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Determining Earthquake Impacts on Arkansas' Roadway Network: An Application of HAZUS.

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A thesis submitted in partial fulfillment of the requirements for Honors Designation with the degree of Bachelor of Science in Civil Engineering

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Abstract

Natural hazards are a dangerous and unpredictable aspect of life on earth. They can cause devastating damage to our surroundings that makes movement of people, goods, and emergency services difficult. There is a need to plan for these disasters to ensure that damages to our infrastructure and people are minimized. It can be difficult for planners to determine which parts of a roadway network are most vulnerable to a specific disaster and what their impact on the rest of the network may be. This thesis uses a nationally available natural disaster estimation tool developed by FEMA called "Hazus" (FEMA, 2020). This thesis focuses on the effect of a large magnitude earthquake in the New Madrid Seismic Zone (NMSZ) on the roadway network of Arkansas. Results from this analysis showed that an earthquake with a magnitude of 7.7 from the NMSZ would produce more than $3 billion dollars in damages to the transportation system alone and affect over 23,000 miles of road. Furthermore, the results of this thesis highlight which counties may be at greater risk of damage from such an event as well as the functional classifications of the roads most affected. This thesis can be used to guide emergency management and transportation planners on the process and methodology of using Hazus, and the results of this thesis can be used to help determine mitigation and resilience strategies for the roadway network of Arkansas.

Chapter 1: Introduction

Highways are an important part of our everyday lives. From traveling to work, accessing healthcare, visiting friends and family, and moving freight from one corner of the United States to another, we are reliant upon our highways. Over 164,000 miles of highways in the National Highway System allow for 49.3 million tons of freight valued at more than $52.5 billion to be moved daily (Bureau of Transportation Statistics, 2017a). This daily tonnage, according to the Bureau of Transportation Statistics, is projected to increase by approximately 1.4 percent per year until 2045 (Bureau of Transportation Statistics, 2017a).

Figure 1: National Highway System (REF: FHWA, 2020)

Trucking alone accounts for moving about 70% of the goods in the United States (Bureau of Transportation Statistics, 2017b). The economic impact just from trucking may justify the need for expanding and maintaining our highway network. Apart from moving freight, highways move people. In case of emergency, highways allow for emergency personnel to be dispatched and reach their locations quickly. In normal circumstances, highways allow for a higher degree of mobility for everyone.

Highways are designed for a 20-year period with some states electing to design for closer to 30-40 years (Federal Highway Administration (b), 2017). Maintenance is key in keeping these roads as functional and usable as possible during their lifetime. Road maintenance is a scheduled and common occurrence across the US; therefore, delays due to normal road closure are better understood and easier to predict compared to something unpredictable like natural disasters.

Natural disasters are a highly dangerous and highly unpredictable fact of life. They can assume many forms—from extreme temperatures and dangerously fast spinning winds to volcanic explosions and violent ground shaking. One impact of natural disasters, apart from the obvious destruction of buildings and taking of lives, is the closure of portions of our roadway network. In 2011, persistent rainfall and snowpack melting caused extreme flooding in some of the United States' major rivers (NOAA, 2011). Flooding in the Mississippi River caused officials to close I-40 along a 23-mile stretch from Brinkley, AR. to Hazen, AR (The Associated Press, 2011). This closure forced drivers headed to Little Rock, AR to take a 120-mile detour instead of the normal 70-mile-route (The Associated Press, 2011). Figure 2 and Figure 3 depict the pre- and post-flood truck flows.

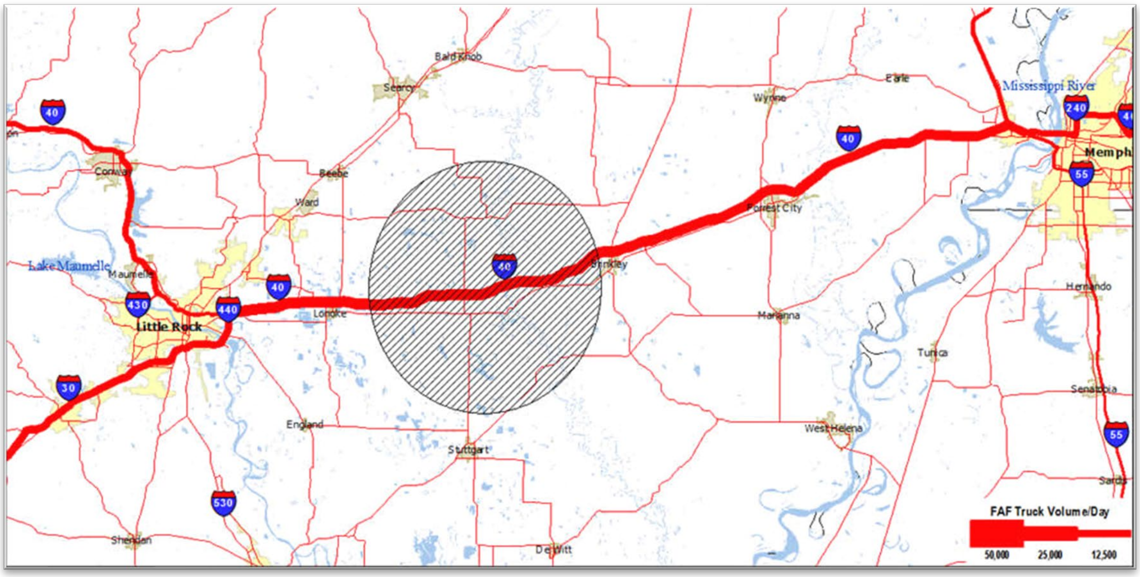


Figure 2: Pre-flood I-40 Truck Flows (REF: Federal Highway Administration (a), 2021)

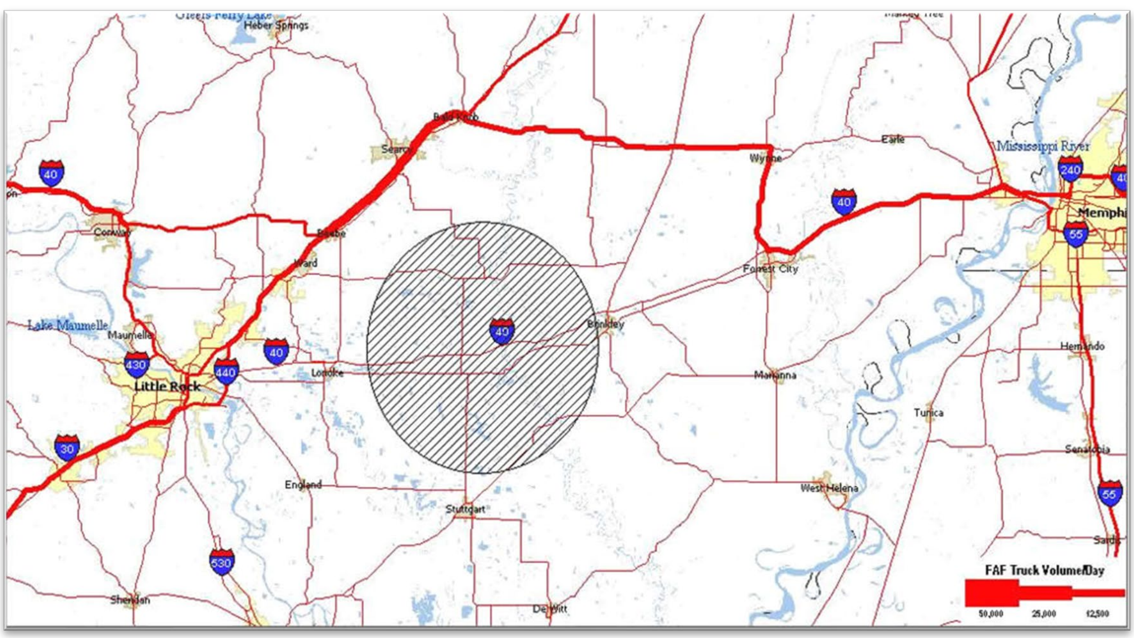


Figure 3: Post-flood I-40 Truck Flows (REF: Federal Highway Administration (a), 2021)

Some trucking companies reported delays of two to three hours while others had to cut routes short due to federal limits on how long commercial drivers can work (The Associated Press, 2011).

Thanks to the 160,000+ miles of highway in the U.S, cross-country truck drivers were able to circumvent Arkansas and the flooded I-40, but for those that could not, the supply chain disruption caused losses amounting to approximately $3 billion (NOAA, 2011). It is clear from this road closure that closures, whether man or nature-made, can have expensive effects.

Other natural disasters, like earthquakes, occur across the world frequently; though, rarely are they large enough to disrupt the supply chain and people's lives (IRIS, 2011). The National Earthquake Information Center locates roughly 12,000-14,000 earthquakes per year (IRIS, 2011). The vast majority of those events are just barely able to be felt by those living on or near to fault lines (IRIS, 2011). The nearest active seismic zone to Arkansas capable of producing an earthquake with non-negligible effects is the New Madrid Seismic Zone (NMSZ) (Figure 4) (Hendricks, 2019). This fault line stretches approximately 150 miles from Arkansas into Missouri and Illinois (Hendricks, 2019). The NMSZ was responsible for some of the most violent earthquakes in the history of the continental United States in 1811-1812 (Hendricks, 2019). Those earthquakes in 1811-1812 measured over magnitude 7.5 and destroyed buildings, shaped the land due to liquefaction, and produced shaking felt all the way in New England and Canada (AGS, 2019).

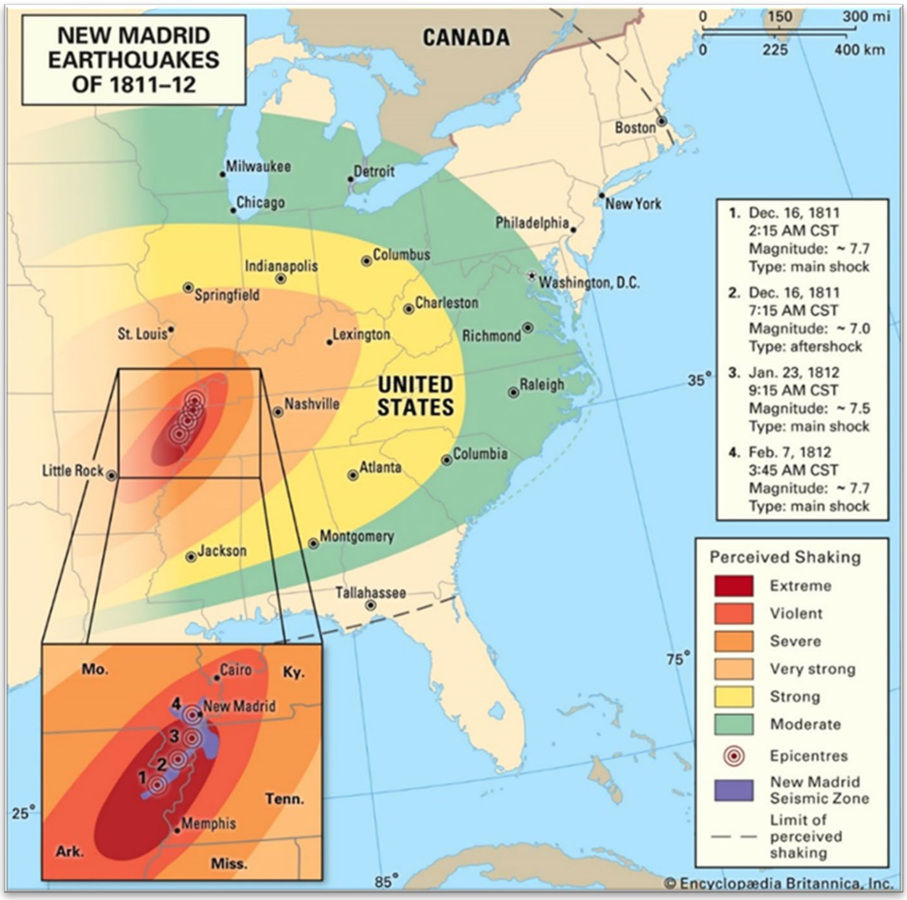


Figure 4: New Madrid Seismic Zone 1811-1812 (REF: Rafferty, 2011)

A NMSZ earthquake measuring over a magnitude of 7.5, like what occurred in 1811-12, can be expected to occur every 200 to 300 years (Hendricks, 2019). If that is the case, then we are due a violent earthquake in the near future. An earthquake of this magnitude, now, would have even more devastating effects than it did in 1811: more lives would be lost and billions of dollars in damage would be incurred (Hendricks, 2019). Ground failure from such an event would certainly close roads and destroy buildings. As mentioned above, road closure events bring upon delays and massive losses since most goods transported are by trucks on highways. Furthermore, in case of an event like this where lives are at stake, the importance of highways is even more evident. Emergency and medical personnel, without a functioning and resilient highway system, would have difficulty reaching areas in need.

This thesis aims to simulate an event consisting of a magnitude 7.7 earthquake in the New Madrid Seismic Zone to determine the potential losses and damages to the roadway network of Arkansas. Those losses and damages can be used to identify the vulnerability of links that are the most critical for freight movement in the state. This will be accomplished by implementing a nationally available disaster planning tool developed by FEMA called "Hazus" (FEMA, 2020). Despite the unpredictability of natural disasters—their occurrences can be simulated, losses predicted, and have mitigation strategies developed to minimize their damages.

Chapter 2: Background

Methods to determine the effects of natural disasters on public infrastructure include using historical data, mathematical models, and simulations. The Texas Department of Transportation (TxDOT) developed a mitigation plan update in 2013. In this update, they used historical data and questionnaires to determine which magnitudes of earthquakes may occur at what frequency, and to what degree they cause damage (NCTCOG, 2013). This approach is more subjective, and the data regarding each damage association is anecdotal rather than empirical. The questionnaires used were distributed to regional emergency management coordinators to gather information about their highest priority natural hazards (NCTCOG, 2013). This requires that the 254 regional emergency management coordinators know enough about their region's natural hazard past, vulnerability, and impacts of future disasters, to give accurate and meaningful answers (NCTOG, 2013). Furthermore, a limitation of using historical data compared to using more quantitative methods like simulations that take advantage of various hazard and probability maps is the ability to manipulate and test a variety of scenarios. Testing and analyzing results from different scenarios under different parameters lend themselves to yielding more complete data and strategies.

The Colorado Department of Transportation (CDOT) estimated the effects of hazards to their highway system to reduce system risk and improve resilience (Flannery, 2017). To determine risk, they used a criticality assessment developed by a "Working Group" composed of select individuals from across CDOT's specialty groups (engineering, planning, operations, design, and maintenance) (Flannery, 2017). Risk from threats like flooding, landslide, avalanches, and extreme weather were determined in their vulnerability assessment governed by their risk equation (Figure 5) (Flannery, 2017).

$$Risk = C \times V \times T$$

Where,

R = Potential loss due to analyzed event, $
C = Outcome of an event occurrence, $
V = Given event has occurred, probability of that estimated consequences will be realized, %
T = Likelihood event will occur, %

Figure 5: Risk Equation; Vulnerability Assessment (REF: Flannery, 2017)

This calculation of potential losses due to an analyzed event is based primarily on CDOT's asset management databases and the experience of their Working Group. This method of analysis can be time consuming and personnel resource intensive, e.g., working groups met at four workshops over the course of two years (Flannery, 2017). This may limit the transferability of the approach and its findings. If the approach were to be expanded to a statewide level with varied geographies, highway assets, and system usages, it would require significant efforts to conduct additional workshops.

As an alternative to subjective approaches that are human-resource intensive, there are mathematical models that can be used to estimate the impacts of natural disasters. The Federal Emergency Management Agency (FEMA) created 'Hazards United States-Multi Hazard', commonly referred to as "Hazus-MH" or just "Hazus", as a free and open-sourced program. Hazus is the combination of geographic information systems (GIS) with engineering, science, and mathematical models (Nastev & Todorov, 2013). This simulation tool determines the potential losses associated with flooding, earthquakes, tsunamis, and hurricanes. It operates by associating mathematical models in the form of graphs like fragility curves (for road damages), capacity curves (for building destruction), and restoration curves (to determine functionality after an amount of time) (FEMA(b), 2020). Figure 6 provides a simplified overview of how Hazus operates.

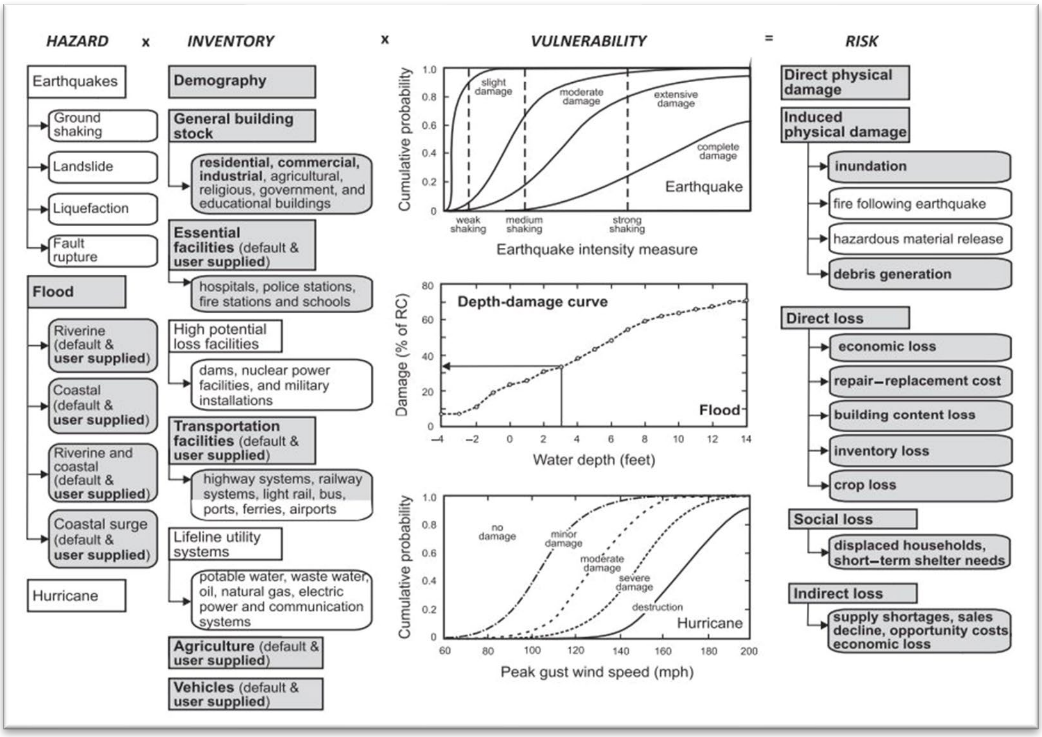


Figure 6: Hazus Functionality Simplified (REF: Nastev & Todorov, 2013)

Hazus is a publicly available program capable of simulating a variety of natural disaster events like flooding, earthquakes, hurricanes, and tsunamis (FEMA, 2021). It is being used increasingly by states in communities to determine losses, mitigation approaches, and help raise awareness of natural disasters (Climate.gov, n.d). Furthermore, the Canadian Government through their Natural Resources Canada (NRCan), adopted Hazus and uses it as a "best practice method for assessing physical vulnerability, socioeconomic security and public safety from natural hazards" (Nastev & Todorov, 2013).

Hazus was chosen for this thesis because of its ability to incorporate user data alongside a large array of nationally acquired information to create more accurate analyses. Furthermore, this approach to hazard modeling was chosen because it allows for running multiple scenarios related to geographical features like soil types and water levels, roadway infrastructure, and cost models. Finally, data visualization and quantification is possible through widely available GIS programs like ArcGIS and QGIS.

Chapter 3: Methodology

This thesis is accomplished through four sections: (1) Data Preprocessing, (2) Hazus Modeling, (3) Impact Visualization, (4) Impact Quantification.

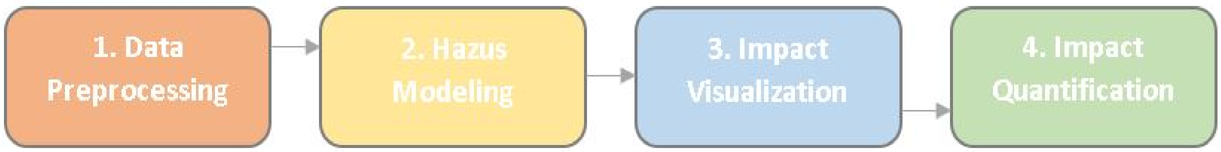


Figure 7: Objectives Flowchart

This section describes the efforts undertaken during the course of this thesis to simulate a large magnitude earthquake in the New Madrid Seismic Zone.

Section 3.1 *Data Preprocessing*

The goal of this section is to acquire and format information in the form of tables and maps relevant to the user's study region for use in updating Hazus' default database and running simulations that better match the users' needs and priorities. A basic earthquake analysis can be performed using FEMA's provided collection of inventory databases in conjunction with the USGS ShakeMap website. The USGS ShakeMap scenarios provided are useful in Hazus simulations because they contain ground acceleration data as well as soil information (FEMA, 2020). This data, alongside FEMA's default facility information, can perform basic analyses and produce initial earthquake estimates.

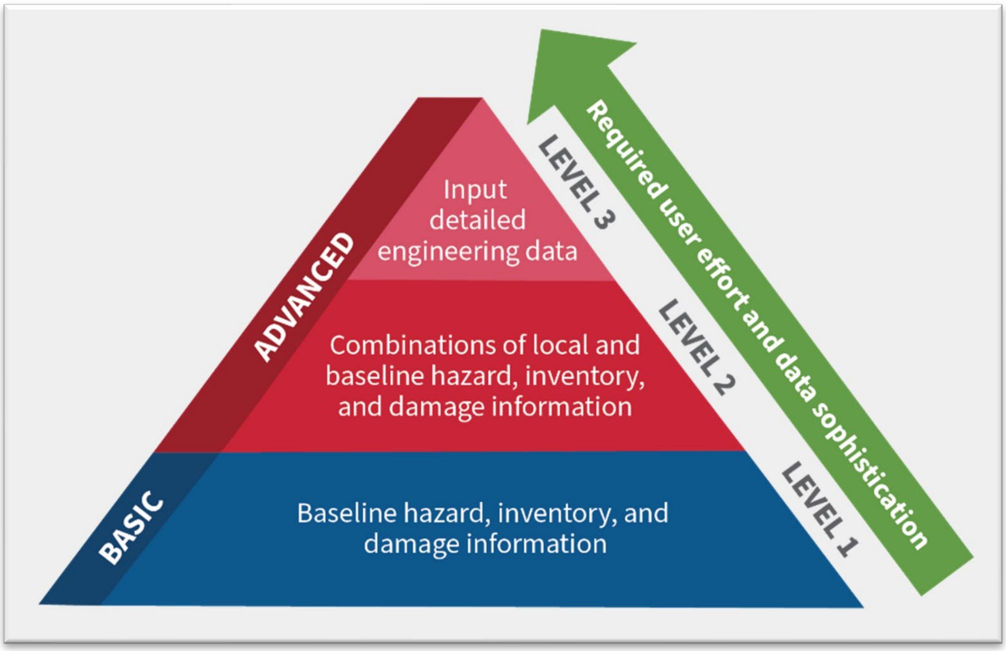


Figure 8: Hazus Analysis Levels (REF: FEMA, 2021)

To produce in-depth analyses with more accurate and representative loss estimates, data needs to be gathered, formatted, and input into Hazus by the user; however, this route requires much more effort (see Figure 8). FEMA's Standard Operation Procedures (SOP) manuals cover what data users may want to add for their analysis. To generate losses for infrastructure such as roads, liquefaction and landslide susceptibility maps for a study region need to be added in addition to the USGS provided soil map as Hazus does not consider ground shaking alone as a factor for determining road damage (FEMA, 2021). Instead, it considers ground failure (related to landslides and liquefaction) to be the main risk factor in predicting road damages (FEMA, 2021). Bridges and tunnels on the other hand, can be affected by just ground shaking and experience damages.

If landslide and liquefaction maps are not readily available in electronic format containing the necessary attributes outlined in the Earthquake SOP manuals, then the user must manually digitize the maps and provide the necessary attributes.

The landslide map depicted below in Figure 10 was created using a Digital Elevation Model provided by the Arkansas GIS Office and ArcMap (Figure 9). The DEM contained National Elevation Dataset (NED) data in the form of one-meter tiles and those tiles provided the bare earth elevation data for the entire state of Arkansas (Arkansas GIS Office, 2018). The dark and light areas on the map represent low and large elevations, respectively. ArcMap's spatial analysis tool aptly named "Slope," was used to determine the slope of each tile of the DEM (ESRI, 2020). Those slopes were used to assign a landslide susceptibility for areas of the state based on rock and soil types as well as groundwater level.

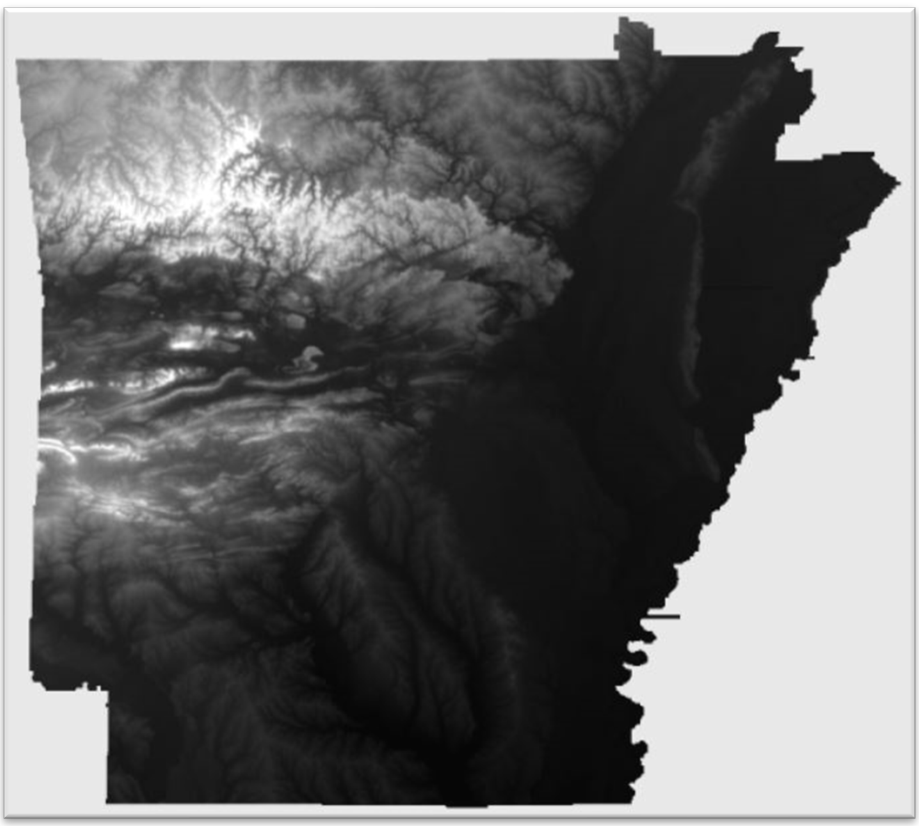


Figure 9: Arkansas DEM Map (REF: Arkansas GIS Office, 2018)

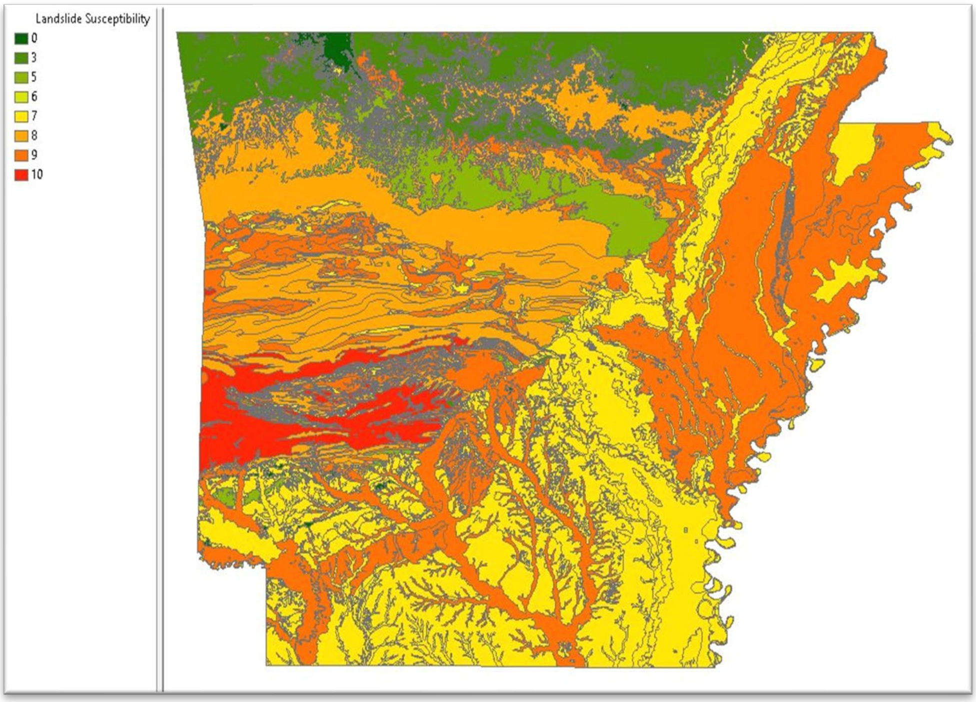


Figure 10: Arkansas Landslide Susceptibility Map (B)

Table 1 depicts the table of susceptibility classes from the earthquake SOP manual and Table 2 contains the attribute table of the aforementioned landslide map (FEMA, 2020).

Table 1: Hazus Landslide Susceptibility Classification Table (REF: FEMA, 2020)

Geologic Group		Slope Angle, degrees 0–10	10–15	15–20	20–30	30–40	>40
(a) DRY (groundwater below level of sliding)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone)	None	None	I	II	IV	VI
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone)	None	III	IV	V	VI	VII
C	Argillaceous Rocks (shales, clayey soil, existing landslides, and poorly compacted fills)	V	VI	VII	IX	IX	IX
(b) WET (groundwater level at ground surface)							
A	Strongly Cemented Rocks (crystalline rocks and well-cemented sandstone)	None	III	VI	VII	VIII	VIII
B	Weakly Cemented Rocks and Soils (sandy soils and poorly cemented sandstone)	V	VIII	IX	IX	IX	X
C	Argillaceous Rocks (shales, clayey soil, existing landslides, and poorly compacted fills)	VII	IX	X	X	X	X

Table 2: Landslide Map (B) Attribute Table

Landslide_Wet

FID *	Shape *	ROCKTYPE1	Type	Shape_Length	Shape_Area	Geo. Class	Number
1	Polygon	limestone	3	18.299789	0.34632	A	2
2	Polygon	dolostone (dolomite)	0	4.622638	0.049283	A	1
3	Polygon	shale	9	0.041674	0.000034	C	2
4	Polygon	dolostone (dolomite)	3	12.198029	0.328747	A	2
5	Polygon	shale	9	0.161643	0.000205	C	2
6	Polygon	limestone	3	0.01032	0.000004	A	2
7	Polygon	shale	9	0.285286	0.000899	C	2
8	Polygon	shale	9	0.010337	0.000005	C	2
9	Polygon	dolostone (dolomite)	0	0.014446	0.000009	A	1
10	Polygon	shale	9	0.524824	0.001024	C	2
11	Polygon	dolostone (dolomite)	3	0.217905	0.000651	A	2
12	Polygon	shale	7	0.046246	0.00007	C	1
13	Polygon	limestone	0	0.014443	0.00001	A	1
14	Polygon	shale	7	0.023716	0.000021	C	1
15	Polygon	limestone	0	0.00611	0.000002	A	1
16	Polygon	sandstone	8	0.135528	0.000541	B	2
17	Polygon	shale	7	0.636535	0.000795	C	1
18	Polygon	dolostone (dolomite)	3	1.930479	0.002821	A	2
19	Polygon	shale	9	0.787407	0.000906	C	2
20	Polygon	limestone	3	38.911398	0.296402	A	2

(0 out of *4000 Selected)

In Table 2, the "ROCKTYPE1" column comes from a map of Arkansas' geological data from USGS (USGS, 2000). This column was used alongside the "Geologic Group" rows from the Hazus Landslide Susceptibility Classification Table (Table 1) to assign a letter to each polygon from the DEM map (FEMA, 2020). Those letter classifications were then matched with their respective slope values—from the "Number" column—to determine the landslide susceptibility for that polygon. The "Number" column was created from the raw tile slopes provided by the DEM map and consolidated into ranges matching the "Slope Angle, degrees" column in Table 1. For example: 1 = 0-10 degrees, 2 = 10-15 degrees, 3 = 15-20 degrees, and so on and so forth. For the two different groundwater conditions: a) DRY (groundwater below level of sliding) and b) WET (groundwater at level of ground surface), two different landslide susceptibility maps may be created (FEMA, 2020). The only difference between the two is the landslide susceptibility classification associated with each polygon. Figure 10: Arkansas Landslide Susceptibility

Map (B) depicts the wet condition for Arkansas which in analysis, may yield the most conservative losses.

Apart from hazard maps, updates to Hazus' default data can be made as well. Users can import and replace the data that comes with Hazus. Road network information comes from National Highway Planning Network created by the Federal Highway Administration in 2005 (FEMA, 2021). This data is updated every three to six years and the most recent data is from 2019 (FEMA, 2021). Users may elect to add their own road networks, and other facility data, based on their research needs and priorities. The Hazus Inventory Manual further describes all that is required to update each facility.

Section 3.2 ***Hazus Modeling***

The goal of this chapter is to import any data acquired and formatted in the form of tables and maps from chapter 1 into Hazus and ensure that it is recognized by the software during simulation. After data preprocessing has been completed, the data needs to be imported into Hazus via the Comprehensive Data Management System (CDMS) and Hazard Scenario Wizard (Figure 11 and Figure 12).

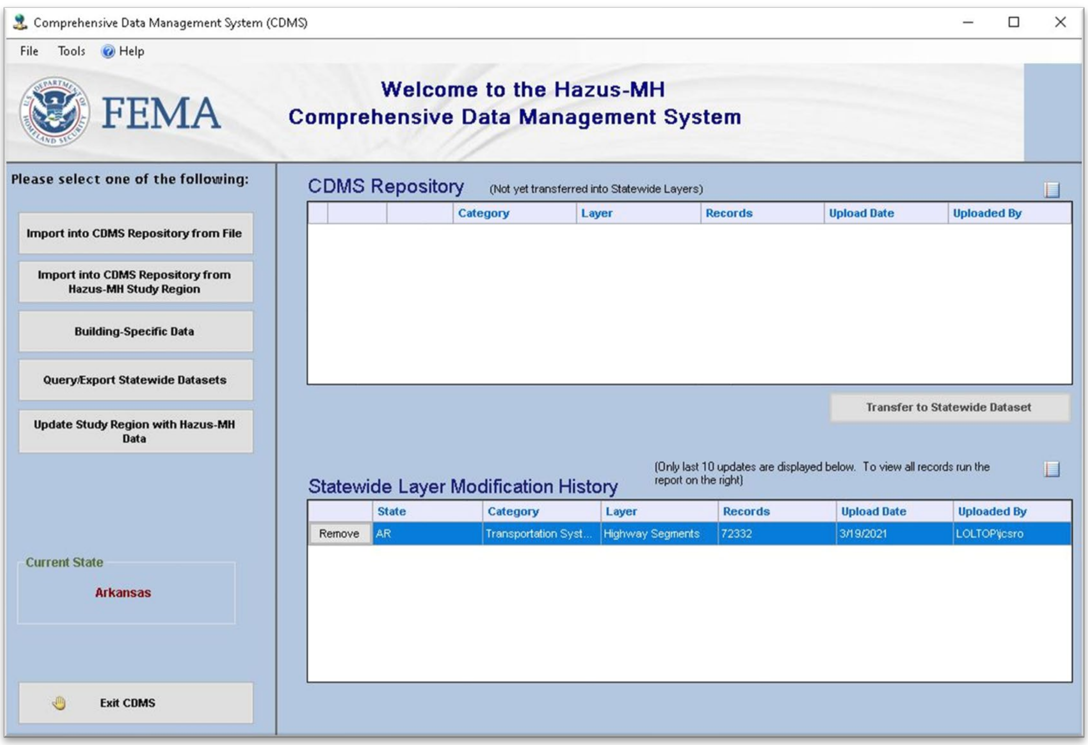


Figure 11: Comprehensive Data Management System (CDMS) (REF: FEMA, 2019)

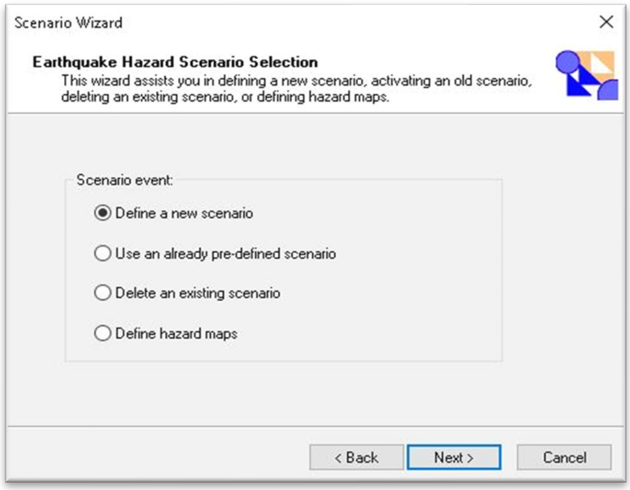
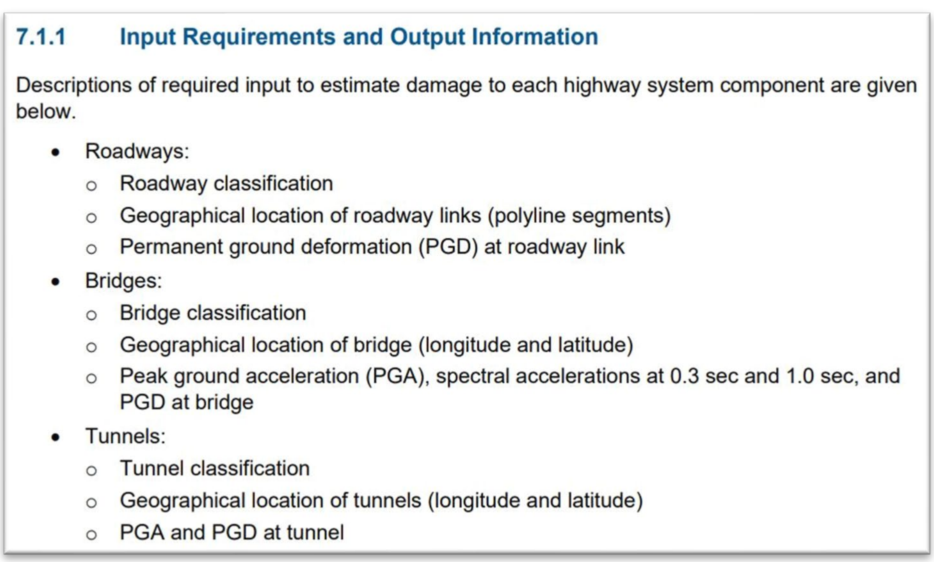


Figure 12: Hazard Scenario Wizard (REF: FEMA, 2020)

The CDMS comes with the installation of Hazus and allows users to view, import, and export data that comes preinstalled with the software (FEMA, 2019). Data in the form of .csv files or geodatabase files for all sorts of facilities like transportation, buildings, utilities, etc., can be viewed and changed here for any state (FEMA, 2019). The CDMS is where something like an updated roadway network file would go; though, it must contain some specific attributes in order to be accepted.



7.1.1 Input Requirements and Output Information

Descriptions of required input to estimate damage to each highway system component are given below.

- Roadways:
  - Roadway classification
  - Geographical location of roadway links (polyline segments)
  - Permanent ground deformation (PGD) at roadway link
- Bridges:
  - Bridge classification
  - Geographical location of bridge (longitude and latitude)
  - Peak ground acceleration (PGA), spectral accelerations at 0.3 sec and 1.0 sec, and PGD at bridge
- Tunnels:
  - Tunnel classification
  - Geographical location of tunnels (longitude and latitude)
  - PGA and PGD at tunnel

Figure 13: Transportation Facilities Requirements (REF: FEMA, 2019)

Depicted in Figure 13 above are the input requirements for some transportation facilities. The highway component classification is how Hazus can determine economic losses (FEMA, 2021). For example: a 4-lane major road costs more to replace and repair than a 2-lane local road. The geographical location and ground acceleration/deformations are how Hazus generates damages based on fragility curves (FEMA, 2021). Segment functionality is based on restoration curves (FEMA, 2021).

In the scenario wizard (Figure 12), the user can either define a new scenario, use an existing scenario, delete a scenario, or define the hazard maps created in Objective 1. When creating a new scenario, six options are available and described below in Figure 14 from the earthquake SOP manual.

1. Historical epicenter – defining your scenario based on a historical event
2. Source event – defining your scenario based on a seismic event from the source event database
3. Arbitrary event – defining your scenario based on fault type, event type, epicenter location, magnitude, depth, width, and fault rupture characteristics, used with an applicable attenuation function
4. Probabilistic hazard – defining your scenario based on return period and magnitude or annualized loss
5. User-supplied hazard – defining your scenario based on user supplied ground motion data.
6. USGS ShakeMap – defining your scenario based on a USGS ShakeMap XML grid file for a recent, historic or scenario event

Figure 14: New Hazard Scenario Options (REF: FEMA, 2020)

The ShakeMap route is simple and strongly suggested by FEMA. According to the earthquake SOP manual, "[USGS ShakeMaps] provide near-real-time maps and digital data of ground motion and shaking intensity following significant earthquakes, as well as predicted ground motions for hypothetical scenario events" (FEMA, 2020). This attribute as well as the fact that ShakeMaps may include instrument readings and reports of how the event felt, support that this is the preferred route to follow when choosing how to define an earthquake hazard scenario in Hazus (FEMA, 2020). This study of Arkansas utilized the USGS ShakeMaps.

In the scenario wizard, it is important to add your preprocessed hazard maps. This is where Hazus connects the hazard maps to its database of facility information (FEMA, 2020).

If large amounts of data are added by the user, Hazus may run into issues allocating memory and assigning the hazard maps to the facilities. The use of Microsoft SQL Server Management Studio allows for one to view Hazus' study regions and the contained information. Thanks to the help team from Hazus, --a benefit of using this software--when issues with the program arise, they can assist. A member of FEMA's Hazus help team was able to provide queries, shown below in Figure 15, that essentially force Hazus to assign the hazard maps to the study region's data. This ensures that the hazard maps are used in analysis and losses can be generated.

```
Update a
SET a.[LqfSusCat] = b.[Type]
FROM [eqSrLqf] b
INNER JOIN [eqHighwaySegmentHFT] a
ON b.Shape.STIntersects(geometry::Point(a.Longitude, a.Latitude, 4326))= 1

Update a
SET a.[LndSusCat] = b.[Type]
FROM [eqSrLnd] b
INNER JOIN [eqHighwaySegmentHFT] a
ON b.Shape.STIntersects(geometry::Point(a.Longitude, a.Latitude, 4326))= 1
```

Figure 15: Hazard Map Queries (REF: A. Hoke, personal communication, April 15, 2021)

After ensuring that any externally acquired data has been correctly input into Hazus—the program will crash if it is not—and selecting a scenario to run an analysis on, then an analysis can be run.

Section 3.3 ***Impact Visualization***

The goal of this section is to view the results of the completed Hazus simulation in terms of damage maps and/or attribute tables. For visualization of results immediately in Hazus, users can navigate to the results tab on the top ribbon of Hazus and then choose a facility to depict results of (Figure 16). After choosing a facility, a table shows the results of the specific tab the user is on; or the user can decide to display a specific attribute from the table in the map by selecting a column and then clicking the "map" button (Figure 17).

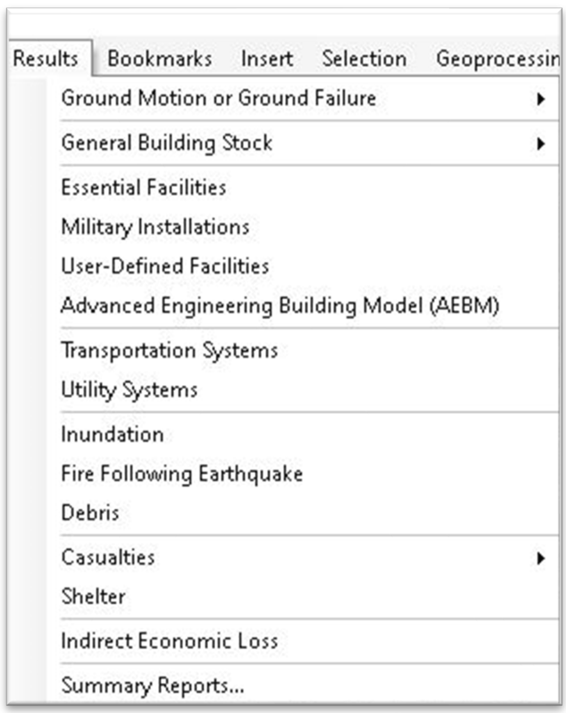
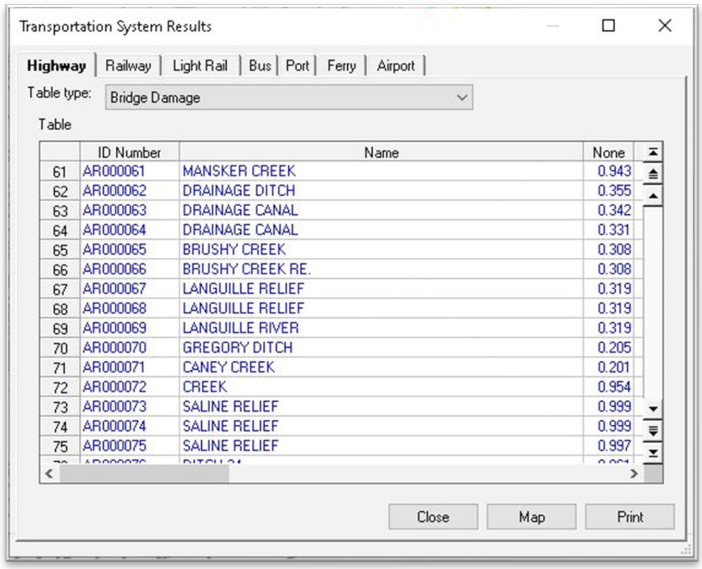


Figure 16: Results Tab in Hazus



	ID Number	Name	None
61	AR000061	MANSKER CREEK	0.943
62	AR000062	DRAINAGE DITCH	0.355
63	AR000063	DRAINAGE CANAL	0.342
64	AR000064	DRAINAGE CANAL	0.331
65	AR000065	BRUSHY CREEK	0.308
66	AR000066	BRUSHY CREEK RE.	0.308
67	AR000067	LANGUILLE RELIEF	0.319
68	AR000068	LANGUILLE RELIEF	0.319
69	AR000069	LANGUILLE RIVER	0.319
70	AR000070	GREGORY DITCH	0.205
71	AR000071	CANEY CREEK	0.201
72	AR000072	CREEK	0.954
73	AR000073	SALINE RELIEF	0.999
74	AR000074	SALINE RELIEF	0.999
75	AR000075	SALINE RELIEF	0.997

Figure 17: Facility Results in Hazus

To further analyze Hazus' results after successfully completing an analysis, ArcMap (or QGIS) may be used. Hazus comes with a tool pre-installed called the "Hazus Export Tool" (Figure 18) (FEMA, 2020). This tool, very well-named, allows users to export their Hazus study regions as geodatabase files. These geodatabase files contain all of the facilities from the study region. Those individual maps can then be opened in GIS software like ArcMap or QGIS.

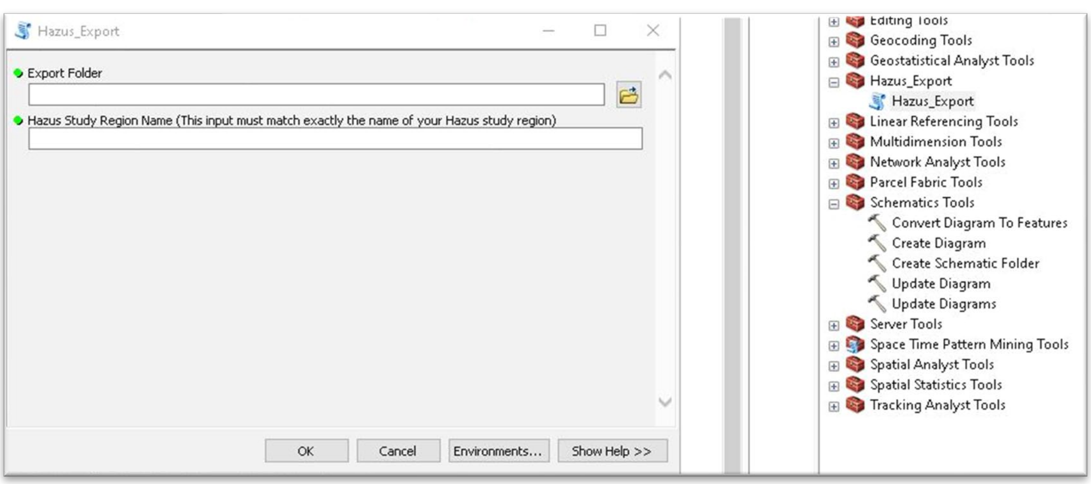


Figure 18: Hazus Export Tool

Section 3.4 ***Impact Quantification***

The goal of this section is to quantify the results of the user's Hazus simulation in terms of charts, tables, or maps that showcase damage to certain areas of interest—like specific links in a roadway network, or number of miles affected. Although Hazus is capable of viewing and analyzing the data maps within the program (it is an ArcGIS based program of course), depending on the size of the study region and number of items displayed, the program can become slow and tedious to use. Exporting the results for analysis in another program is a better alternative. The attribute tables of the maps alone can be exported into programs like Microsoft Excel or Power Bi and data processing such as creating graphs, interpreting results on maps, and estimating economic losses can be completed there.

Hazus itself can generate reports for the results of a scenario (Figure 19). The main all-encompassing report to generate is the "Global Summary Report." This report summarizes the number of facilities in the analysis, shows hazard maps, and shows overall lost estimate and total damages for each facility system. It is a good "big picture" umbrella report; however, based on research need and priorities, external impact quantification through another program is likely a better alternative (FEMA, 2020).

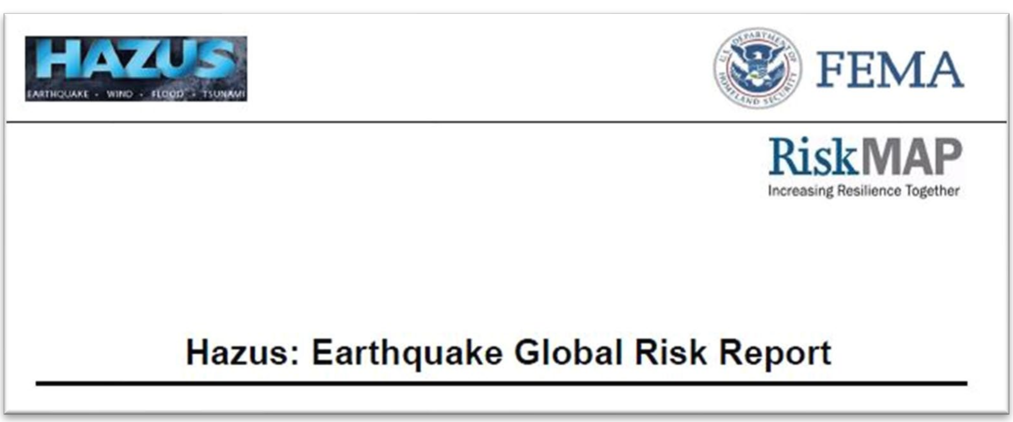


Figure 19: Global Summary Report

Chapter 4: Results

The sections described in the method chapter were followed to complete a simulation of a magnitude 7.7 earthquake in the New Madrid Seismic Zone. The results of the analysis will be presented as maps and summary statistics as tables, figures, and charts. The goal is to quantify the damage expected from an earthquake event on the AR highway system, summarizing the number of links, the total mileage, and the types of links impacted.

Data that needed to be acquired prior to beginning the analysis were related to highway network links and ground failure. The highway network used was not the provided system from the National Highway System that comes in Hazus; rather, a network of roadway links for the state of Arkansas was created by a graduate student from the University of Arkansas. Below is a screenshot of the network in Figure 20

Although ground failure maps (related to landslides and liquefaction) were initially created for this analysis as described in the methods section, further research and contact with the Arkansas Geological Survey resulted in already-made shapefiles that contained landslide and liquefaction maps. Those already-made shapefiles were used for the magnitude 7.7 earthquake simulation.

Figure 21 and Figure 22 below are the landslide map from U.S. Geological Survey and the liquefaction map from the Arkansas Geological Survey. The landslide map (Figure 21) was modified slightly from the U.S. Geological Survey to include polygons with a higher susceptibility value due to the occurrence of past landslides in those areas documented by the Arkansas Department of Transportation (see Figure 23 below).

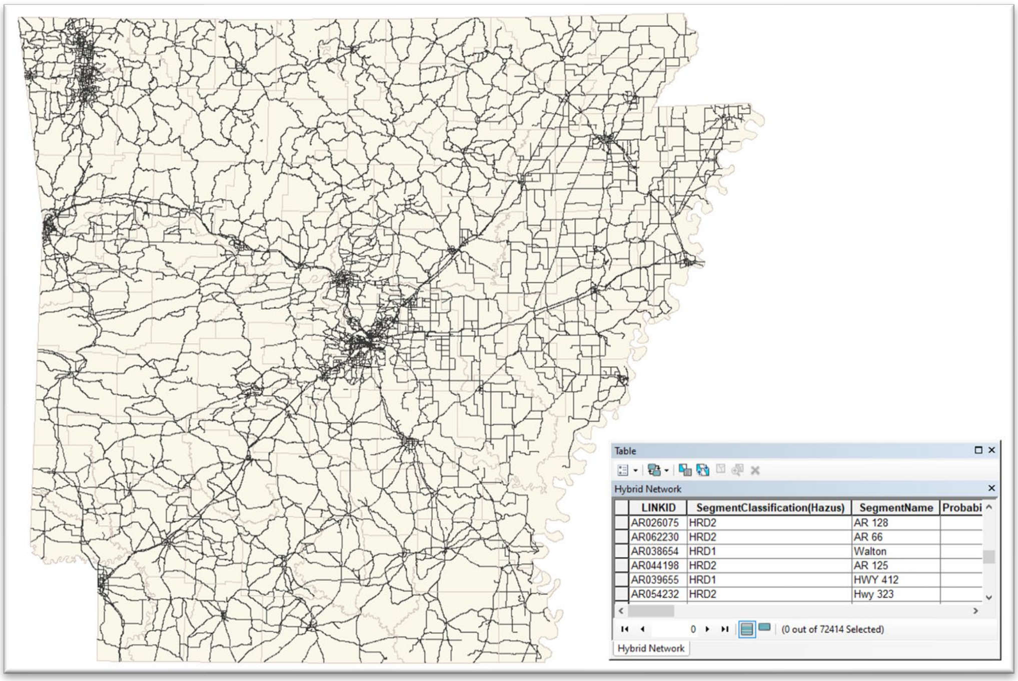


Figure 20: Hybrid Network

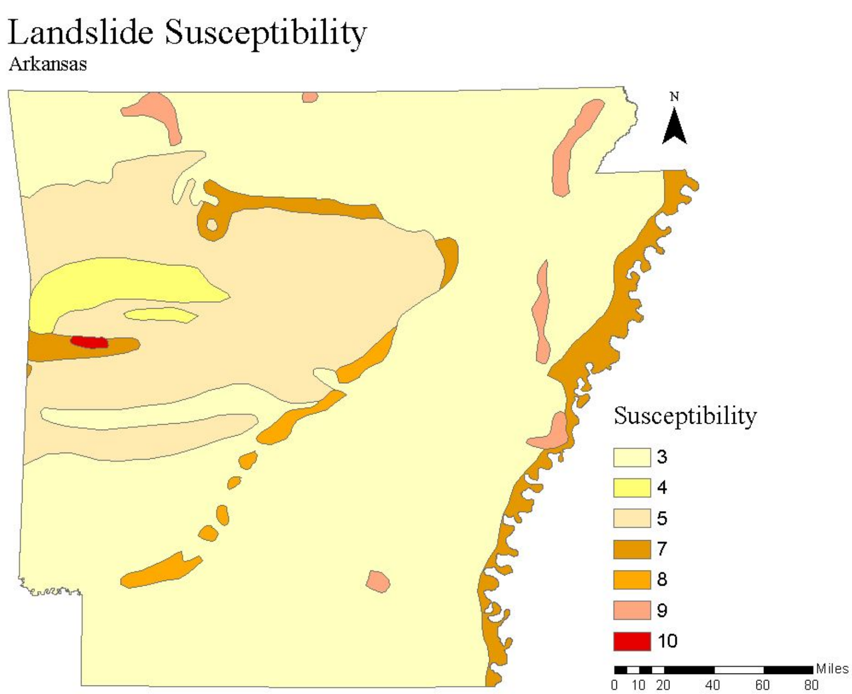


Figure 21: USGS Landslide Map (REF: USGS, 2021)

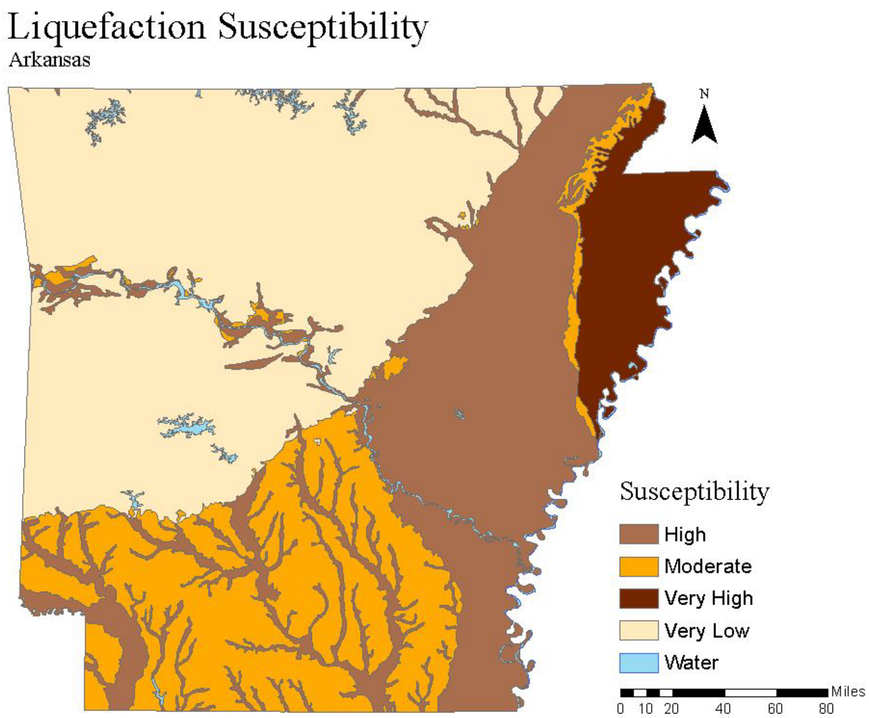


Figure 22: Liquefaction Susceptibility (REF: Ausbrooks & Doerr, 2010)

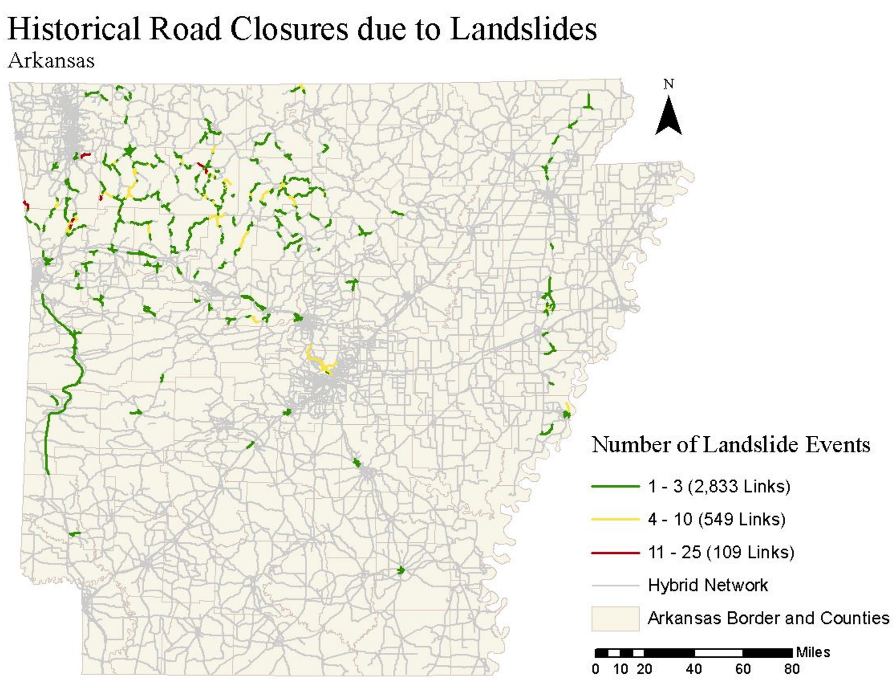


Figure 23: Arkansas Department of Transportation Historical Landslides

This network (Figure 20) is a combination of the All Roads Network of Linear Referenced Data (ARNOLD) network and the Arkansas Travel Demand Model (AR TDM) network. It contains over 72,000 links and it was imported into Hazus for the analysis via the CDMS.

An important part of the transportation system in Arkansas apart from roads are bridges and culverts (typically referred to as "assets"). They allow for roads to cross bodies of water safely and if they fail, can pose threats to drivers and mobility of the road network. Because of their importance, damages were simulated for the bridges and culverts as well. Figure 24 depicts a map of the almost 13,000 assets (bridges and culverts) in the state.

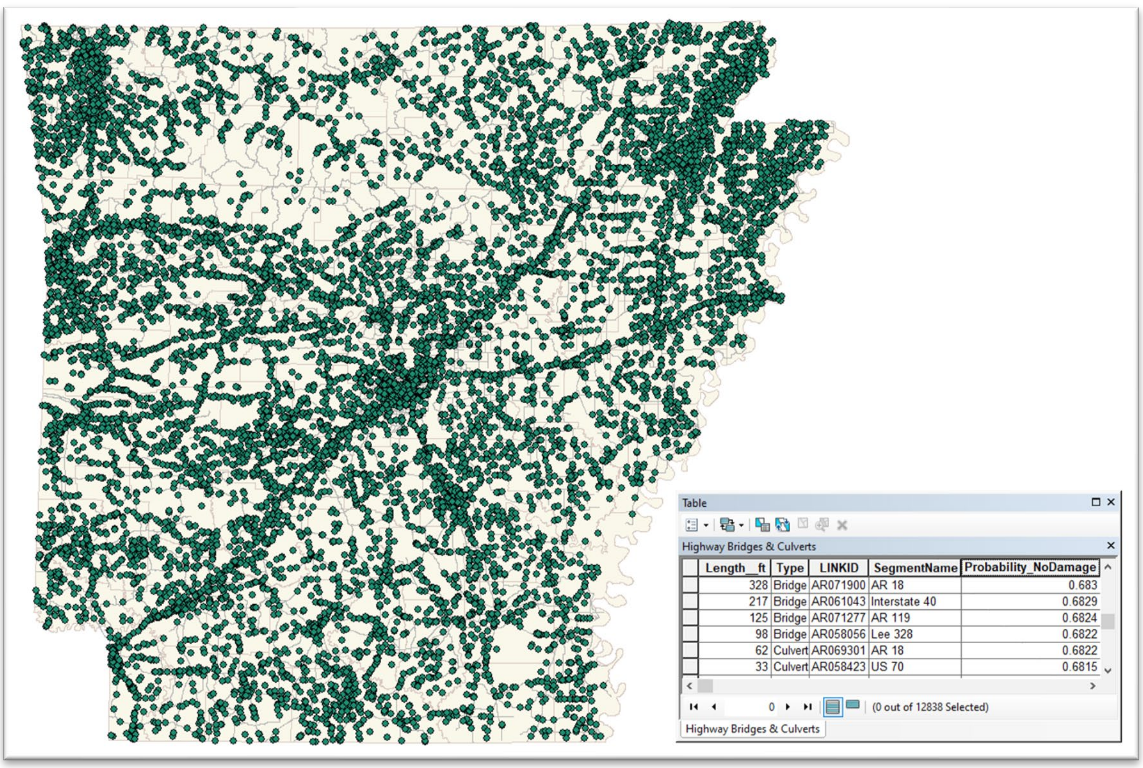


Figure 24: Highway Assets

Results from this HAZUS analysis, gathered in the Global Summary Report below in Table 3, depict total estimated earthquake damages to the transportation system alone to be approximately $4 billion dollars.

Table 3: Global Summary Report Analysis Results

(Millions of dollars)

System	Component	Inventory Value	Economic Loss	Loss Ratio (%)
Highway	Segments	126287.3825	3194.9013	2.53
	Bridges	27079.9182	778.3173	2.87
	Tunnels	48.7778	0.0000	0.00
	Subtotal	**153416.0785**	**3973.2186**	
Railways	Segments	6634.2255	0.0000	0.00
	Bridges	8900.4345	0.0000	0.00
	Tunnels	0.0000	0.0000	0.00
	Facilities	79.8900	0.0000	0.00
	Subtotal	**15614.5500**	**0.0000**	
Light Rail	Segments	0.0000	0.0000	0.00
	Bridges	0.0000	0.0000	0.00
	Tunnels	0.0000	0.0000	0.00
	Facilities	0.0000	0.0000	0.00
	Subtotal	**0.0000**	**0.0000**	
Bus	Facilities	25.9157	0.0000	0.00
	Subtotal	**25.9157**	**0.0000**	
Ferry	Facilities	2.6620	0.0000	0.00
	Subtotal	**2.6620**	**0.0000**	
Port	Facilities	580.9335	0.0000	0.00
	Subtotal	**580.9335**	**0.0000**	
Airport	Facilities	601.9909	0.0000	0.00
	Runways	4355.7941	0.0000	0.00
	Subtotal	**4957.7850**	**0.0000**	
	Total	**174,597.92**	**3,973.22**	

Of those nearly $4 billion dollars, the majority come from damages associated with the highway segments themselves.

With regard to assets, i.e., bridges and culverts, the majority of the likelihood of damages lie in the northeastern region of Arkansas closest to the NMSZ. Figure 25 and Figure 26 below depict the probability of any asset damage as well as the probability of complete asset damage. Complete asset damage refers to the asset being totally unusable whereas "any damage" refers to the probability of damage occurring to that asset being greater than zero percent.

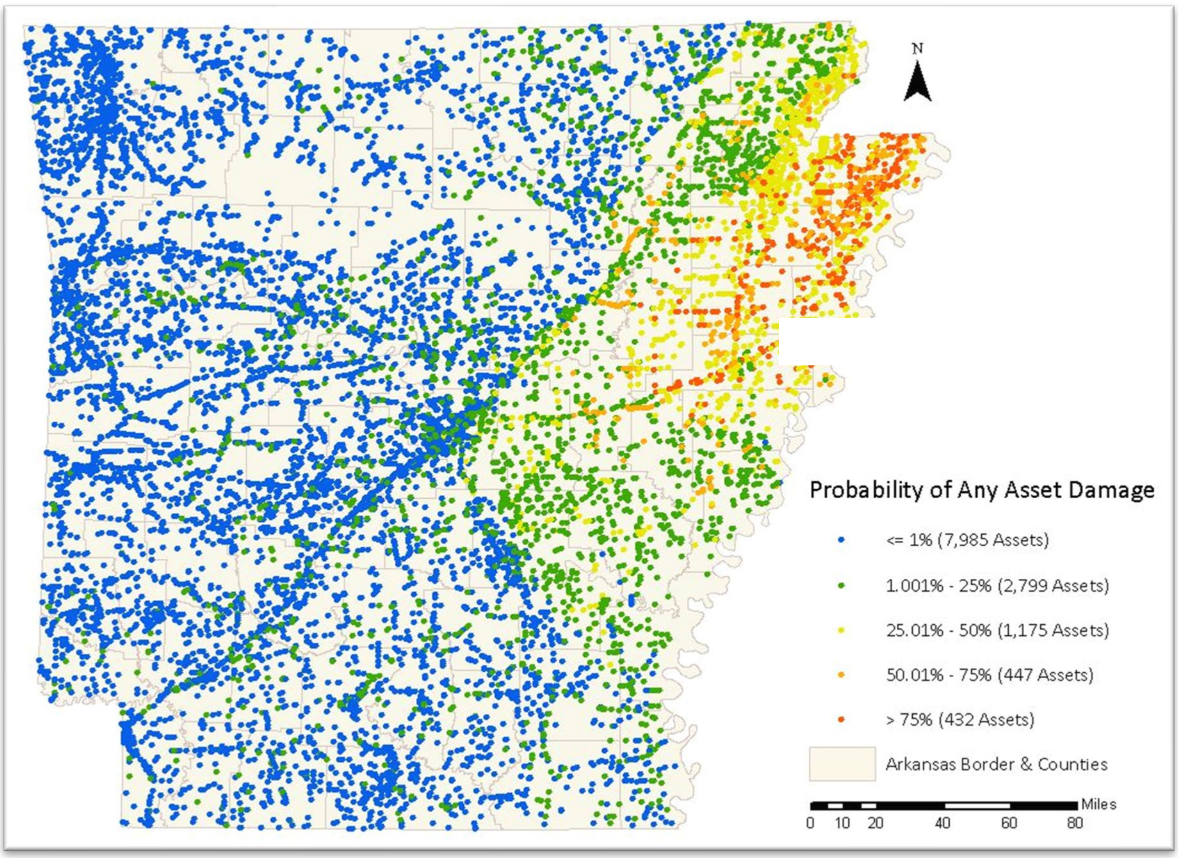


Figure 25 Any Asset Damage Map

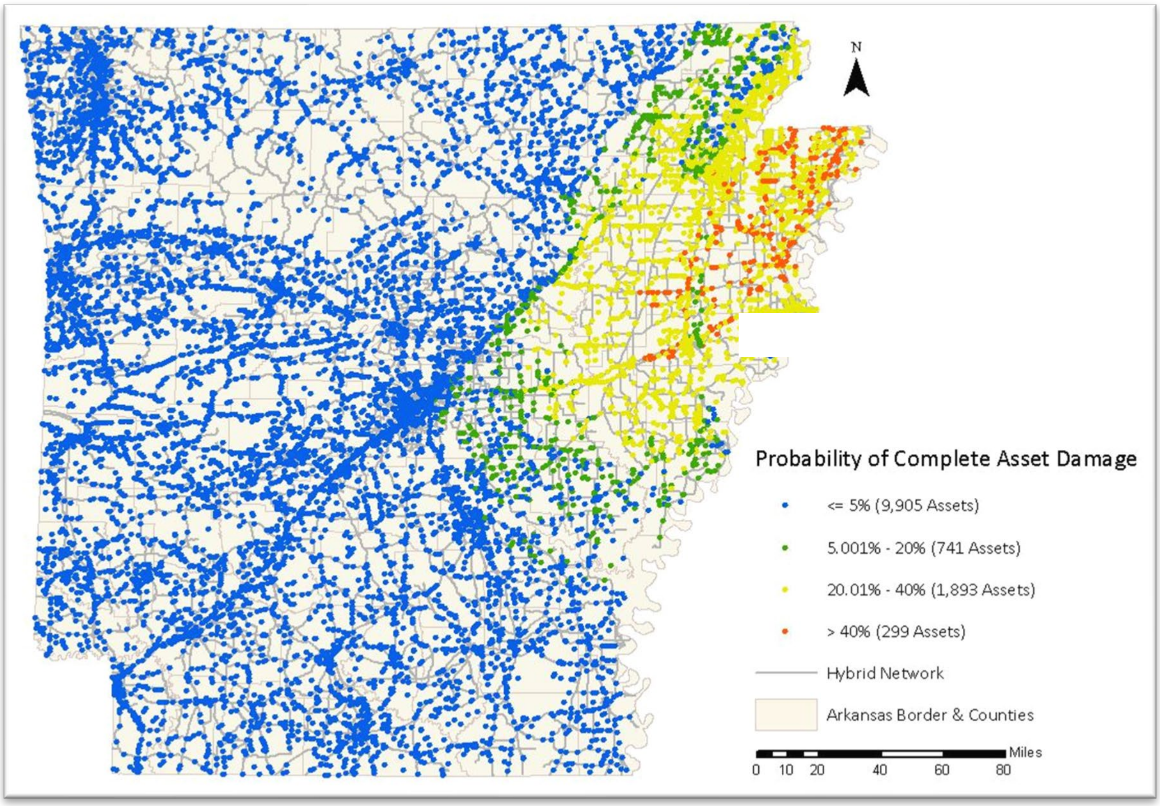


Figure 26 Complete Asset Damage Map

Regarding earthquake damage to the highway segments themselves, over $3 billion total dollars in damages are predicted. That cost comes from approximately 23,000 miles of affected highway. The top 25 counties in terms of overall economic loss with their corresponding affected length of highway miles is shown in Figure 27. That information has been normalized to depict the top 25 counties in terms of economic loss per mile of affected highway (Figure 28).

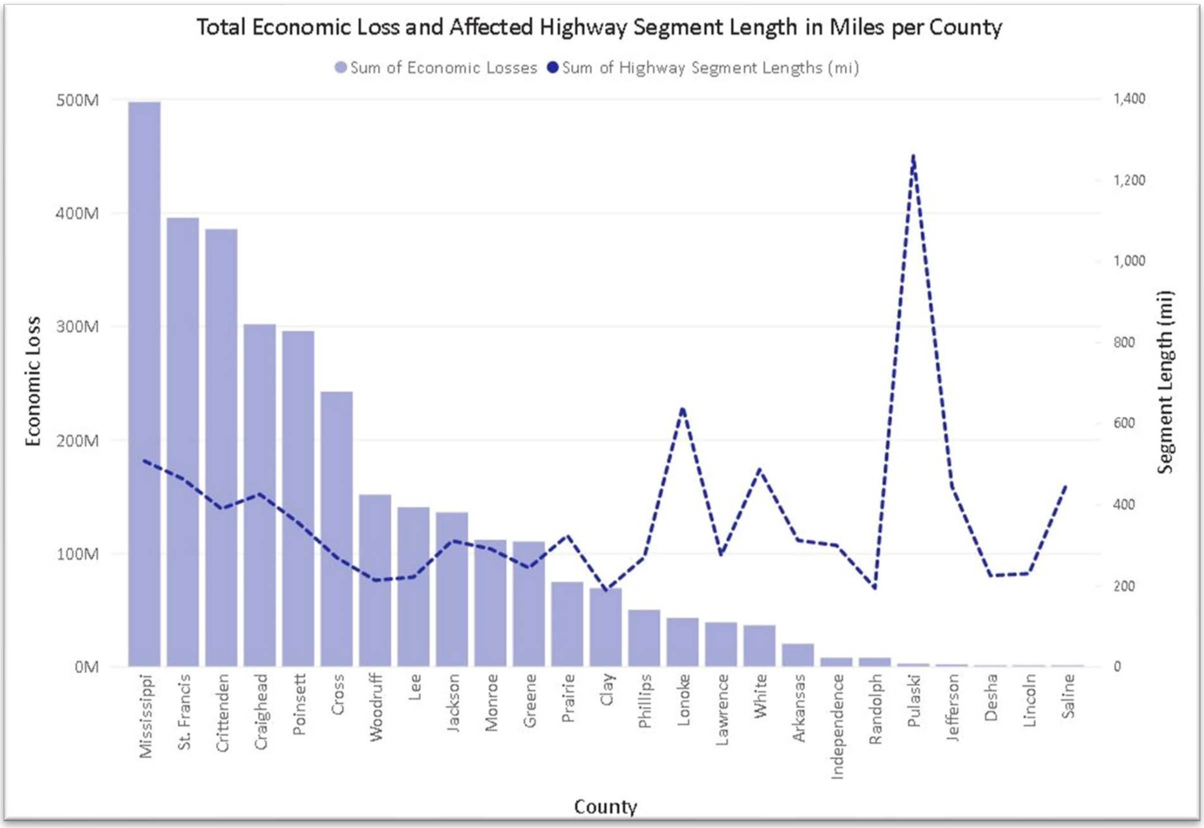


Figure 27 Total Economic Loss per County

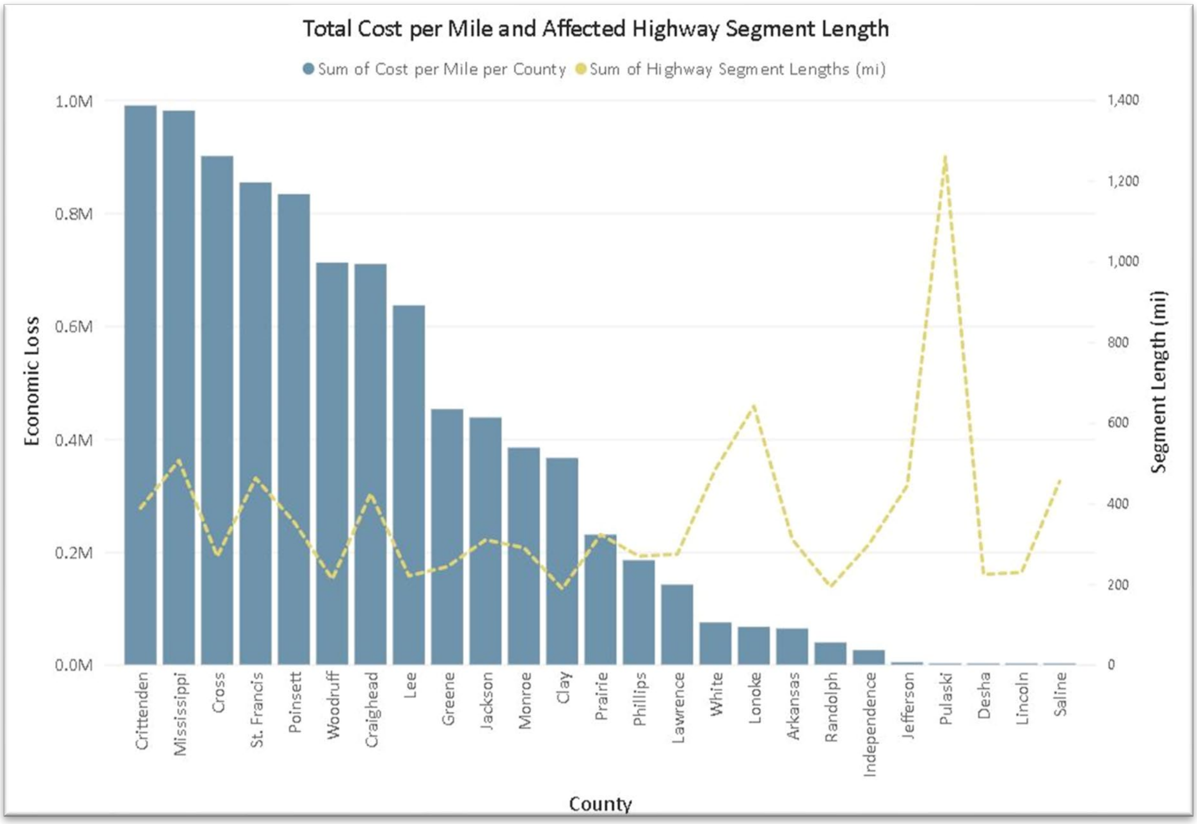


Figure 28 Normalized Losses per County

Whether viewing economic loss per mile of highway per county, or as a cumulative loss, both graphs above have similar counties within the top five most economically affected. This is likely due to the proximity of the epicenter of the earthquake as the cumulative number of affected miles is much less than a county like Lonoke or Pulaski. The order of the counties does change between figures, but not by a significant amount. Those top 25 counties tend to remain in the top 25 due to the amount of impact an earthquake would have on them based solely on location.

The functional classifications of the affected highway segments are an important aspect to consider. Damaged interstate highway segments would cause bigger disruptions to overall driver mobility and freight movement than something like a collector road segment; therefore, it can be useful to visualize the breakdown of affected links in terms of their functional classifications. Figure 29 outlines the highway segment functional classifications that are affected by the simulated NMSZ earthquake.

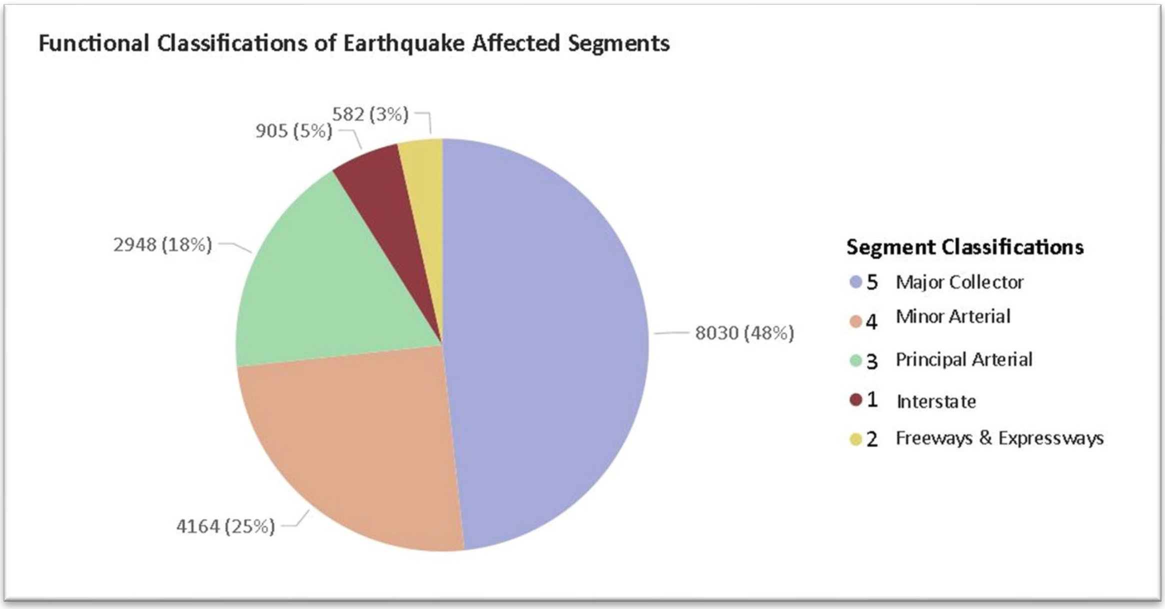


Figure 29 Functional Classifications of Earthquake Affected Links

Chapter 5: Discussion

The results of the analysis showed that a large magnitude earthquake in the New Madrid Seismic Zone would have dangerous and costly affects. The counties that would be most affected are those that are located nearest to the NMSZ, though, consequences of such an event would be felt across the state. Not only are highway segments in danger, but buildings, bridges, schools, airports, and anything else attached to the ground are at a risk of being destroyed. Though the majority of the affected links fall under a major collector or minor arterial functional classification, those roads serve to mobilize the citizens of Arkansas. Damage to those links could halt emergency operations and access to safer areas. Furthermore, there is damage to nearly 1,000 interstate and over 2,900 principal arterial road links. These links, while absolutely important to civilians, are key in moving goods across the state. The financial impact of damages on those links could easily have losses in the billions of dollar range as seen with the Mississippi River flooding in 2011 (NOAA, 2011).

In the same vein as link damage, asset damage and functionality is also significant. Nearly 300 assets are at a greater than 40% chance of complete damage—meaning little to no functionality—in the case of a large earthquake. Those bridges and culverts are hydraulic conduits that allow people to safely travel over them. If they fail, people and goods can become stranded.

Chapter 6: Conclusion

Earthquakes are a dangerous fact of life that can occur almost anywhere and at any time. A large magnitude earthquake in the New Madrid Seismic Zone would have devastating damage to not only Arkansas, but Missouri, Mississippi, Tennessee, and other surrounding states. Those damages will have lasting effects on individuals, infrastructure, and the economy of those regions. Attempting to understand and predict the potential effects of such an event is the primary motivation of this study. Specific to Arkansas, the simulated large magnitude earthquake produced damages upwards of $3 billion to the transportation system alone. These costs relate to replacement costs and projected damage, not necessarily to how infrastructure damage may influence freight movement, emergency operations, and overall mobility in the state.

Identifying and planning for potential damage from such a disaster, especially considering the time since the last large earthquake event and likelihood of another in the not-so-distant future, should be important to any state department of transportation. The purpose of this analysis was to simulate a large magnitude earthquake and visualize the impacts on the highway network of Arkansas. To simulate that event, regional landslide, liquefaction, and soil data had to be gathered to better apply the widely available and increasingly popular natural disaster modeling tool called HAZUS-MH, or simply, Hazus. The results produced by Hazus in this analysis established that many billions of dollars in physical damages to the transportation system alone were likely to occur in a large magnitude earthquake event. Among those billions of dollars in damages, are over 23,000 miles of affected roadways, hundreds of severely damaged bridges and culverts, and number of lost lives and affected families.

The major importance of this thesis was identifying a tool that can be applied and adapted to utilize data gathered by a user to run an accurate and meaningful natural disaster simulation for a specific region. This program can be manipulated to fit a variety of regions and produce hazard results based on research needs. The current limitations of the program lie mainly in the data gathering area and flood hazard utilization. Though an analysis can be run using facilities provided by FEMA, determining results more accurate to your needs and region can require months of data gathering and compilation. For other hazard modeling like flooding, more detailed data regarding building types, soil structure, and flood maps are required. If not readily available, the time to locate and/or create these things can be costly. Furthermore, flooding is another natural hazard capable of greatly disrupting the transportation system. Currently, Hazus is incapable of running simulations that identify damage to roadway links due to flooding. This information could be valuable as shown again by the Mississippi River flooding event in 2011 in Arkansas. Despite these current limitations, the functionality and future potential of this program is clear. Future research in the area of emergency management and planning can absolutely make use of this program. Identifying areas of higher vulnerability and damage susceptibility can allow researchers, engineers, and state departments to determine what roads, structures, and assets are most at risk and proactively make decisions that can mitigate potential damages.

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