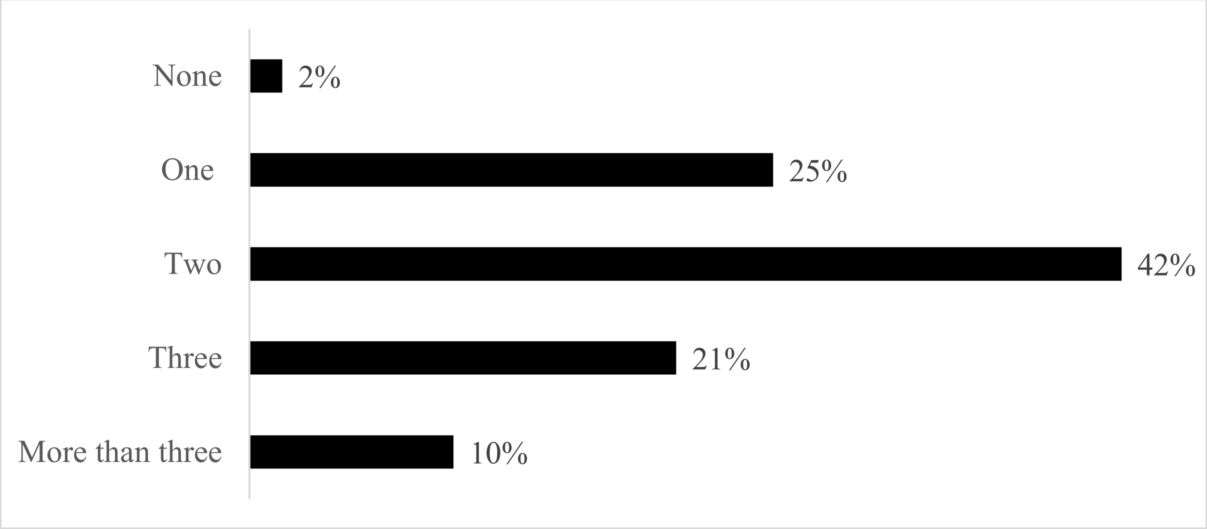


Figure 33. Personal vehicle availability for evacuation (N=640)

The survey asked the respondents to provide the preferred destinations in a mandatory evacuation. A word cloud of the responses is shown in Figure 34 and a map of the destinations is shown in Figure 35.

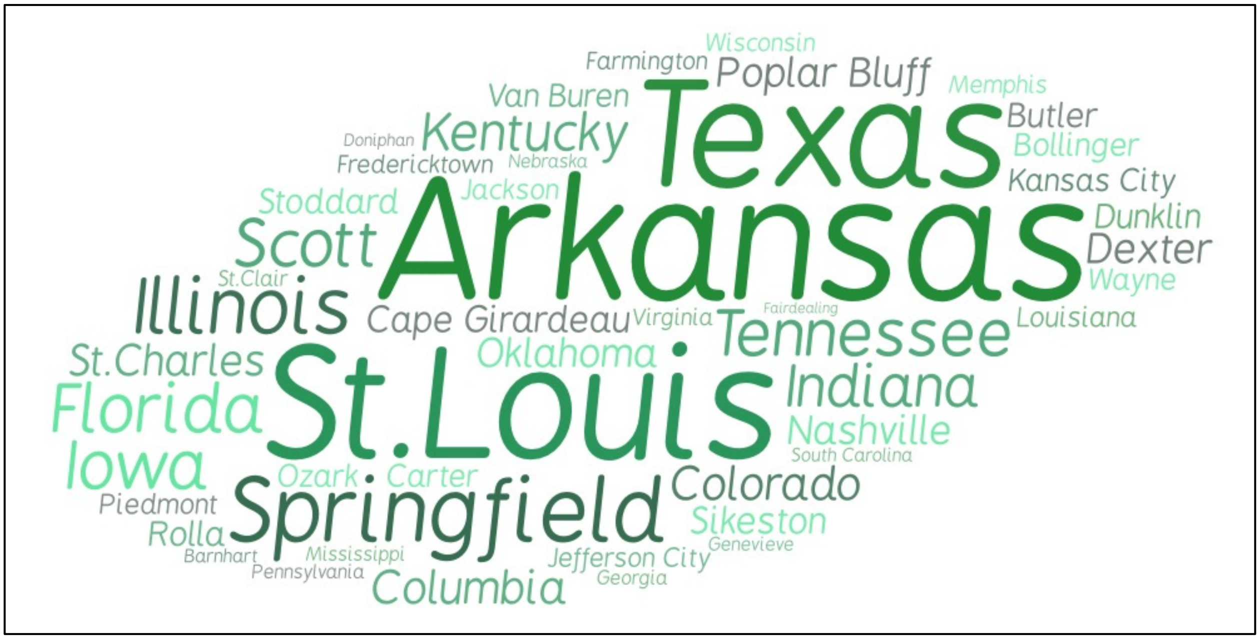


Figure 34. Word Cloud of destination choices for evacuation trips in a mandatory evacuation (N=603)

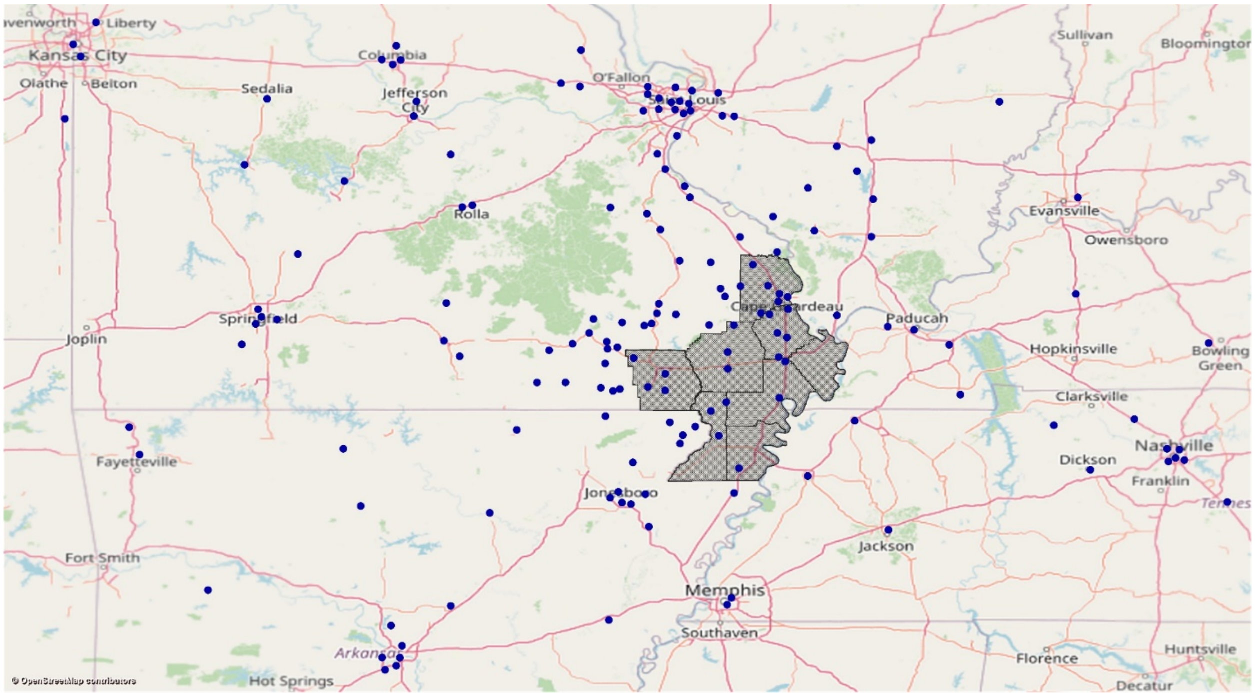


Figure 35. Map showing destination choices for evacuation trips in a mandatory evacuation (N=603)

In addition to the preferred destination, respondents were also asked to provide their preferred route they would take to reach their destination. A word cloud of the routes is shown in Figure 36. The size of the word indicates the relative number of responses with larger font size words indicating higher number of responses. For example, I-55 and US 60 were selected by more individuals than MO 25.

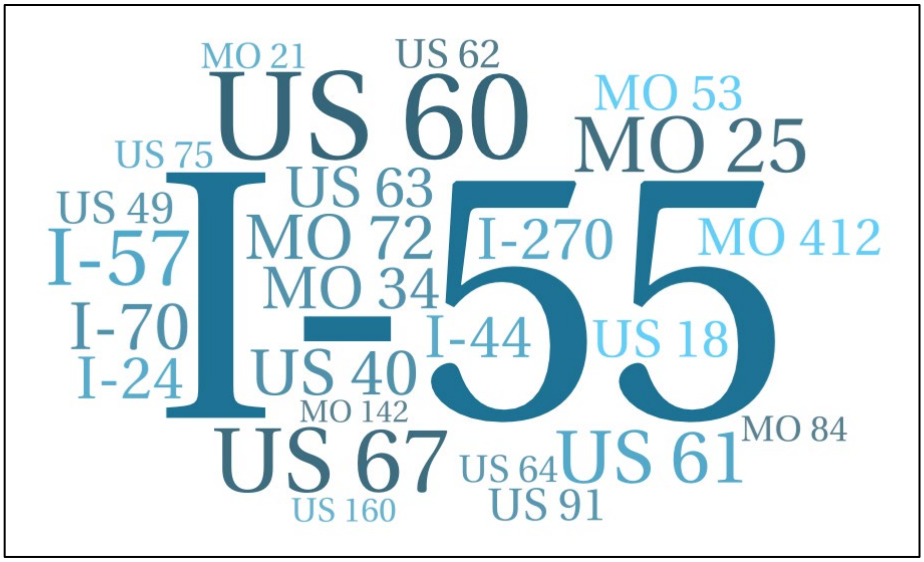


Figure 36. Word Cloud of route choices for evacuation trips in a mandatory evacuation (N=539)

4.3.2 Estimating Travel Demand

The evacuation travel demand, i.e., number of trips, was estimated using survey responses pertaining to four specific household decisions – 1) whether to evacuate or not, 2) if evacuating, what destination to evacuate to and 3) when to evacuate, and 4) how many vehicles to use in the evacuation. The travel demand to different destinations were scaled up using US Census and Bureau of Transportation Statistics data. The travel demand in this study consists of evacuation trips and background trips. Background trips are trips made by individuals that choose to not evacuate and are making trips to collect supplies to shelter in place. Table 3 shows the travel demand estimated for the region. This demand was further processed using the destination information obtained from the survey to create a 254 x 254 origin-destination (OD) matrix for use in the simulation model.

Table 3. Travel demand for evacuation and background trips

Demand Type	Number of Trips
Evacuation demand	47,100
Background demand	185,016
Total trips	232,116

4.4 Performance Evaluation of Evacuation Scenarios

The impact of a magnitude 7.8 earthquake occurring in the New Madrid Seismic Zone were studied using six evacuation scenarios. A baseline scenario assumes that the road network is intact, and no roadways are damaged. The survey results showed that the evacuation demand will be spread over a week. However, the low numbers of trips shown in Table 3 spread over a week will not result in any congestion issues in the road network. In order to assist MoDOT with scenarios that will generate congestion, this study modeled worst-case scenarios by simulating two levels of demand for each scenario – evacuation demand departing over a 12-hour period and a 6-hour period.

While the baseline scenario serves as a reference, it is not realistic to expect the road network to not sustain any damage due to a magnitude 7.8 earthquake. The USGS developed a ShakeCast tool that estimates severity and extent of earthquake shaking. The research team, through assistance from MoDOT, requested ShakeCast data from USGS for the magnitude 7.8 earthquake. Figure 37 shows the location of damaged links on MO 162, MO 153, and some of US 62 that are reported to be vulnerable. The roadway links with the highest possible damage expected (i.e., 'red' damage level) were removed from the simulation model for the next four scenarios. Scenarios 3 and 4 simulate demand over 12 hours and 6 hours, respectively. Scenarios 5 and 6 impose further constraint on the road network by closing a bridge on MO 25 at the MO 25/US 60 interchange that is heavily used by evacuees. All six scenarios are summarized in Table 4.

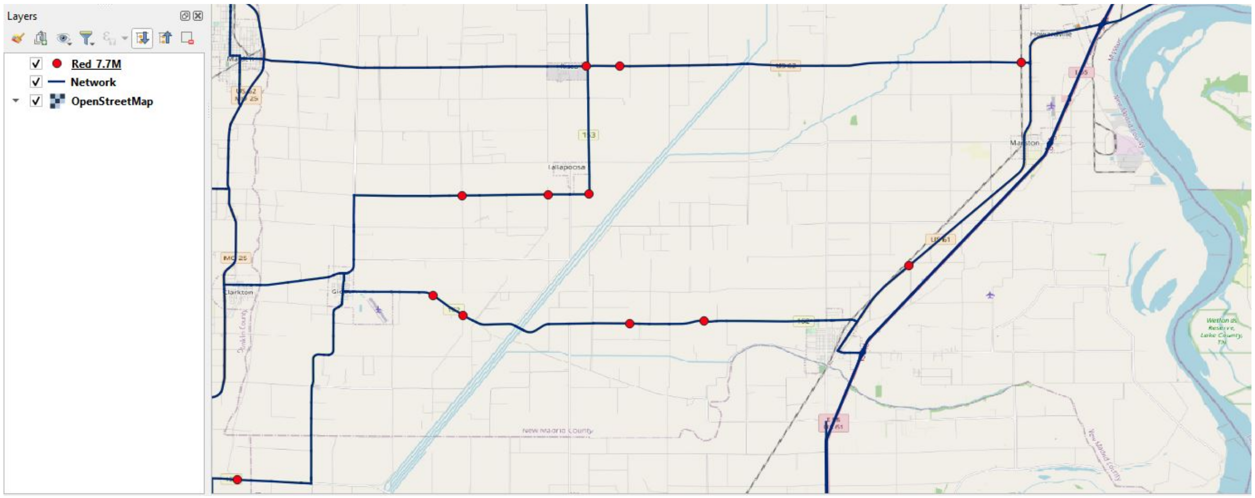


Figure 37. "Red" level bridge locations in ShakeCast data

Table 4. Evacuation scenarios studied in this project

Scenario	Scenario type	Demand duration	Description
1	Baseline	12 hours	Road network is intact
2	Baseline	6 hours	Road network is intact
3	Network Damage	12 hours	Removed roadway links damaged due to earthquake (based on USGS ShakeCast data for magnitude 7.8 earthquake)
4	Network Damage	6 hours	Removed roadway links damaged due to earthquake (based on USGS ShakeCast data for magnitude 7.8 earthquake)
5	Network Damage	12 hours	Removed roadway links damaged due to earthquake (based on USGS ShakeCast data for magnitude 7.8 earthquake) plus additional bridge damage
6	Network Damage	6 hours	Removed roadway links damaged due to earthquake (based on USGS ShakeCast data for magnitude 7.8 earthquake) plus additional bridge damage

As previously mentioned, the evacuation demand was loaded onto the road network either over 12 hours (scenarios 1, 3, and 5) or over 6 hours (scenarios 2, 4, and 6). The evacuation was assumed to start at 7:00 am for all scenarios. Average vehicle delay and speed plots are shown in Figures 18 and 19 for all six scenarios. While the demand was loaded over 12-hour or 6-hour periods starting from 7:00 am, the simulations were active until the last evacuating vehicle reached its destination. This resulted in simulation time horizon of 14 hours (for 12-hour demand) and 9 hours (for 6-hour demand).

The results shown in Figures 37 and 38 are explained next. For scenario 1, delay remained steady over the entire evacuation period and stayed under 60 seconds.

The average speeds are inversely related to delay as can be seen in Figure 39. The average speeds did not go below 60 mph for the entire evacuation period. For scenario 2, delay increased for the first two hours and peaked at 130

seconds at 9:00 am (average speed of 57 mph), then dropped under 100 seconds around 10:30 am, stayed at the same level until 12:30 pm, after which a second spike in delay occurred with the delay peaking at 138 seconds at 13:30 pm. The delay values started decreasing after that time reaching 60 second by 14:30 pm.

Impact of road closures was studied in scenarios 3 to 6. For scenario 3, the average delay and speed plots do not show any major impact. Delay remained under 60 seconds for the most part except around 19:00 pm where it reaches 65 seconds before dropping again. Average speeds were greater than 60 mph for the entire evacuation duration. The compressed demand in scenario 4, compared to scenario 3, increased the peak delay at 9:00 am to 140 seconds and at 13:30 pm to 150 seconds and dropped average speeds to 53 mph and 55 mph, respectively. For scenario 5, the additional road closure of the MO 25 bridge increased the average delay by 15 seconds compared to scenario 3 and by 19 seconds compared to scenario 1 (see Table 5). The peak delay stayed under 80 seconds for the entire evacuation period. The average speeds dropped to 55 mph around 14:30 pm but remained above 53 mph for the entire evacuation.

Scenario 6 is the most extreme of all scenarios as it combines the most extensive road closures with a short demand loading window. The overall delay was 118 seconds with peak reaching 180 seconds at 9:00 am. The second peak of 170 seconds occurred at 13:30 pm. Sustained speed drops can be observed in Figure 39 from 9:30 am to 13:30 pm with speeds in the mid to low 40s indicating congested conditions in the road network. Average speed for the evacuation period dropped to 50 mph with lowest observed speed of 43 mph.

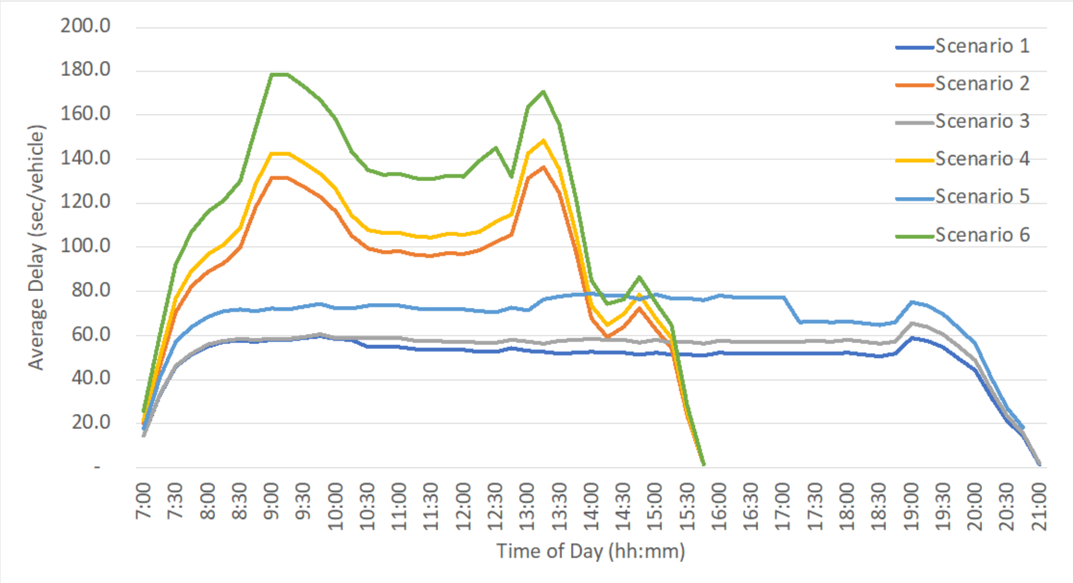


Figure 38. Average delay plot for the evacuation scenarios

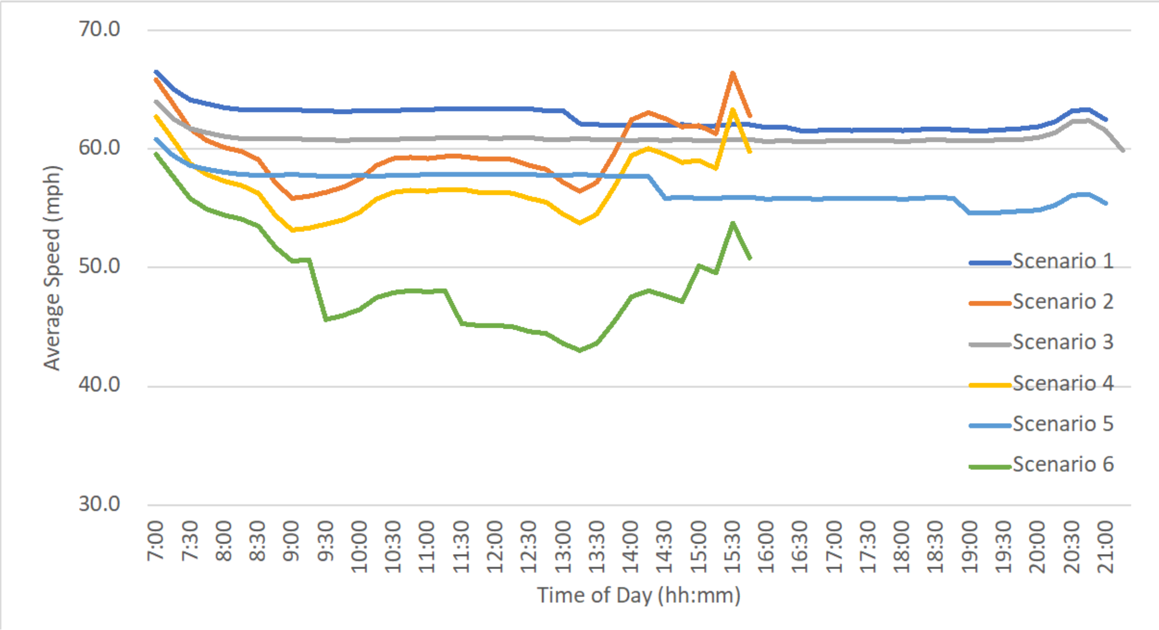


Figure 39. Average speed plot for the evacuation scenarios

Table 5. Average delay and speeds over the entire evacuation period

Scenario	Average Delay (seconds/vehicle)	Average Speed (mph)
1	49	62
2	90	59
3	53	61
4	97	56
5	68	56
6	118	50

The average vehicle density expressed as number of vehicles per mile per lane is a good indicator of the level of service (LOS) in the road network. For simplicity, the Highway Capacity Manual's LOS criteria for basic freeway segments shown in Table 6 was used for all segments in the road network. Using the cutoff values shown in the second column of Table 6, the average LOS on various roadways in the road network was computed. A visualization of the average LOS for the six scenarios is shown in Figure 40.

Table 6. Level of service criteria for basic freeway segment (Source: Highway Capacity Manual, 2022)

Level of Service	Density (passenger cars/mile/lane)
A	density <=11
B	11 < density <= 18
C	18 < density <= 26
D	26 < density <= 46
E	46 < density <= 58
F	58 < density

The roadway links are color coded based on the average density values observed during the evacuation period. Figure 40 shows that the roadway segments in scenario 1 are mostly operating in LOS A and B with a few segments operating in LOS C and D. The conditions start to worsen in scenario 2 as more segments are operating in LOS B, C, and D. Scenario 3 simulates the impact of road closures and as a result the LOS values worsened on some segments. Segments that operated in LOS A in scenario 1 deteriorated to LOS B and those in LOS B operated at LOS C in scenario 3. A few segments experienced LOS E and F in scenario 3. Road densities continued to increase, and LOS values worsened in scenarios 4, 5, and 6.

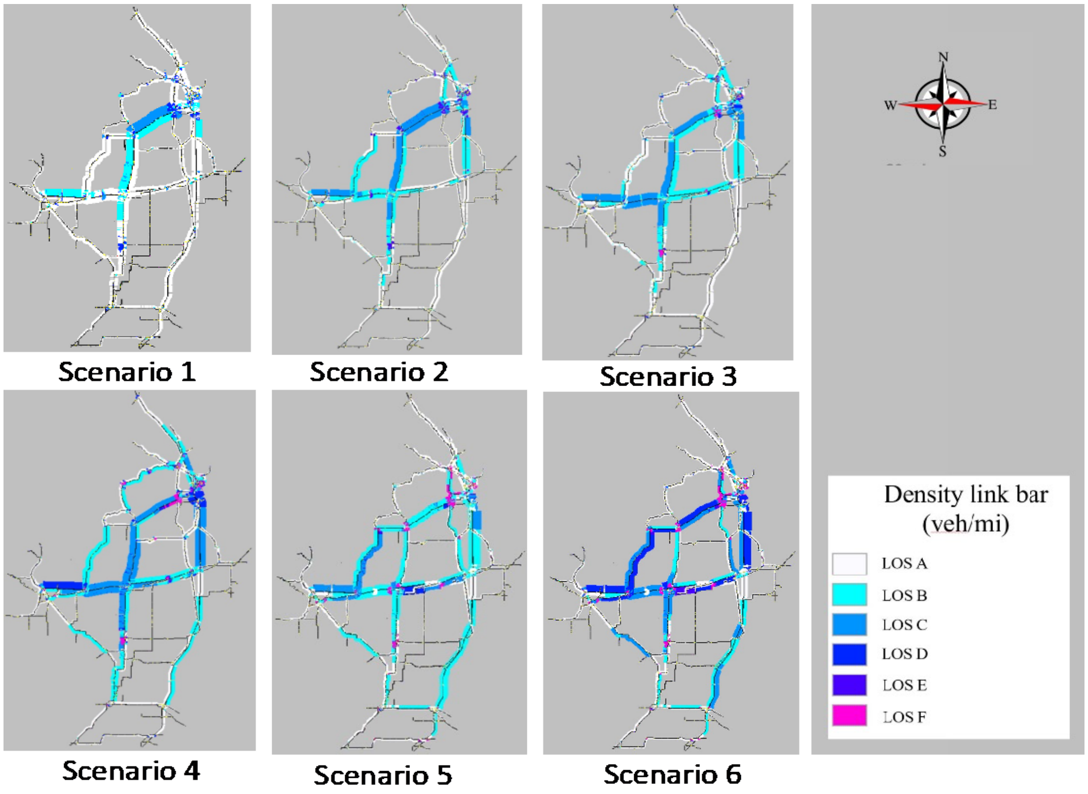


Figure 40. Visualization of roadway level of service for evacuation scenarios

While Figure 40 provides a network-level visualization of the traffic conditions, a closer look at the roadway segments operating at LOS E and F would help MoDOT design plans to alleviate congestion on these segments. A list of the bottlenecks operating in LOS E and F were compiled for each scenario and are shown in Table 7. For each bottleneck, the length of the roadway segment as measured from the upstream cross street to the downstream cross street is shown. As can be expected due to the network constraints, the number of bottlenecks and their severity increased from scenario 1 through 6. Bottlenecks were observed on MO 34, US 60, MO 25, Highway C, and Business US 60.

Table 7. Location of bottlenecks for evacuation scenarios

Scenario	Bottleneck Locations	
	LOS E	LOS F
1	MO 34 WB (0.6 miles, from S Spring St to South West End Blvd)	N/A
	MO 34 WB (0.8 miles, from Minnesota Rd to S Kingshighway)	
2	MO 34 WB (0.6 miles, from S Spring St to South West End Blvd)	N/A
	MO 34 WB (0.8 miles, from Minnesota Rd to S Kingshighway)	
	Highway C (1.9 miles, from Country Rd 209 to MO 91)	
	MO 25 SB (0.4 miles, from Gasconade St to N Douglass St)	
x3	MO 34 WB (0.6 miles, from S Spring St to South West End Blvd)	MO 25 SB (0.4 miles, from Gasconade St to N Douglass St)
	MO 34 WB (0.8 miles, from Minnesota Rd to S Kingshighway)	
	MO 25 NB (1.2 miles, from Country Rd 245 to MO 77)	
	US 60 EB (0.4 miles, from Country Rd 593 to MO 114)	
4	MO 34 WB (0.6 miles, from S Spring St to South West End Blvd)	MO 25 NB (1.2 miles, from Country Rd 245 to MO 77)
	MO 34 WB (0.8 miles, from Minnesota Rd to S Kingshighway)	
	MO 25 NB (1.5 miles, from Country Rd 249 to Country Rd 245)	MO 25 SB (0.4 miles, from Gasconade St to N Douglass St)
	US 60 EB (0.4 miles, from Country Rd 593 to MO 114)	
5	MO 25 NB (0.9 miles, Moore Ln to S Ruth St)	MO 34 WB (0.6 miles, from S Spring St to South West End Blvd)
		MO 34 WB (0.8 miles, from Minnesota Rd to S Kingshighway)

		US 60 EB (0.4 miles, from Country Rd 593 to MO 114)
		MO 25 SB (0.4 miles, from Gasconade St to N Douglass St)
		MO 25 SB (1.5 miles, from Country Rd 230 to Country Rd 216)
		MO 25 NB (2.4 miles, from Country Rd 316 to MO 72)

Table 7 continued. Location of bottlenecks for evacuation scenarios

Scenario	Bottleneck Locations	
	LOS E	LOS F
6	US 60 EB (7 miles, MO 25 to State Hwy N)	MO 34 WB (0.6 miles, from S Spring St to South West End Blvd)
		MO 34 WB (0.8 miles, from Minnesota Rd to S Kingshighway)
		MO 25 NB (1.2 miles, from Country Rd 245 to MO 77)
	MO 25 NB (1.5 miles, Country Rd 249 to Country Rd 245)	MO 25 SB (1.5 miles, from Country Rd 230 to Country Rd 216)
		MO NB (2.4 miles, from Country Rd 316 to MO 72)
		US 60 EB (0.4 miles, from Country Rd 593 to MO 114)
	MO 25 NB (0.9 miles, Moore Ln to S Ruth St)	MO 25 SB (0.4 miles, from Gasconade St to N Douglass St)
		E Business US 60 (0.2 miles, from N Poplar St to MO 25)
		Highway C (1.9 miles, from Country Rd 209 to MO 91)

Summary of Task 4

This task focused on the assessment of evacuation of performance under a 7.8 magnitude earthquake. Six scenarios consisting of various combinations of evacuation demand and road network constraints were analyzed. The road network conditions measured using delay, speed, and vehicle density showed that the conditions deteriorated due to the roadway damage inflicted by the earthquake. A list of potential bottlenecks in the road network where congested conditions are likely to sustain for the entire evacuation period was prepared. Despite the deterioration of conditions, the vehicle speeds averaged over the entire evacuation period were found to be over 50 mph for all scenarios and the average delay was under two minutes per vehicle. The clearance times i.e., the time at which the last evacuating vehicle safely reaches its destination were found to be 14 hours for the 12-hour demand and 9 hours for the 6-hour demand scenarios.

TASK 5: Mobile Application for Earthquake Warning and Preparation

5.1 Background

The phone application 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 safest route options to nearby shelters. Having selected a route, the user will be presented with guided directions. The route selection will be determined from incorporating the results from the traffic simulation (task 4) and taking into the account the structural damage determined from the Modified Mercalli Intensity scale (task 3).

The notifications will be customizable based on MODOT's input which could include messages about unusable roadways, nearest shelter, and highlighting routes for evacuation from the seismic zone. The application was developed in three stages including the user-interface & flow, reading a CSV file, and incorporating application programming interfaces of Google Map and Mapbox into the application.

5.2 User Interface & Flow

This application was developed in both iOS and Android native languages for Missouri Department of Transportation (MoDOT) to have full customization capabilities and functions. The user experience was heavily considered throughout the design of the app to ensure a simple design that presents all necessary information with easy flow between screens was achieved. It was important that the app was not complex but could get the desired information across to the end user. The application flow works as follows (also shown in figure 41):

1. The user opening the app for the first time will grant MoDOT access to the phone GPS coordinates and push notification handling.
2. The application will read in the CSV file containing the evacuation route data.
3. The application will sync to the Google Database to determine if there is an earthquake event.

4. Once steps 2 & 3 are completed, the app will display a warning message to the user if the user is in a warning zone.
5. The user will then see a screen displaying a message preview of the event and will have the option to view two routes for earthquake shelters
6. Upon viewing the routes and becoming familiar with them, the user can then initiate the turn-by-turn directions.

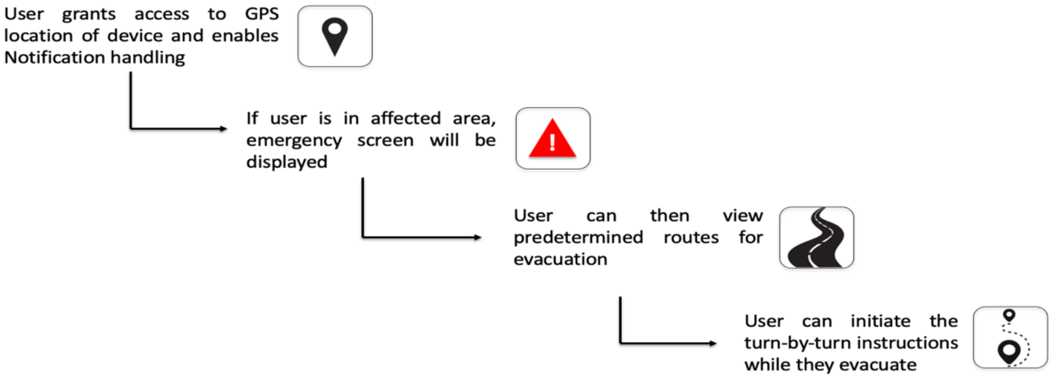


Figure 41. Application Flow Diagram

MoDOT’s current color scheme was coded into the application with easily accessible buttons and having text being clearly visible. When the user opens the application on an Android or iOS device, the loading screen displays the MoDOT logo with a prompt to allow location access to the device as shown in Figure 42. If location access is not granted, the user is prompted to go into settings to allow location access for the application. The application will also ask for push notifications being enabled 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 recommended safest route for the user to take during evacuation, and the step-by-step navigation. As show in Figure 43 (for iOS) and Figure 44 (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 occurrence.

The simulation data that was read into the program will only enable 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 amid the potential 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 via Google Maps. The app will have the current user GPS coordinate 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 a screen that displays step-by-step route instructions. The navigation feature has voice turn-by-turn instructions with projected arrival time and 3D route progress.

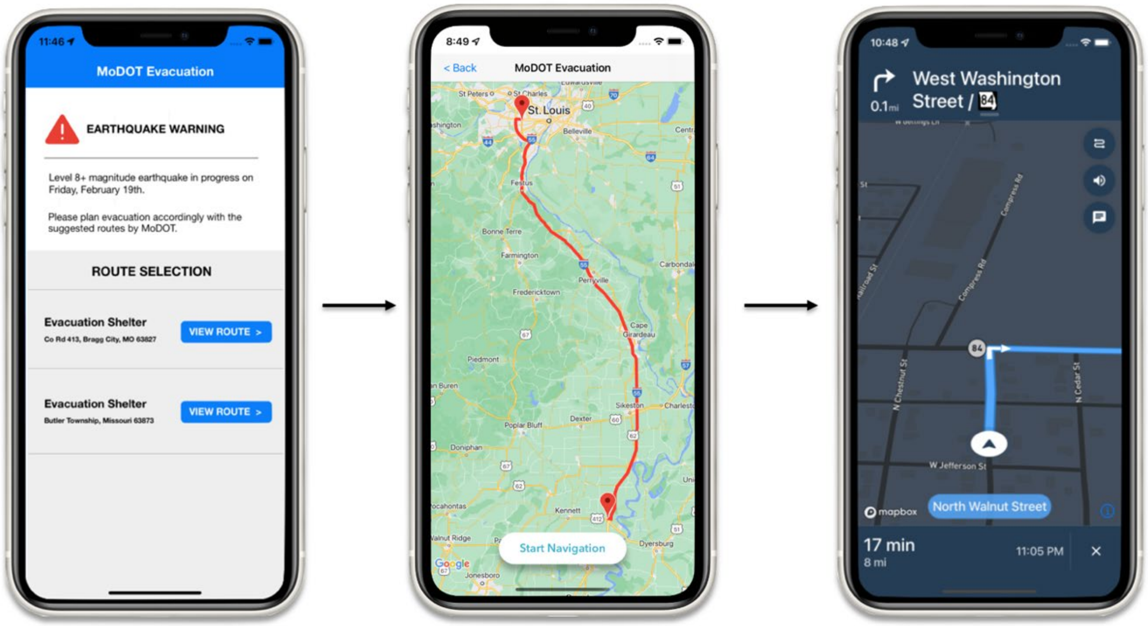
All of these features were incorporated into the app via Mapbox Navigation API. The flow of the app has a back button on the map screen and a cancel button during navigation to allow a seamless flow. When a warning is not present for a user, the phone will display “There are no earthquake warnings in 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 application to run successfully.


Allow “MoDOT” to use your location?

MoDOT would like to use your device location for routing

Figure 42. iOS View of MoDOT Evacuation Application Onboarding Process

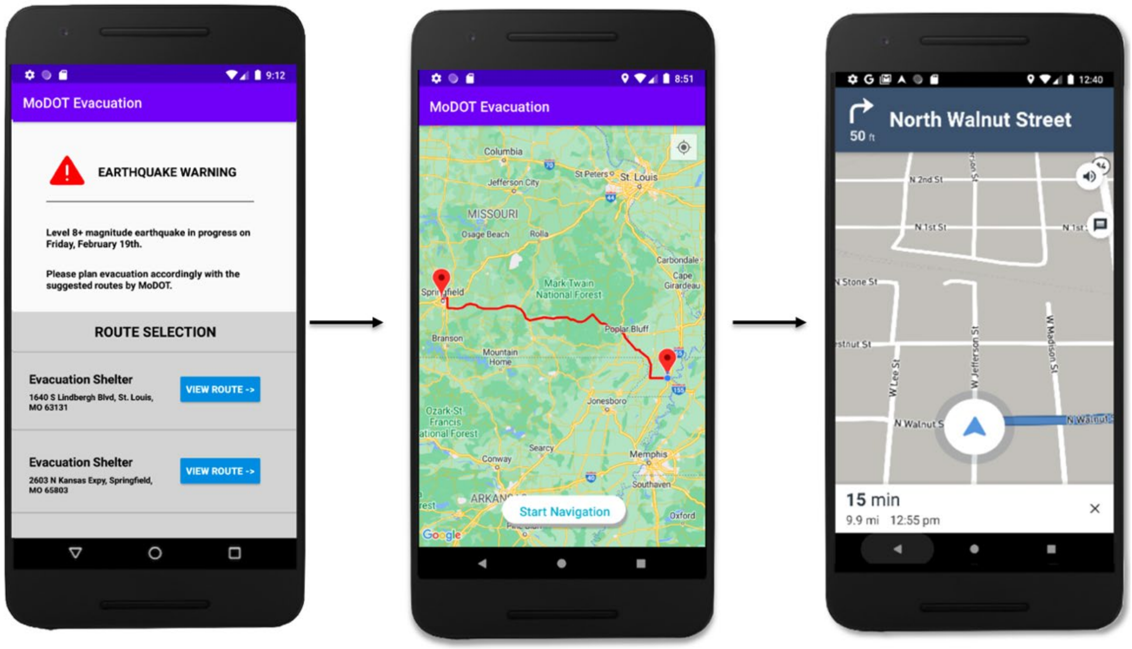
Dynamic notifications are enabled within the application where MoDOT can send customized notifications to end users. These notifications could encompass messages regarding last-minute warnings about an earthquake event, the current development of an earthquake in the area, and the potential for earthquake aftershocks in the near future. An example message setup is shown in Figure 47. An apple certificate was generated through an Apple Developer account to allow push notifications on Apple devices.



Level 8+ magnitude earthquake in progress on Friday, February 19th.

Please plan evacuation accordingly with the suggested routes by MoDOT.

Figure 43. Apple View of MoDOT Evacuation Application Flow



Level 8+ magnitude earthquake in progress on Friday, February 19th.

Please plan evacuation accordingly with the suggested routes by MoDOT.

Figure 44. Android View of MoDOT Evacuation Application Flow

Extending further into the application, Figure 43 and 44 displays three phone screens to showcase the functionality of the app.

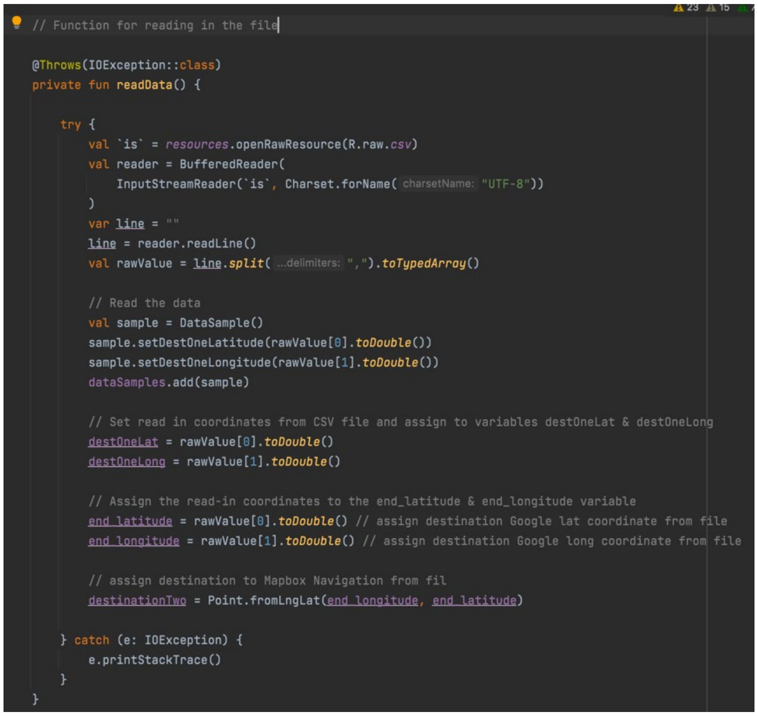
The left screen depicts the main warning screen followed by the Google Map, map preview screen and navigation. With the "Start Navigation" button pressed, the user is able to initiate step-by-step navigation. The "View Route" button allows the user to reach the second screen to view the suggested route on the 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 a picture. Google Firebase Authentication procedures and Firestore Database would need to be implemented into the code to allow the incorporation of these features. Both applications hold parallel functionality to the end user with both having the same potential for future add-on features. An iPhone 11 and Android Nexus 5X were the devices chosen for simulation.

5.3 Reading in a CSV File for Waypoint Information

The data housing the end destination points and path waypoints were exported as an Excel file and converted to a CSV file. The CSV file 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. Shown below in Figures 45 and 46 depict the code needed in order to read in the CSV file and store the values inside the file as variables inside the program.

```
    // read CSV file into the program and assign variables
    func move() {
    let myData = readCSV(inputFile: "Destinations.csv", separator: ",")
    let dir: [String] = myData
    let num = dir.count // have file be read up to last cell count
    for i in 0..<num{
        if i == 0{
            let intptlat = Double(myData[0])!
            initializeLoc.plat = intptlat
        }
        if i == 1{
            let intplot = Double(myData[1])!
            initializeLoc.plot = intplot
        }

    }
}

    func readCSV(inputFile: String, separator: String) -> [String]{


       // Get the file URL
      // let file = "Users/nak/Desktop/Swift Projects/MoDOT/Outputexcelcsv.csv"
       let fileTwo = Bundle.main.path(forResource: "Destinations", ofType: "csv")!
       let inputFile = URL(fileURLWithPath: fileTwo)


       // Get Data
            do {
               let savedData = try String(contentsOf: inputFile)
               return savedData.components(separatedBy: separator)
            } catch {
               return ["Error file couldn't be found"]
            }


    }
```

Figure 45. Apple Code for CSV File Read and Assigning Variables



```
// Function for reading in the file

@Throws(IOException::class)
private fun readData() {

    try {
        val `is` = resources.openRawResource(R.raw.csv)
        val reader = BufferedReader(
            InputStreamReader(`is`, Charset.forName( charsetName: "UTF-8"))
        )
        var line = ""
        line = reader.readLine()
        val rawValue = line.split( ...delimiters: ",").toTypedArray()

        // Read the data
        val sample = DataSample()
        sample.setDestOneLatitude(rawValue[0].toDouble())
        sample.setDestOneLongitude(rawValue[1].toDouble())
        dataSamples.add(sample)

        // Set read in coordinates from CSV file and assign to variables destOneLat & destOneLong
        destOneLat = rawValue[0].toDouble()
        destOneLong = rawValue[1].toDouble()

        // Assign the read-in coordinates to the end_latitude & end_longitude variable
        end_latitude = rawValue[0].toDouble() // assign destination Google lat coordinate from file
        end_longitude = rawValue[1].toDouble() // assign destination Google long coordinate from file

        // assign destination to Mapbox Navigation from fil
        destinationTwo = Point.fromLngLat(end_longitude, end_latitude)

    } catch (e: IOException) {
        e.printStackTrace()
    }
}
```

Figure 46. Android Code for CSV File Read and Assigning Variables

5.4 Application Programming Interface (API) Integration

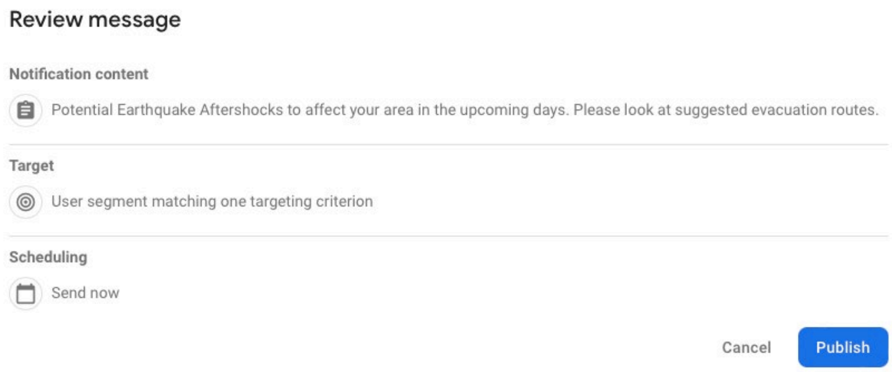
For the end user's safety, the following APIs were introduced into this application to aid in the evacuation process.

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 plugin. Google Maps were utilized to display the desired & safest route to the end user. Google Firebase/Database/Cloud Messaging services provided all the backend (behind the scenes) development environment 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 to view the suggested route or for navigation.

Having Google Maps and Mapbox integrated into the application allows MoDOT to have further customization of how the maps are presented and navigation. 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 function calls inside the code. The California Integrated Seismic Network (CISN) provides continuous alerts for earthquake activity within the area for people through texts and/or emails.

The system aims to provide warnings in a number of seconds prior to the occurrence of ground shaking at a site; since the system broadcasts the location and time of the earthquake, the 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.

5.4.1 Google Cloud Messaging



Review message

Notification content

Potential Earthquake Aftershocks to affect your area in the upcoming days. Please look at suggested evacuation routes.

Target

User segment matching one targeting criterion

Scheduling

Send now

Figure 47. Google Notification Message Preview

The application currently is implemented with Google messaging services (Figure 47) for the dynamic notifications that is a part of a four-step process: setting up the notification message, target, scheduling, and conversion events. The first step entails the actual message and message preview to be sent to the user. Secondly, the target is set for if the notification will be sent to Apple and/or Android devices. Next, the scheduling of when the notification will be pushed is set and finally, the conversation events are determined. Which entails whether there is a ping on the phone per notification or if the MoDOT app icon will have a numerical badge that increases for each notification sent that the user still needs to open. The expiration of the notification can also be set in the conversion events. As of now, notifications can be sent to a device with a warning message customized by MoDOT. As mentioned in this paper, this application could incorporate the notification system similar to CISN but with additional mapping capabilities for safely evacuating individuals within a specific region potentially affected by earthquake aftershocks.

Summary of Task 5

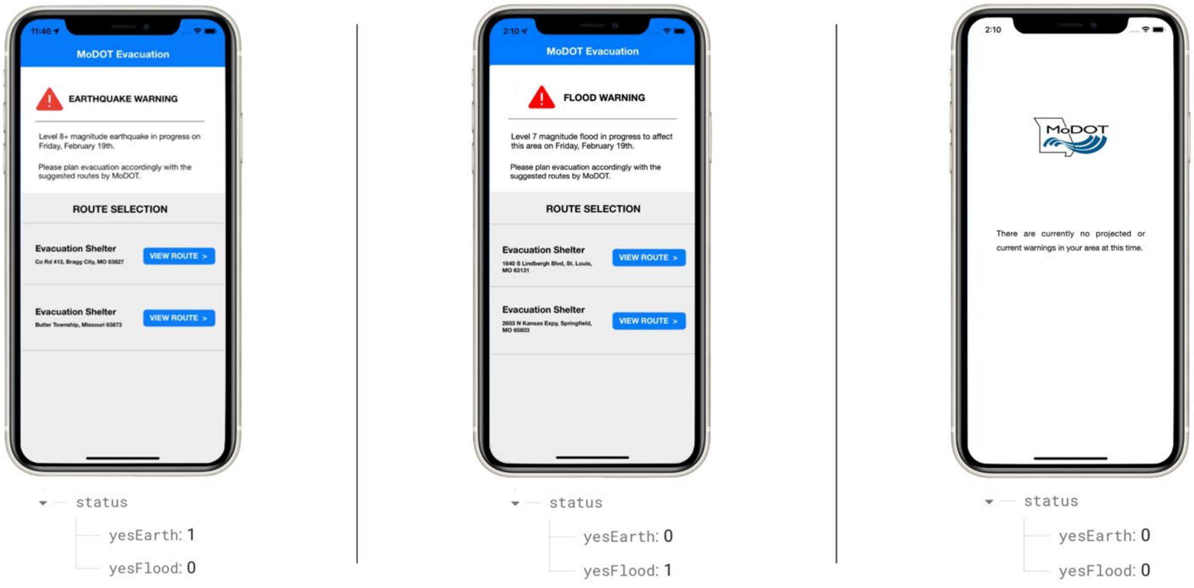
This task focused on using the output from Task 3 and Task 4 to provide directions to residents and responders in the affected region. This was completed by creating a stimulating user-interface, providing code to read-in a CSV file and assign the values to destination and waypoint variables. Cloud messaging for push notifications was incorporated to allow MoDOT to send custom messages to users regarding warnings of potential earthquake aftershocks and to notify users of evacuation routes. Lastly, Google Maps and Mapbox APIs were infused into the application to allow the user to view the safest route determined by MoDOT for evacuation and turn-by-turn navigation capabilities. This application is geared towards individuals living in the affected region for evacuation purposes and for emergency personal to plan facility restoration accordingly.

3. Results and Future Work

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. This project encompassed five tasks that contributed to the project objective of delivering seamless communications tools as part of emergency response and preparedness. With the data from MoDOT, USGS, and SEMA, the team was able to prepare the survey instrument for first responders and isolate the data sources linked to this area (task 1). The results from task 2 indicate that from the information provided about areas that are suspectable to high levels of damage due to a large-scale seismic event, the New Madrid Seismic Zone would be the area for the study. By utilizing the Modified Mercalli Intensity scale to measure the shaking produced by an 8+ magnitude earthquake in the New Madrid Seismic Region, the team was able to extract the CSV file that contained the structural damage report for the region (task 3). The road network conditions measured using delay, speed, and vehicle density showed that the conditions deteriorated due to the roadway damage inflicted by the earthquake (task 4). The application (task 5) achieved the following:

1. Able to display a warning message, desired route for evacuation, and provide turn-by-turn navigation from source coordinates to selected destinations (shelters) and notification handling.
2. Able to read in file with waypoint data to assist in determining end destination and desired route formulation.
3. Utilized Google and Mapbox APIs to handle navigation and routing within application.

For extended use of the application, the iOS version was equipped with database handling to read from a real-time Firebase Database as shown in figure 48.



EARTHQUAKE WARNING

Level 8+ magnitude earthquake in progress on Friday, February 19th.

Please plan evacuation accordingly with the suggested routes by MoDOT.

Evacuation Shelter
Co Rd 413, Bragg City, MO 63827

Evacuation Shelter
Butler Township, Missouri 63873

status
yesEarth: 1
yesFlood: 0

FLOOD WARNING

Level 7 magnitude flood in progress to affect this area on Friday, February 19th.

Please plan evacuation accordingly with the suggested routes by MoDOT.

Evacuation Shelter
1640 S Lindbergh Blvd, St. Louis, MO 63131

Evacuation Shelter
2603 N Kansas Expy, Springfield, MO 65803

status
yesEarth: 0
yesFlood: 1

There are currently no projected or current warnings in your area at this time.

status
yesEarth: 0
yesFlood: 0

Figure 48. iOS Database Handling for Multiple Event Types

In figure 48, there are three iPhone screens depicting three scenarios with screenshots of the real-time database below the phones. For event one, if yesEarth = 1 and yesFlood = 0, it accounts for an earthquake warning that will be shown to the user. If yesFlood = 1 and yesEarth = 0, it accounts for a flood warning that will also be shown to the user. In the event where there are no current warnings for the user (yesFlood = 0 and yesEarth = 0) then a no warning message will appear. This further database extension allows the app to be customized for various events (earthquake, flood, tornado, etc.).

For future work there will need to be additional points of interest to go through for the application to evolve. First, 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 actual route. Currently, the program creates an array of all the elements from the csv file that can be individually assigned a value. That value determines the end location and/or help with determining which route to display to the user in the app (e.g., waypoints along the route). The app is currently programmed only for the New Madrid Seismic Zone where additional classes of waypoints will be needed for all regions of Missouri. This will allow MoDOT to "override" the current Google Map and Mapbox direction and navigation algorithms. One cannot 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 function. Notifications are enabled through Google Cloud Messaging services for the app and can simulate various warning messages. However, to provide location specific notifications, further code that encompasses recording and storing the user's current location ID and checking if that location point is within the region of a warning zone will need to be implemented.

Potentially, the React Native framework could also be implemented within this application to combine the Android and iOS code into one code platform (for the user-interface specific code). Another point of interest to consider is whether cellular towers will still be functioning amongst earthquake shocks. This will have a dramatic effect on the usability of the phone/device for the application requires GPS location and internet. Further code implementation of the APIs for their off-line map capabilities for the user to download the route ahead of time will need to be considered. On a final note, it's worth noting if the app will offer more than one route suggestion for a location to the user. Having users take the same road may lead to congestion for the route does not sync with real time traffic data. The prospect of being able to notify a user ahead of time about potential earthquake aftershocks and provide a route suggestion for the user to evacuate safely for a New Madrid Seismic Region was accomplished. With this application, engineering managers, transportation planners, and civilians can use 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.

References

Akhilesh Ojha, Dr. Steven Corns, Dr. Tom Shoberg, Dr. Ruwen Qin, and Dr. Suzanna Long (2018). *Modeling and Simulation of Emergent Behavior in Transportation Infrastructure Restoration in Emergent Behavior in Complex Systems Engineering: A Modeling and Simulation Approach.* Wiley Press.

Bernardini, Gabriele & Santarelli, Silvia & Quagliarini, Enrico & D'orazio, Marco. (2017). *Dynamic guidance tool for a safer earthquake pedestrian evacuation in urban systems. Computers, Environment and Urban Systems.* 65. 150-161. 10.1016/j.compenvurbsys.2017.07.001.

Cheng, Ming & Wu, Stephen & Heaton, Thomas & Beck, James. (2014). *Earthquake early warning application to buildings. Engineering Structures.* 60. 155–164. 10.1016/j.engstruct.2013.12.033.

Gude, Vinayaka, Corns, Steve, and Long, Suzanna (2020). *Flood Prediction and Uncertainty Estimation using Deep Learning Water*. 12(3):884, DOI 10.3390/w12030884.

Ramachandran, Varun, Shoberg, Tom, Long, Suzanna, Corns, Steven M. and Carlo, Hector J. (2015a). *Identifying Geographical Interdependency in Critical Infrastructure Systems Using Open Source Geospatial Data in Order to Model Restoration Strategies in the Aftermath of a Large-Scale Disaster*. International Journal of Geospatial and Environmental Research 2 (1/4): 1-19.

Ramachandran, Varun, Long, Suzanna, Shoberg, Tom, Corns, Steven M. and Carlo, Hector J. (2015b). *Framework for Modeling Urban Socioeconomic Resilience Time in the Aftermath of an Extreme Event.* Natural Hazards Review, http://dx.doi.org/10.1061/(ASCE)NH.1527-6996.0000184.

Ramachandran, Varun, Long, Suzanna, Shoberg, Tom, Corns, Steven M. and Carlo, Hector J. (2016). *Post-disaster Supply Chain Interdependent Critical Infrastructure System Restoration Modeling: A Review of Necessary Data*. Data Sciences Journal, 15: 1, pp. 1-13, http://dx.doi.org/10.5334/dsj-2016-001.

Ross, Z. E., Meier, M. A., Hauksson, E., & Heaton, T. H. (2018). *Generalized seismic phase detection with deep learning.* Bulletin of the Seismological Society of America, 108(5), 2894–2901, https://doi.org/10.1785/0120180080.