



TRC2303

Evaluation of Impacts Due to a Bridge Closure: A Case Study of the Mississippi River Bridges in Arkansas

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University of Arkansas - Fayetteville
College of Engineering, Department of Civil Engineering

Final Report

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Arkansas Department of Transportation

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16. Abstract The TRC 2303 report presents a comprehensive analysis of the impacts of bridge closures across the Mississippi River in Arkansas, focusing on four key crossings: I-40, I-55, HWY 49, and HWY 82. Prompted by the emergency closure of the I-40 Hernando de Soto Bridge in 2021, the study evaluates both full and partial closures to quantify economic, safety, and mobility consequences. Using ARDOT's Road User Cost (RUC) framework and the Arkansas Statewide Travel Demand Model (ARSTDM), the report estimates daily costs and system-level changes in Vehicle Hours Traveled (VHT) for autos, single-unit trucks (SUT), and tractor-trailer trucks (TTT). Partial closures of high-volume bridges like I-40 and I-55 result in substantial daily costs, e.g., up to \$2.4 million for I-40 along with widespread VHT increases. This is especially so for TTT, for which 6,902 miles of roadway exhibited more than a 4% increase in VHT under the I-40 closure scenario. In contrast, HWY 49 and HWY 82 closures had more localized effects, with HWY 82 showing the highest auto and SUT impacts but minimal freight disruption. Waterway disruption costs, derived from Automatic Identification System (AIS) data, also rose sharply between 2021 and 2024, with HWY 49 carrying the highest vessel volumes and HWY 82 showing the fastest growth. To support planning, the study delivered a web-based Bridge Closure Impact Analysis Tool that automates cost calculations and visualizes impacts. Mitigation strategies include operational measures, maintenance practices, and planning-based approaches, with partial closures recommended where feasible. Overall, the report equips ARDOT with data-driven tools to prioritize investments, manage emergencies, and maintain transportation resilience across river crossings.			
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METRIC CONVERSIONS

SI* (MODERN METRIC) CONVERSION FACTORS				
APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in ²	square inches	645.2	square millimeters	mm ²
ft ²	square feet	0.093	square meters	m ²
yd ²	square yard	0.836	square meters	m ²
ac	acres	0.405	hectares	ha
mi ²	square miles	2.59	square kilometers	km ²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft ³	cubic feet	0.028	cubic meters	m ³
yd ³	cubic yards	0.765	cubic meters	m ³
NOTE: volumes greater than 1000 L shall be shown in m ³				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m ³	cubic meters	35.314	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

CONTENTS

List of Figures.....	vi
List of Tables.....	xi
List Of Abbreviations, Acronyms, and Symbols	xii
Executive Summary	1
Chapter 1. Project Overview	6
Structure of the Report	6
Background	6
Project Objectives.....	13
Chapter 2. Analysis of the Hernando De Soto Bridge Closure.....	15
Description of Data Sources and Acquired Data.....	15
Analysis of Passenger Vehicle OD Using Third-party Probe Data	16
Analysis of Commercial Vehicle OD Using Third-party Probe Data	20
Chapter 3. Analysis of Possible Bridge Closure Scenarios	25
Methods Adopted for Arkansas Bridge Closures	25
Analysis of Multimodal Impacts for Mississippi River Bridges in Arkansas.....	32
Summary of Findings	65
Chapter 4. Implementation	72
Bridge Closure Impact Analysis Tool.....	72
Mitigative Solutions for Minimizing the Impact of Closures.....	75
Chapter 5. Conclusions.....	79
Chapter 6. References.....	83
Appendix A. Observed Travel Patterns During the I-40 Bridge Closure	A-1
Appendix B. Methods for Multimodal Impact Assessment for Bridge Closures	B-1
Appendix C. Inputs, Assumptions, and Application of the Road User Cost (RUC) Analysis Tool	C-1

LIST OF FIGURES

Figure 1. Comparison of Daily Full and Partial Road User Costs by Bridge.....	2
Figure 2. Mileage of Network with Zero Percent Change in VHT During Closure of Each Bridge.....	4
Figure 3. Mileage of Network with Four or More Percent Change in VHT During Closure of Each Bridge ...	4
Figure 4. Estimated waterway disruption costs per 24-hour closure (2021 vs 2024)	5
Figure 5. Brent Spence Bridge location	8
Figure 6. Percent of traffic and average travel time across three bridges in Pennsylvania.....	9
Figure 7. Overview of a traditional four-step travel demand model.....	10
Figure 8. Arkansas Bridges spanning the Mississippi River.....	12
Figure 9. Example AADT count stations for the Hernando de Soto and Memphis-Arkansas Bridges (Ref: ARDOT, 2022).....	13
Figure 10. Comparison of Passenger Vehicle Flows from TAZs to the I-40 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 Bridge Closure	17
Figure 11. Comparison of Passenger Vehicle Flows from TAZs to the I-55 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 Bridge Closure	18
Figure 12. Comparison of Passenger Vehicle Flows from TAZs to the HWY 49 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 Bridge Closure	19
Figure 13. Comparison of Passenger Vehicle Flows from TAZs to the HWY 82 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 Bridge Closure	20
Figure 14. Comparison of Average Daily Commercial Vehicle Flows from TAZs to the I-40 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 bridge closure	21
Figure 15. Comparison of Average Daily Commercial Vehicle Flows from TAZs to the I-55 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 bridge closure	22
Figure 16. Comparison of Average Daily Commercial Vehicle Flows from TAZs to the HWY 49 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 bridge closure	23
Figure 17. Comparison of Average Daily Commercial Vehicle Flows from TAZs to the HWY 82 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 bridge closure	24
Figure 18. From raw data to vessel tracks at the I-40 bridge. The scattered points on the left are processed to create the clear vessel trajectories shown on the right.....	31
Figure 19. Study Area States Selected to Assess the I-40, I-55, HWY 49, and HWY 82 Bridges.....	37
Figure 20. Cumulative Distribution of Percentage Change in VHT Across Each Vehicle Type on Scenario 1223, I-40 Full Bridge Closure	40
Figure 21. Percentage Difference in VHT for Autos During the PM Period Under a Full Closure of the I-40 Bridge	41
Figure 22. Percentage Difference in VHT for SUT During the PM Period Under a Full Closure of the I-40 Bridge	42

Figure 23. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the I-40 Bridge (Arkansas View)	43
Figure 24. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the I-40 Bridge (Whole Study Area View).....	44
Figure 25. Percentage Difference in VHT for Autos During the PM Period Under a Full Closure of the I-55 Bridge	45
Figure 26. Percentage Difference in VHT for SUT During the PM Period Under a Full Closure of the I-55 Bridge	46
Figure 27. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the I-55 Bridge (Arkansas View)	47
Figure 28. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the I-55 Bridge (Whole Study Area View)	48
Figure 29. Percentage Difference in VHT for Autos During the PM Period Under a Full Closure of the HWY 49 Bridge	49
Figure 30. Percentage Difference in VHT for SUT During the PM Period Under a Full Closure of the HWY 49 Bridge	50
Figure 31. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the HWY 49 Bridge (Arkansas View)	51
Figure 32. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the HWY 49 Bridge (Whole Study Area View)	52
Figure 33. Percentage Difference in VHT for Autos During the PM Period Under a Full Closure of the HWY 82 Bridge	53
Figure 34. Percentage Difference in VHT for SUT During the PM Period Under a Full Closure of the HWY 82 Bridge	54
Figure 35. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the HWY 82 Bridge (Arkansas View)	55
Figure 36. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the HWY 82 Bridge (Whole Study Area View)	56
Figure 37. Scenario 1350 – Percentage Difference in VHT for Autos During the AM Period.....	57
Figure 38. Scenario 1350 – Percentage Difference in VHT for SUT During the AM Period.....	58
Figure 39. Scenario 1350 – Percentage Difference in VHT for TTT During the AM Period (Arkansas View)	59
Figure 40. Scenario 1350 – Percentage Difference in VHT for TTT During the AM Period (Study Area View)	60
Figure 41. AADT for vessels at four bridge locations, comparing volumes for 2021 and 2024	62
Figure 42. I-40 Vessel Traffic by Month for 2021 and 2024.....	62
Figure 43. I-55 Vessel Traffic by Month for 2021 and 2024.....	63
Figure 44. HWY 49 Vessel Traffic by Month for 2021 and 2024.....	64

Figure 45. HWY 82 Vessel Traffic by Month for 2021 and 2024.....	65
Figure 46. Summary of Road User Costs by Bridge and Closure Type.....	67
Figure 47. Estimated Road User Costs by Bridge and Closure Duration under Full Closure Scenario	68
Figure 48. Estimated Road User Costs by Bridge and Closure Duration under Partial Closure Scenario	68
Figure 49. 30-Day Delay, Operational, and Detour Costs by Bridge under Full Closure Scenario	69
Figure 50. 30-Day Delay, Operational, and Detour Costs by Bridge under Partial Closure Scenario.....	70
Figure 51. Interface for configuring single- and multi-bridge closure scenarios to analyze regional traffic redistribution.....	73
Figure 52. Screenshot of the "Summary" page of the Bridge Closure Impact Assessment Tool.....	74
Figure 53. Screenshot of the dynamic and interactive map within the Bridge Closure Impact Assessment Tool.....	74
Figure A-1. OD Flows to and from I-40 for April 15 through 30, 2021.....	A-2
Figure A-2. OD Flows to and from I-40 for May 11 through July 31, 2021	A-3
Figure A-3. D Flows to and from I-40 for August 1 through August 6, 2021	A-4
Figure A-4. OD Flows to and from I-40 for October 15 through October 30, 2021.....	A-5
Figure A-5. OD Flows to and from I-40 for January 1 through 30, 2022.....	A-6
Figure A-6. OD Flows to and from I-40 for April 15 through 30, 2022.....	A-7
Figure A-7. OD Flows to and from I-40 for July 15 through 30, 2022	A-8
Figure A-8. OD Flows to and from I-40 for October 15 through 30, 2022	A-9
Figure A-9. OD Flows to and from I-55 for April 15 through 30, 2021.....	A-10
Figure A-10. OD Flows to and from I-55 for May 15 through July 31, 2021	A-11
Figure A-11. OD Flows to and from I-55 for August 1 through 6, 2021	A-12
Figure A-12. OD Flows to and from I-55 for October 15 through 30, 2021.....	A-13
Figure A-13. OD Flows to and from I-55 for January 15 through 30, 2022.....	A-14
Figure A-14. OD Flows to and from I-55 for April 15 through 30, 2022.....	A-15
Figure A-15. OD Flows to and from I-55 for July 15 through 30, 2022	A-16
Figure A-16. OD Flows to and from I-55 for October 15 through 30, 2022	A-17
Figure A-17. OD Flows to and from HWY 49 for April 15 through 30, 2021.....	A-18
Figure A-18. OD Flows to and from HWY 49 for May 15 through July 31, 2021	A-19
Figure A-19. OD Flows to and from HWY 49 for August 1 through 6, 2021	A-20
Figure A-20. OD Flows to and from HWY 49 for October 15 through 30, 2021	A-21
Figure A-21. OD Flows to and from HWY 49 for January 1 through 30, 2022	A-22
Figure A-22. OD Flows to and from HWY 49 for April 15 through 30, 2022	A-23

Figure A-23. OD Flows to and from HWY 49 for July 15 through 30, 2022	A-24
Figure A-24. OD Flows to and from HWY 49 for October 15 through 30, 2022	A-25
Figure A-25. OD Flows to and from HWY 82 for April 15 through 30, 2021	A-26
Figure A-26. OD Flows to and from HWY 82 for May 11 through July 31, 2021	A-27
Figure A-27. OD Flows to and from HWY 82 for August 1 through 6, 2021	A-28
Figure A-28. OD Flows to and from HWY 82 for October 15 through 30, 2021	A-29
Figure A-29. OD Flows to and from HWY 82 for January 15 through 30, 2022	A-30
Figure A-30. OD Flows to and from HWY 82 for April 15 through 30, 2022	A-31
Figure A-31. OD Flows to and from HWY 82 for July 15 through 30, 2022	A-32
Figure A-32. OD Flows to and from HWY 82 for October 15 through 30, 2022	A-33
Figure A-33. Comparison of Passenger Vehicle Flows from I-40 bridge to the TAZs (A) and from TAZs to the I-40 bridge (B) (April 15-30, 2021)	A-34
Figure A-34. Comparison of Passenger Vehicle Flows from I-40 bridge to the TAZs (A) and from TAZs to the I-40 bridge (B) (May 11 through July 31, 2021)	A-35
Figure A-35. Comparison of Passenger Vehicle Flows from I-40 bridge to the TAZs (A) and from TAZs to the I-40 bridge (B) (August 01-06, 2021)	A-36
Figure A-36. Comparison of Passenger Vehicle Flows from I-40 bridge to the TAZs (A) and from TAZs to the I-40 bridge (B) (October 15-30, 2021)	A-37
Figure A-37. Comparison of Passenger Vehicle Flows from I-55 bridge to the TAZs (A) and from TAZs to the I-55 bridge (B) (April 15-30,2021)	A-38
Figure A-38. Comparison of Passenger Vehicle Flows from I-55 bridge to the TAZs (A) and from TAZs to the I-55 bridge (B) (May 11 through July 31, 2021)	A-39
Figure A-39. Comparison of Passenger Vehicle Flows from I-55 bridge to the TAZs (A) and from TAZs to the I-55 bridge (B) (August 01-06,2021)	A-40
Figure A-40. Comparison of Passenger Vehicle Flows from I-55 bridge to the TAZs (A) and from TAZs to the I-55 bridge (B) (October 15-30, 2021)	A-41
Figure A-41. Comparison of Passenger Vehicle Flows from HWY 49 bridge to the TAZs (A) and from TAZs to the HWY 49 bridge (B) (April 15-30,2021)	A-42
Figure A-42. Comparison of Passenger Vehicle Flows from HWY 49 bridge to the TAZs (A) and from TAZs to the HWY 49 bridge (B) (May 11 through July 31, 2021)	A-43
Figure A-43. Comparison of Passenger Vehicle Flows from HWY 49 bridge to the TAZs (A) and from TAZs to the HWY 49 bridge (B) (August 01-06, 2021)	A-44
Figure A-44. Comparison of Passenger Vehicle Flows from HWY 49 bridge to the TAZs (A) and from TAZs to the HWY 49 bridge (B) (October 15-30,2021)	A-45
Figure A-45. Comparison of Passenger Vehicle Flows from HWY 82 bridge to the TAZs (A) and from TAZs to the HWY 82 bridge (B) (April 15-30,2021)	A-46

Figure A-46. Comparison of Passenger Vehicle Flows from HWY 82 bridge to the TAZs (A) and from TAZs to the HWY 82 bridge (B) (May 11 through July 31,2021)	A-47
Figure A-47. Comparison of Passenger Vehicle Flows from HWY 82 bridge to the TAZs (A) and from TAZs to the HWY 82 bridge (B) (August 01-06,2021)	A-48
Figure A-48. Comparison of Passenger Vehicle Flows from HWY 82 bridge to the TAZs (A) and from TAZs to the HWY 82 bridge (B) (October 15-30,2021)	A-49
Figure B-1. Organization of Literature Review.....	B-1
Figure C - 1. Example Inputs to the Traffic Tab	C-4
Figure C - 2. Screenshot of the Economic Cost Tab	C-4
Figure C - 3. Screenshot showing inputs of the crash tab.....	C-5
Figure C - 4. Screenshot showing Detour Cost Tab with inputs.....	C-7
Figure C - 5. Figure Showing Summary of Results from all Inputs	C-8

LIST OF TABLES

Table 1. Arkansas Bridges over the Mississippi River and their Traffic Characteristics	11
Table 2. Geographic Scope of Probe Data by Bridge	15
Table 3. Traffic Data Collection Summary	26
Table 4. ARSTDM Time Periods	27
Table 5. Data Set Variables (Applicable to Both Scenarios).....	28
Table 6. Network Detour Costs for I-40 Full Bridge Closure (Per Day)	33
Table 7. Detailed User Costs for I-40 Partial Bridge Closure (Per Day)	33
Table 8. Detailed User Costs for I-55 Full Bridge Closure (Per Day).....	34
Table 9. Detailed User Costs for I-55 Partial Bridge Closure (Per Day)	34
Table 10. Detailed User Costs for HWY 49 Full Bridge Closure (Per Day).....	35
Table 11. Detailed User Costs for HWY 82 Full Bridge Closure (Per Day)	36
Table 12. Lane Availability by Direction and Bridge for Each Scenario.....	37
Table 13. Estimated 24-hour waterway closure cost by bridge for 2021 and 2024	61
Table 14. Summary Estimated Daily Road User Costs for Full and Partial Closures	66
Table 15. Categories of operational mitigative solutions to roadway closures.....	75
Table 16. Categories of maintenance-based mitigative solutions to roadway closures.....	76
Table 17. Categories of planning-based mitigative solutions to roadway closures.....	78
Table B-1. Survey and Interview-Based Studies on Disruption to the Transportation System	B-3
Table B-2. Data Sources to Evaluate Traffic Operations During Bridge Closures	B-5
Table B-3. Travel Demand Model Applications for Bridge Closure Events	B-7
Table B-4. Simulation Models for Waterway Closure Events	B-9
Table B-5. Roadway User Cost Models Applied to Bridge Closure Events	B-10
Table B-6. Waterway User Cost Models Applied to Various Disruptive Scenarios.....	B-12
Table C - 1. Traffic Data Collection Summary	C-2
Table C - 2. Summary of Inputs for the Crash Cost Tab	C-5
Table C - 3. Summary of Inputs for the Detour Cost Tab	C-7

LIST OF ABBREVIATIONS, ACRONYMS, AND SYMBOLS

Acronym	Full Form
AADT	Annual Average Daily Traffic
AADTT	Average Annual Daily Truck Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
AIS	Automatic Identification System
ARSTDM	Arkansas Statewide Travel Demand Model
ARDOT	Arkansas Department of Transportation
ARSTDM	Arkansas Statewide Travel Demand Model
B/C	Benefit-Cost Ratio
BIL	Bipartisan Infrastructure Law
CMF	Crash Modification Factor
CPI	Consumer Price Index
DEM	Digital Elevation Map
DOT	Department of Transportation
ECI	Employment Cost Index
FHWA	Federal Highway Administration
GIS	Geographic Information System
IIJA	Infrastructure Investment and Jobs Act
MOT	Maintenance of Traffic
NCHRP	National Cooperative Highway Research Program
OD	Origin-Destination
PPI	Producer Price Index
RUC	Road User Cost
TAZ	Traffic Analysis Zone
TPP	Transportation Planning and Policy
USDOT	United States Department of Transportation
VHT	Vehicle Hours Traveled
VMT	Vehicle Miles Traveled

EXECUTIVE SUMMARY

Overview

This report presents the findings of TRC 2303, a comprehensive multimodal analysis of the impacts resulting from bridge closures across the Mississippi River in Arkansas. Prompted by the emergency closure of the I-40 Hernando de Soto Bridge in 2021, the study evaluates four critical crossings, Interstate 40 (I-40), Interstate 55 (I-55), Highway 49 (HWY 49), and HWY 82 (HWY 82), to quantify the economic, safety, and mobility consequences of both full and partial closures. The research supports the Arkansas Department of Transportation (ARDOT) in maintenance planning, emergency response, and infrastructure investment prioritization. A key deliverable is the Bridge Closure Impact Analysis Tool, which operationalizes the findings for practical use.

Project Goals and Objectives

This report aims to quantify the impacts of bridge closures and provide ARDOT with a tool for evaluating the impacts of future disruptions. The primary goals were:

- Quantify economic, safety, and mobility impacts of bridge closures on passenger vehicles, freight carriers, and waterway traffic.
- Develop a scenario-based decision support tool, Bridge Closure Impact Analysis Tool, for ARDOT to assess closure impacts.
- Support infrastructure investment prioritization and emergency response planning.

Approach

The analysis combines two complementary methods. First, ARDOT's spreadsheet-based Road User Cost (RUC) framework converts localized work zone friction (user delay, operating, and crash costs) and regional detour friction (added delay, mileage, and safety penalties) into daily dollar costs by bridge and scenario. Second, the Arkansas Statewide Travel Demand Model (ARSTDM) simulates 2,303 closure configurations to estimate system-level changes in Vehicle Hours Traveled (VHT) across passenger autos, single-unit trucks, and tractor-trailer trucks. For river traffic, Automatic Identification System (AIS) records are processed to quantify tug/tow movements and to compute comparable 24-hour waterway disruption costs for 2021 and 2024 conditions.

Roadway User Costs

The Road User Cost (RUC) framework was used to estimate partial and full closure costs for the four study bridges and all possible combinations of multi-bridge closure scenarios. Results are the product of the logic embedded in the RUC formulas and assumptions. Use of the RUC as a framework for the partial and full closures leads to a counterintuitive finding. Partial closures on high-volume facilities impose higher daily user costs than full closures (Figure 1). When maintaining one open lane in each direction on interstates like I-40 and I-55, the severe localized bottleneck produces massive user delay according to the RUC framework. As a result, the I-40 partial closure shows the largest daily impact at approximately \$2.38 million per day.

Conversely, a full closure costs roughly \$199,000 per day according to the RUC framework because traffic redistributes to nearby alternate routes. The degree to which the RUC framework accurately captures the true costs of full and partial closures relative to each other should be further evaluated.

For full closures, the rural bridges bear the highest financial impacts relative to their baseline traffic volumes because of long detour distances. It should be noted that detours are restricted to other bridges in the state of Arkansas. The HWY 82 full closure costs nearly \$995,000 per day, while HWY 49 costs approximately \$20,000 per day. Although these rural routes have lower volumes, the lack of nearby crossings in those corridors turns every trip into a significant financial penalty.

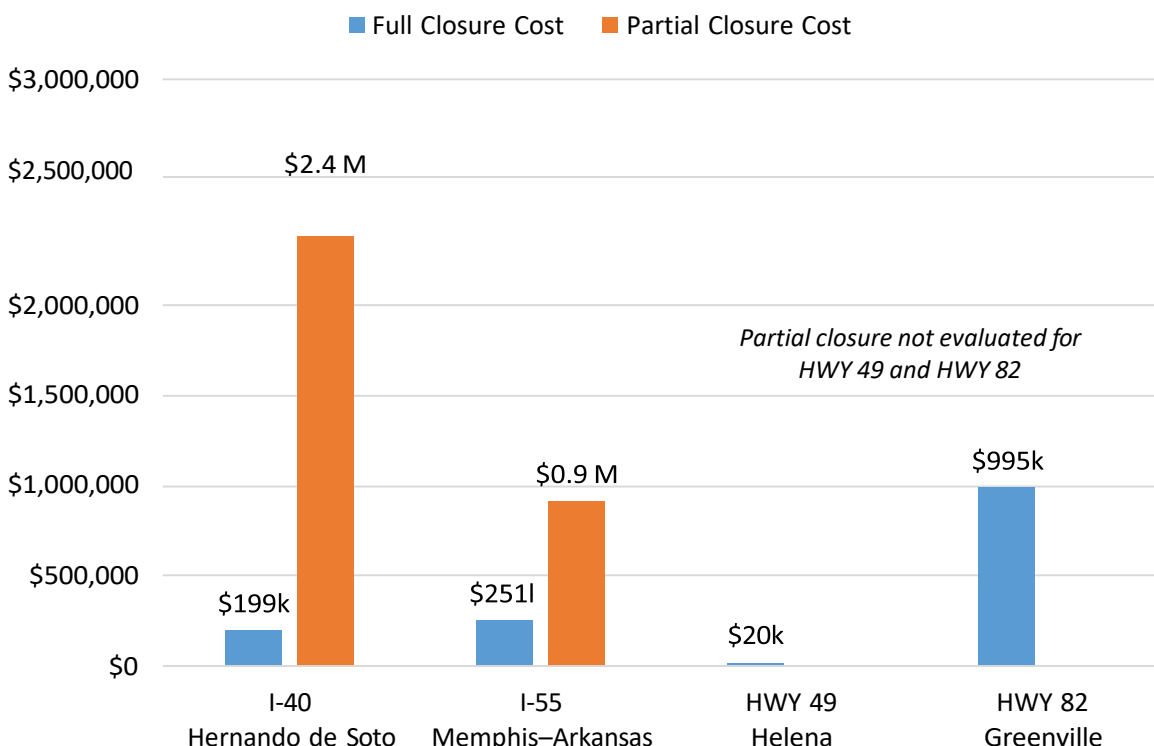


Figure 1. Comparison of Daily Full and Partial Road User Costs by Bridge

System-Level Mobility Effects

The study used the Arkansas Statewide Travel Demand Model (ARSTDm) to simulate 2,303 bridge closure scenarios across four Mississippi River crossings: I-40, I-55, HWY 49, and HWY 82. The model contains approximately 90,100 miles of roadway within and outside of AR. Outside of AR, the network captures only interstates and other major freight network links. The impacts on travel time and volume were estimated for three vehicle classes: autos, single unit trucks (SUT), and tractor trailer trucks (TTT). Full closures of high-volume bridges like I-40 and I-55 resulted in significant increases in VHT, especially for TTT, which experienced widespread disruptions across Arkansas and neighboring states. The PM peak period was identified as the most critical time for system-level impacts (Figure 2 and Figure 3).

Under the I-40 full closure during the PM peak, TTT experienced the most significant disruption, with 6,902 miles of roadway showing more than a 4% increase in VHT, representing 7.7% of the modeled network for TTT. In contrast, autos and SUT were minimally affected, with only 0.55% of links impacted in total for both vehicle types. This scenario had the highest overall impact, particularly for freight traffic, due to I-40's critical role in regional and national logistics.

The I-55 full closure also caused notable disruptions, though less severe than I-40. TTT impacts were observed on 2,313 miles of roadway (2.6% of modeled mileage), while autos and SUT saw 0.58% of links impacted in total for both vehicle types. This scenario still affected major freight corridors but to a lesser extent than I-40, likely due to lower traffic volumes and alternative routing options.

In contrast, the HWY 49 and HWY 82 closures had more localized effects. HWY 49's closure resulted in only 0.87% of modeled links being impacted for TTT, while HWY 82 had the smallest TTT impact at just 0.33% of modeled links. Interestingly, HWY 82 had the highest percentage of impacted links for autos (0.82% of modeled links) and SUT (1.04%), suggesting that while it is less critical for freight, it plays a more important role in regional passenger and light truck mobility. These findings highlight the varying roles of each bridge in the transportation network and underscore the disproportionate impact of closures on freight versus passenger traffic.

Waterway Disruption Costs

Bridge emergencies can also halt river traffic. Using AIS-derived tug/tow volumes, the study estimated 24-hour waterway disruption costs by location for two reference years, 2021 and 2024. From 2021 to 2024, daily waterway disruption costs showed varied trends across the four Mississippi River bridges. Costs for the I-40 and HWY 49 bridges remained stable, while the I-55 bridge saw a decrease. In contrast, the HWY 82 bridge experienced a sharp increase in daily costs. Among the four locations, the HWY 49 bridge consistently represented the highest disruption cost, while the HWY 82 bridge exhibited the most significant growth between the two years. These cost estimates are directly derived from the annual average daily traffic (AADT) volumes for each bridge in their respective years.

Implementation – Bridge Closure Impact Analysis Tool

To operationalize these analytics, the project delivered a web-based Bridge Closure Impact Analysis Tool that automates RUC computations, summarizes system-level changes in VHT and VMT, and presents interactive maps and dashboards. Users can configure full and partial closures for individual or combinations of Mississippi River bridges. The tool allows users to examine specific cost components (localized user delay, operating, and crash costs, as well as added detour delay, mileage, and safety penalties), and evaluate disruptions to commercial waterway navigation. Ultimately, these interactive scenario summaries support project staging, incentive/disincentive clauses, and emergency detour planning.

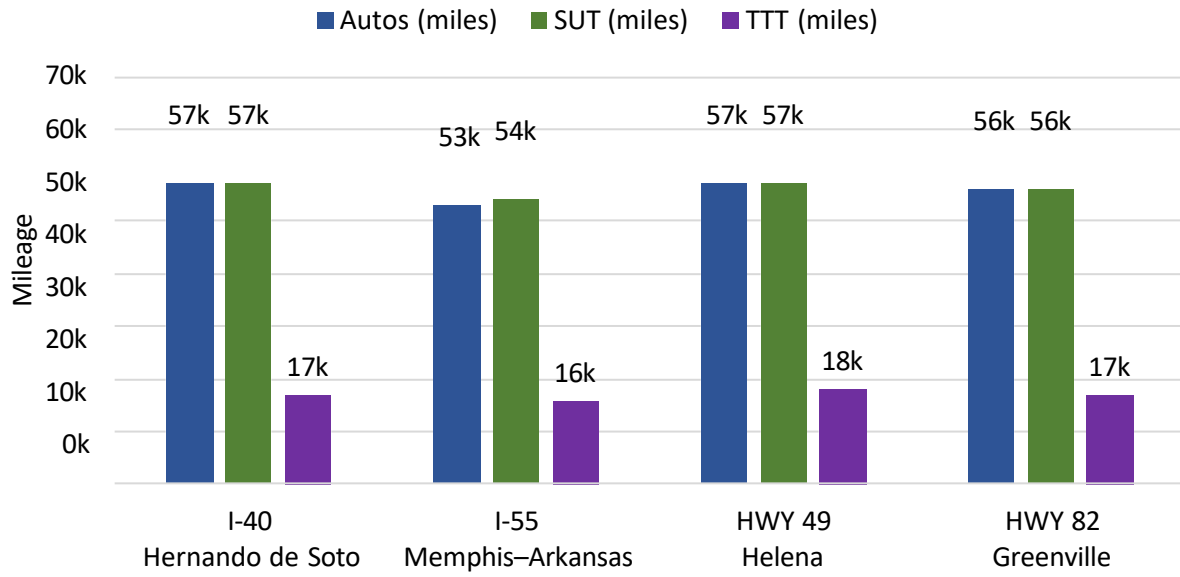


Figure 2. Mileage of Network with Zero Percent Change in VHT During Closure of Each Bridge

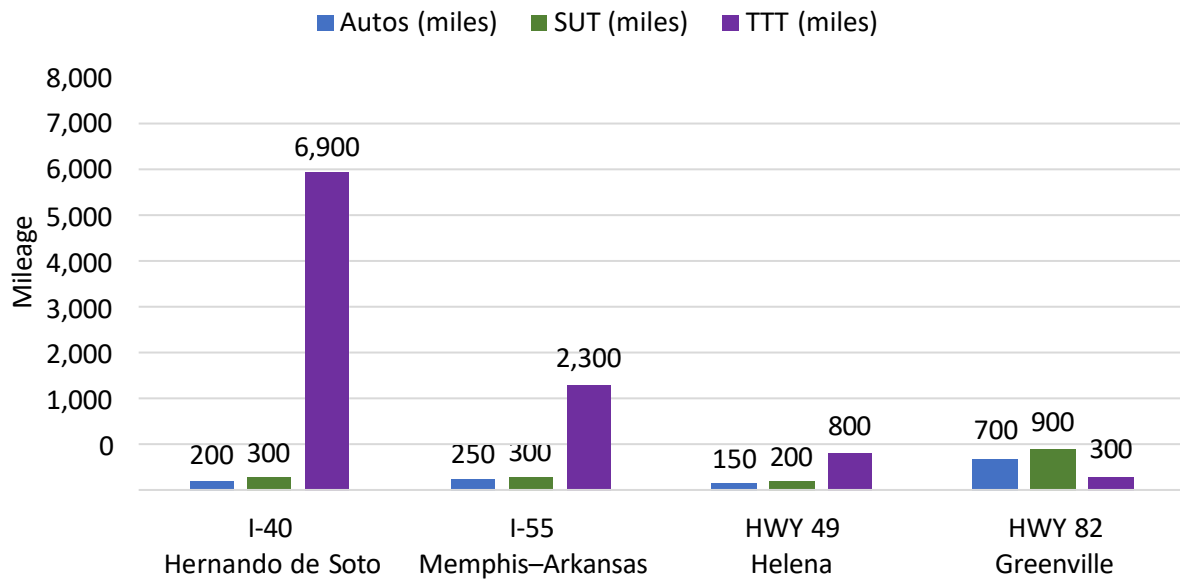


Figure 3. Mileage of Network with Four or More Percent Change in VHT During Closure of Each Bridge

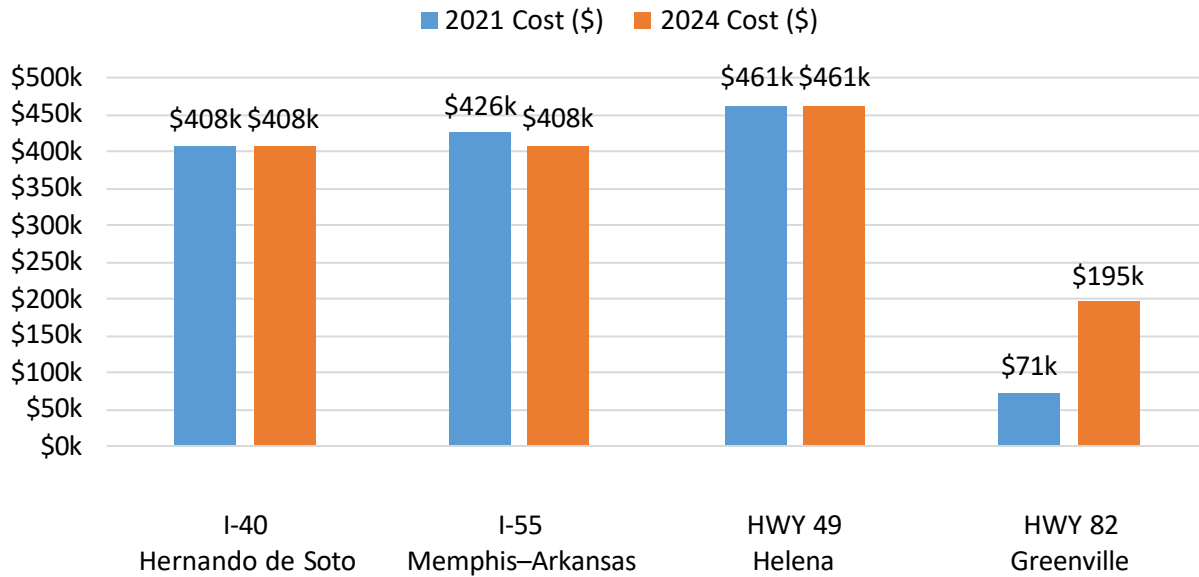


Figure 4. Estimated waterway disruption costs per 24-hour closure (2021 vs 2024)

Mitigation and Recommendations

The analysis points to three complementary lines of mitigation. Operational measures such as dynamic lane management, traveler information, and thoughtful maintenance of traffic can help sustain flow during work activities. Maintenance-based practices including structural health monitoring and life-cycle management can target vulnerabilities and reduce the likelihood of abrupt closures. Planning-based strategies like scenario modeling, coordinated scheduling, and multimodal detour design can shrink user costs by keeping critical capacity available during peak periods. For rural bridges with sparse alternatives (e.g., HWY 49 and HWY 82), pre-planned long-haul detour packages for freight and coordinated river traffic windows can further contain impacts. A recommendation is also made to further evaluate the ARDOT RUC framework in comparing full and partial bridge closures. As used in this project for systems of bridges, the RUC produces counterintuitive results where partial closures are more costly than full closures. While this follows the logic and inputs of the RUC framework, discrepancies in cost estimation in the RUC framework should be examined more closely.

Conclusion

Bridge closures across the Mississippi River in Arkansas have far-reaching consequences for roadway and waterway systems. By integrating RUC estimation, statewide travel demand modeling, and inland waterway vessel data into a single decision tool, e.g., the Bridge Closure Impact Analysis Tool, ARDOT is equipped to respond proactively to future bridge closures and maintain the resilience of Arkansas’s transportation network.

CHAPTER 1. PROJECT OVERVIEW

STRUCTURE OF THE REPORT

Following the Project Overview in Chapter 1, this report is organized as follows:

- **Chapter 2** shows the impact of the Hernando de Soto Bridge closure on traffic patterns in 2021 using probe data sources,
- **Chapter 3** presents the analysis of AR Mississippi River bridge closure scenarios using the AR Statewide Travel Demand Model (AR STDM),
- **Chapter 4** presents an overview of the interactive implementation tool, e.g., the Bridge Closure Impact Analysis Tool, key findings and recommendations for future efforts,
- **Appendix A** shows maps of changes to bridge to/from Traffic Analysis Zone (TAZ) travel patterns resulting from the Hernando de Soto Bridge closure as observed from third-party probe data,
- **Appendix B** presents the methodologies identified in the literature to estimate the impact of bridge closures on multimodal traffic, and
- **Appendix C** provides details on inputs, assumptions, and application of the Bridge Closure Impact Analysis Tool used for this work.

BACKGROUND

Unexpected road closures can have significant impacts on the traveling public and freight carriers in terms of travel delays, safety, and mobility. Bridge closures, in particular, present unique and significant disruptions due to lengthier detours typically around waterways and other geological features. Moreover, the unexpected closure of a bridge causes traffic to detour to nearby bridges, creating bottlenecks with long delays. Recent national examples of disruptive bridge closures include the Hernando de Soto Bridge on Interstate 40 (I-40) over the Mississippi River connecting Arkansas and Tennessee and the Brent Spence Bridge on Interstate 75/71 (I-75/I-71) over the Ohio River connecting Kentucky and Ohio.

The Hernando de Soto Bridge closure along I-40 occurred between May 11, 2021, and August 2, 2021. Typically, the de Soto bridge carries 41,000 vehicles per day with around 30% of that being truck traffic (about 12,000 trucks per day) (ARDOT, 2022). During this time, the bridge was fully closed to both directions of traffic for 49 days (May 11 through July 28) and then partially opened for 36 additional days (until August 2nd)¹. Most traffic rerouted to the I-55 bridge, south of the de Soto bridge. Before the closure of the de Soto bridge, the I-55 bridge carried approximately 46,000 vehicles per day with around 35% of that being truck traffic (about 16,000 trucks per day) (ARDOT, 2022). While the two bridges are only about two miles apart, this detour resulted in an estimated delay of 30 minutes to two hours due to the significant congestion caused by operating the I-55 bridge at well over its intended capacity. Delay of this magnitude caused many commercial drivers to run out of driving hours regulated by federal Hours-of-Service regulations which require rest breaks. In some cases, commercial

¹ARDOT Public Information, The I-40 Mississippi River Bridge Timeline, <https://www.ardot.gov/divisions/public-information/40-ms-river-bridge/40-ms-river-bridge-time-line/>

drivers shifted their work schedules outside of peak congested periods². The Arkansas Trucking Association estimated that the initial full closure cost the trucking industry \$2.4M per day, evening out to \$1M a day. The de Soto bridge closure also had significant impacts on barge traffic³. At the time of the closure, the US Coast Guard reported a queue of 229 barges waiting to cross under the de Soto bridge. By the time the bridge reopened to barge traffic on May 14th (4 days after the start of the closure), there were 61 boats and 1,058 barges in the queue that were anticipated to be cleared in approximately two days⁴.

The Brent Spence Bridge over the Ohio River was unexpectedly closed on November 11, 2020, due to a severe fire caused by the collision of two large trucks carrying fuel and chemicals⁵ (Figure 5). After extensive repairs, the bridge reopened 42 days later on December 23, 2020^{6,7}. The Spence Bridge carries approximately 150,000 vehicles per day, with 20% heavy-duty truck traffic. Like the de Soto bridge, the Spence Bridge closure caused delays to the traveling public, freight carriers, and waterways traffic. During the closure, traffic was rerouted to three nearby bridges (listed in order of increasing distance to the Spence Bridge): the Clay Wade Bridge, the Roebling Bridge, and the Daniel Carter Beard Bridge. The three alternate bridge routes represent an approximate two-to-five-mile detour. A post closure analysis using vehicle tracking data showed that the volume on the Wade bridge increased 318% while average speed decreased 63%; on the Roebling bridge volume increased 180% and speed decreased 15%, and on the Beard bridge volume increased 189% and speed decreased 16%⁸.

As a result of unexpected bridge closures like those exemplified by the Arkansas and Kentucky cases, several states are undertaking planning projects to determine how potential bridge improvement projects may affect mobility in the event of bridge closures. The purpose of planning studies like these is to prioritize infrastructure improvement projects as well as to plan for detours and delays. These planning projects examine how bridges currently serve the transportation network by examining current traffic volumes, travel times, and trip origins and

² FreightWaves, Painful Mess: I-40 bridge closure costing trucking industry \$1M per day, <https://www.freightwaves.com/news/painful-mess-i-40-bridge-closure-costing-trucking-industry-1m-daily>

³ Action News 5, Barge Traffic at a Standstill in Wake of Bridge Closure, <https://www.actionnews5.com/2021/05/12/barge-traffic-standstill-wake-bridge-closure/>

⁴ Margaronis, S., American Journal of Transportation, Mississippi River traffic open by I-40 bridge repairs could cause future disruptions, <https://ajot.com/insights/full/ai-mississippi-river-traffic-open-but-i-40-bridge-repairs-could-cause-future-disruptions>

⁵ Brookbank, S. and Knight, C., Brent Spence Bridge: We are looking at weeks, perhaps more than a month, Cincinnati.com The Enquirer, <https://www.cincinnati.com/story/news/2020/11/12/brent-spence-bridge-closure-75-bridge-fire-ohio-kentucky-detours/6262027002/>

⁶ WDRB.com, Beams replaced, repairs continue on fire damaged Brent Spence Bridge in Cincinnati, https://www.wdrb.com/news/beams-replaced-repairs-continue-on-fire-damaged-brent-spence-bridge-in-cincinnati/article_33526a80-34cd-11eb-b0b4-13aae49f2d4e.html

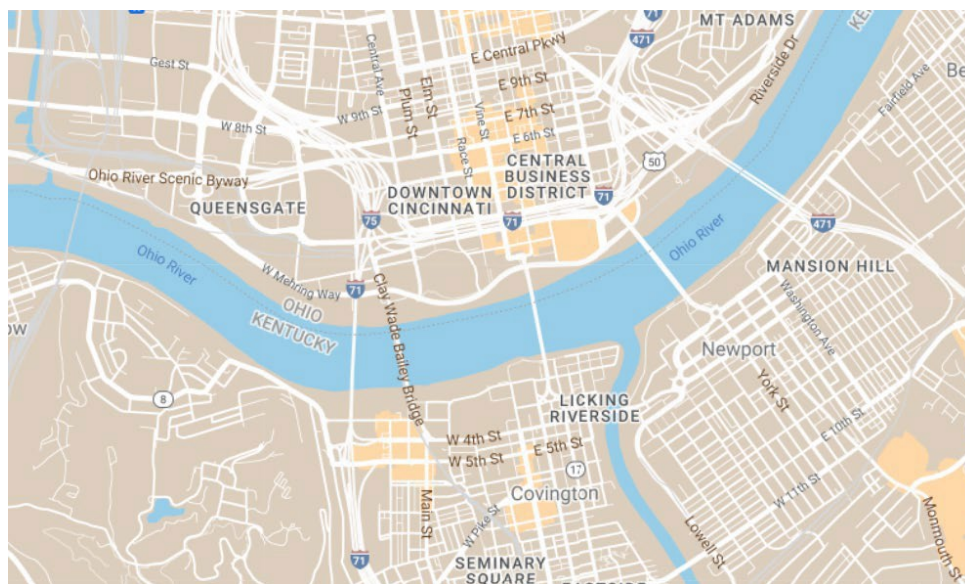
⁷ Kentucky Transportation Cabinet, Brent Spence Bridge Repair, <https://brentspencerepair.com/>

⁸ Geotab, How Geotab ITS used a major bridge closure event to uncover key traffic mobility information, <https://its.geotab.com/blog/transforming-traffic-disruption-into-valuable-transportation-insight/>

destinations. For example, in a 2018 study of bridges in Louisiana, planners used vehicle tracking data to assess current travel times and origins and destinations for three bridges that serve the New Orleans Area. Knowledge of trip origins and destinations helped planners determine what rerouting volumes were likely for each bridge in the case that one of the bridges closed.



(a) Span of the Brent Spence Bridge under repair (Ref: WDRB)

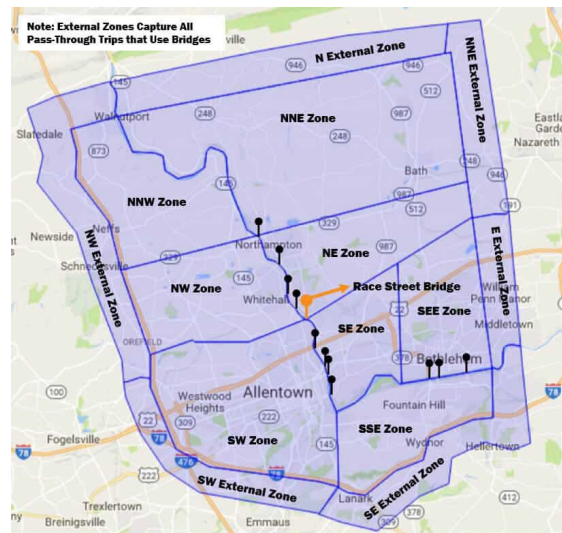


(b) Location of the Brent Spence Bridge on Interstate 71/75 connecting Ohio and Kentucky (Google Maps)

Figure 5. Brent Spence Bridge location

These studies highlight the necessity of early planning, the use of vehicle tracking data, and the impact of bridge closures on daily and freight travel. The use of vehicle tracking data, in particular, has transformed the way in which bridge closures and their impacts are being analyzed. Vehicle tracking data is provided by third-party data vendors who collect, anonymize,

and redistribute the data for a fee. The data is gathered anonymously from cell phones, fleet telematics, and connected vehicle features like OnStar. Third-party vendors offer GIS enabled web-platforms to synthesize the data and run data reports such as select link analyses. Select link analyses are used to understand the origins and destinations of trips that use a given link in the transportation network. For the Race Street Bridge (Bowman and Schewel, 2016) and I-10 (Montz and Alvergue, 2018) examples, a select link analysis was performed for each of the bridges in the region to identify common origins and destinations of travelers (Figure 6). Once common origins and destinations are identified, shortest paths that exclude the closed bridge can be evaluated to determine optimal detour routes and to estimate potential mobility (travel time, traffic volume) impacts of the closure.



(a) Bridges in the Lehigh Valley of Pennsylvania (markers indicate bridge locations)
(Ref: Bowman and Schewel, 2016)

Bridges	Share of Total Trips Using Bridge	Share of SW Zone – NE Zone Trips Using Bridge	Share of NE Zone – SW Zone Trips Using Bridge
21st St Bridge	2.91%	13.58%	12.63%
9th St Bridge	1.41%	5.97%	5.49%
American Pkwy Bridge	1.32%	1.17%	1.21%
Hamilton St Bridge	7.26%	2.68%	2.27%
Hill to Hill Bridge	17.61%	0.42%	0.29%
Lehigh St Bridge	0.41%	2.10%	2.18%
Lehigh Valley Thruway Bridge	45.38%	13.44%	11.40%
Minsi Trail Bridge	7.30%	0.02%	0.02%
New St Bridge	6.01%	.01%	0.02%
Pine St Bridge	2.38%	30.08%	35.36%
Race St Bridge	3.76%	27.26%	25.19%
Tilghman St Bridge	4.24%	3.27%	3.92%
Grand Total	100.00%	100.00%	100.00%

(b) Total trips and trips by origin/destination for 12 bridges in the Lehigh Valley region of Pennsylvania (Ref: Bowman and Schewel, 2016)

Figure 6. Percent of traffic and average travel time across three bridges in Pennsylvania

While anonymous vehicle tracking data allows us to examine real-world travel behaviors that result from historical bridge closures, it does not directly inform “what-if” scenario planning. For example, anonymous vehicle tracking data would reveal the change in traffic volumes and speeds on alternate routes during a bridge closure, as was the case for the Spence Bridge in Kentucky. However, it would not be able to tell us what would happen if the Spence bridge *and* the nearby Clay Wade Bridge closed. For this, a common practice is to use modeling and simulation. Arkansas maintains a statewide travel demand model, referred to as the Arkansas Statewide Travel Demand Model (ARSTDM). The ARSTDM predicts average daily traffic volumes for the entire state network for the AM, midday, PM, and overnight periods for passenger and freight traffic following a four-step approach (Figure 7). As a result of the model framework, the model is capable of predicting traffic volumes under various road closures and capacity reduction scenarios (e.g., lane closures). In the case of a long-term bridge closure, like the de Soto bridge, we anticipate several travel behavioral shifts. First, we expect travelers to reroute around the closed bridge, which will impact the traffic volumes along the alternate routes. This can be identified in the model framework during the route assignment step when traffic between zones is assigned to specific routes. Second, we expect some travelers to alter their trip destinations. For example, rather than crossing the bridge to go to a particular store, the traveler may shop at a store closer to home. This can be identified in the model framework during the trip distribution step when trips are assigned to destinations. For this project, we evaluated the impact of the bridge closures on trip distribution and route assignment as these are the more likely and significant outcomes of bridge closures. The outputs from these ARSTDM scenarios are then integrated into an interactive web-based tool, e.g., the Bridge Closure Impact Analysis Tool, to dynamically calculate the resulting Road User Costs.

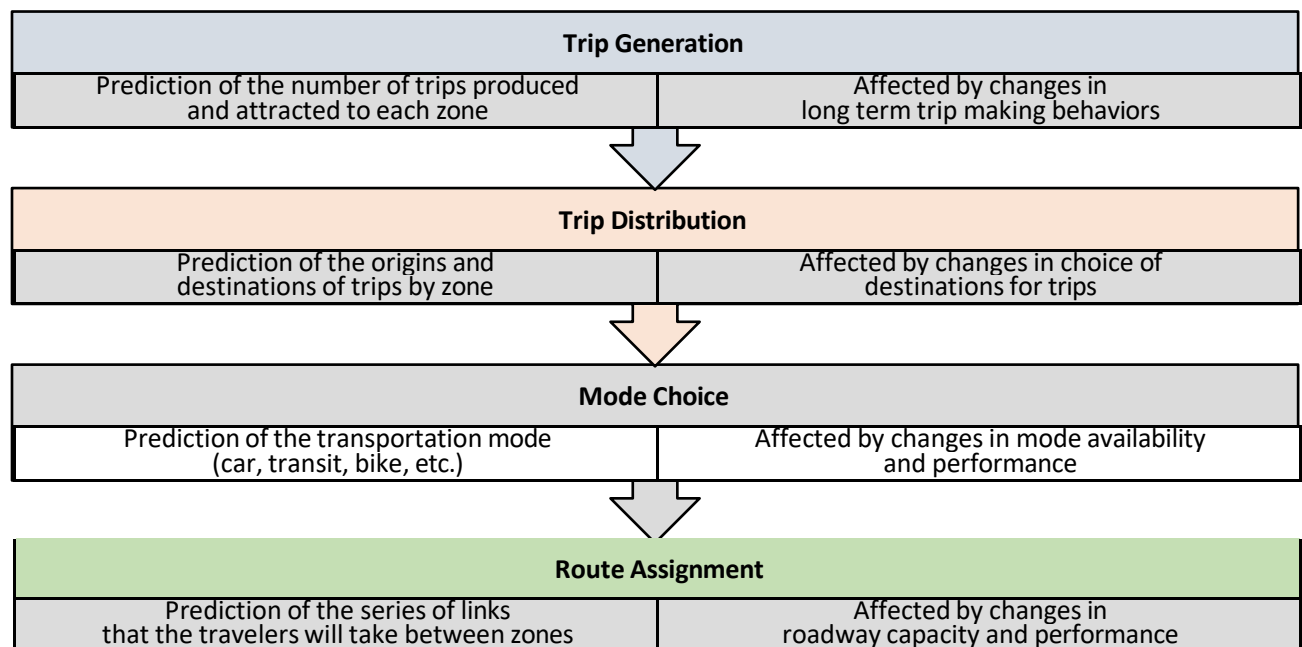


Figure 7. Overview of a traditional four-step travel demand model

The four bridges considered in this project are the Hernando de Soto bridge (I-40), the Memphis and Arkansas Bridge (I-55), the Helena Bridge (HWY 49), and the Greenville Bridge (HWY 82) (Table 1 and Figure 8). The bridges on I-40 and I-55 carry more than 40,000 vehicles per day while the bridges serving highways 49 and 82 serve less than 10,000 vehicles per day (ARDOT, 2022).

Table 1. Arkansas Bridges over the Mississippi River and their Traffic Characteristics

Bridge Name	Number of lanes per direction	AADT (vehicles per day)	Truck Percentage (truck count)	Approx. Driving Distance to Next Bridge
Interstate 40 (I-40) Hernando de Soto Bridge	3	48,200	29% (12,000)	12 miles to Memphis and Arkansas Bridge (I-55)
Interstate 55 (I-55) Memphis and Arkansas Bridge	2	41,200	35% (16,000)	12 miles to de Soto Bridge (I-40)
US Highway 49 (HWY 49) Helena Bridge	1	3,900	20% (880)	143 miles to Memphis and Arkansas Bridge (I-55)
US HWY 82/278 (HWY 82) Greenville Bridge	1	7,100	24% (1,728)	241 miles to Helena Bridge (Hwy 49)

Publicly available traffic data for the four bridges is restricted to AADT count locations that use Automatic Traffic Recording (inductive loops) and video (e.g., Miovision) detection (Figure 9). The existing traffic data provide only daily traffic volumes and truck percentages and are sparsely located. As a result, they cannot be used to determine origins and destinations and must be supplemented with additional data. In this project, we used vehicle tracking data and the existing Arkansas Statewide Travel Demand Model (ARSTDM) to estimate the impact of bridge closures on the traveling public and freight carriers for the ARDOT maintained bridges spanning the Mississippi River. Because the ARSTDM represents a historical base year (2005), raw volume outputs were not used directly. Instead, the model was used to compute the percentage change in traffic distribution for various closure conditions. These relative shifts are then applied to the 2022 AADT baselines within an interactive tool, allowing it to dynamically redistribute traffic for any user-configured closure scenario.

The Mississippi River restricts alternate routes and leads to detours of up to 200 miles to Highway 49 and HWY 82 bridges. Vehicle tracking data from third-party providers was purchased for both passenger and freight trajectories to capture the multimodal highway impacts of closure scenarios in terms of changes in origin-destination patterns and alternate

route usage. Additionally, marine vessel tracking data available from the US Coast Guard was used to estimate the impact of closures on waterway traffic by determining to what extent barge traffic was delayed along the Mississippi River during the closure.

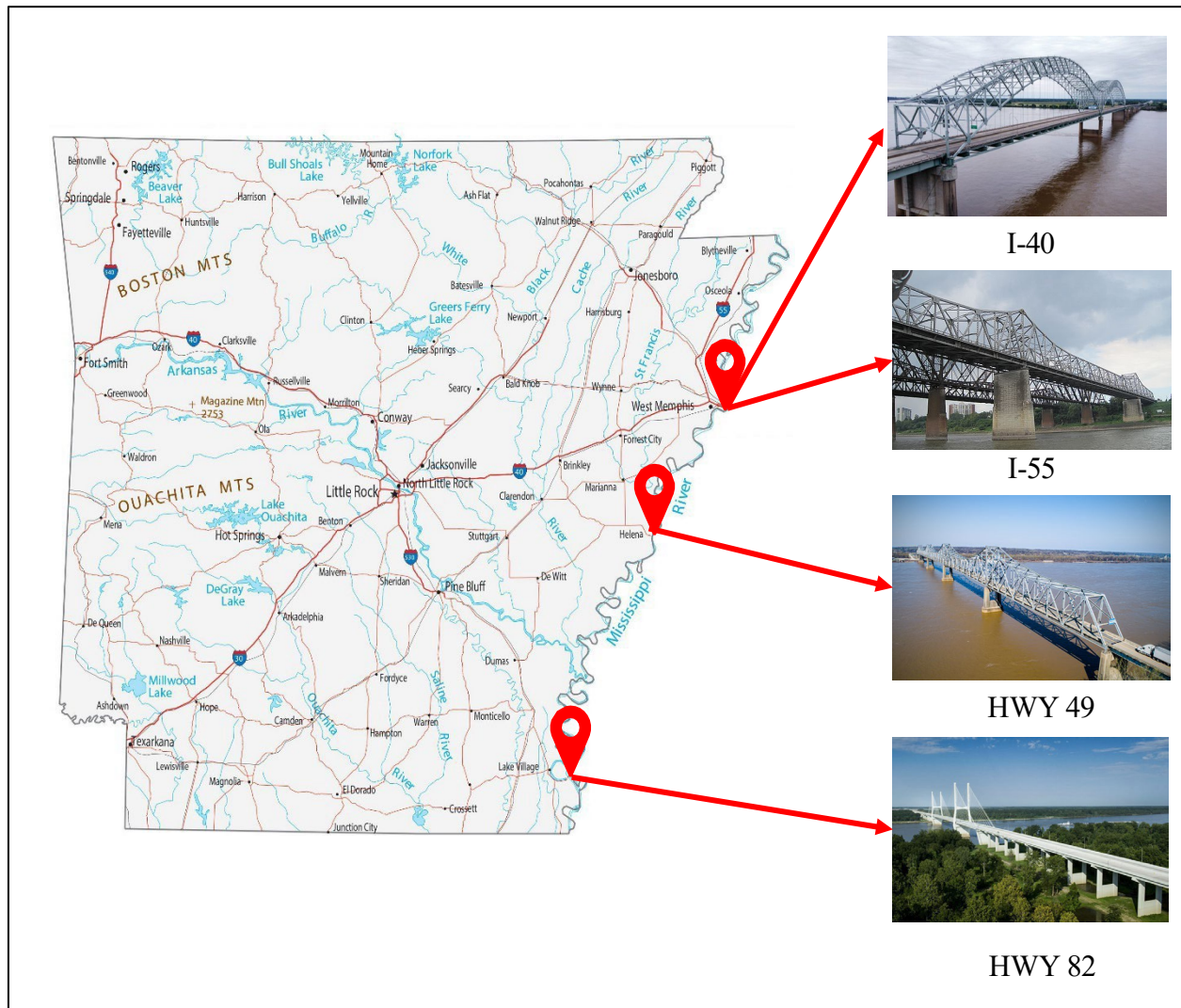


Figure 8. Arkansas Bridges spanning the Mississippi River

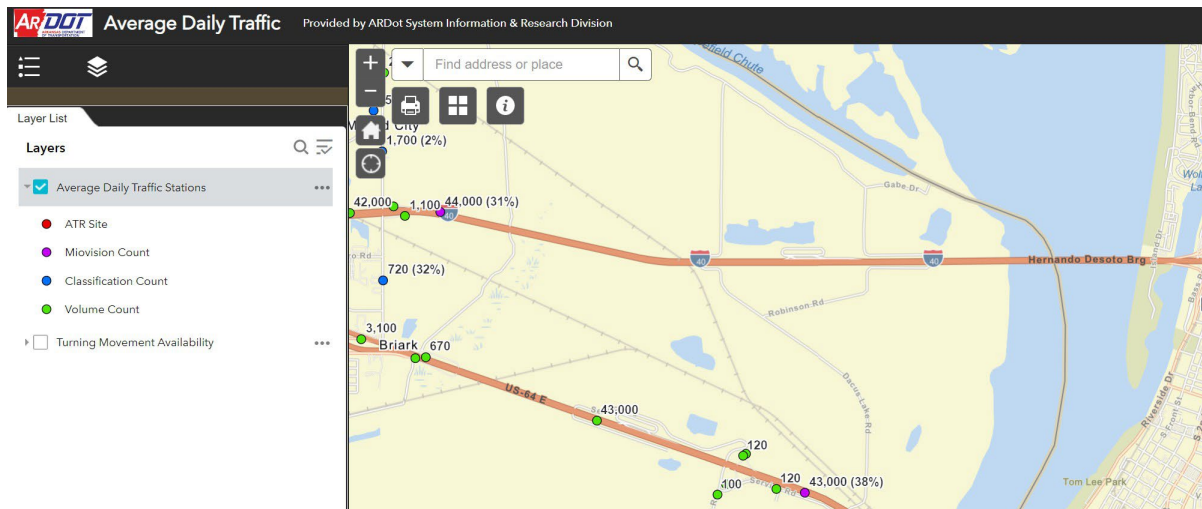


Figure 9. Example AADT count stations for the Hernando de Soto and Memphis-Arkansas Bridges (Ref: ARDOT, 2022)

PROJECT OBJECTIVES

The objective of the research is to quantify the multi-modal impacts due to a Mississippi River bridge closure. Two tools were used for this study. The first is the Road User Cost (RUC) template that ARDOT developed to assess the impacts of road closures due to work zones. The tool considers traffic volumes by time of day, accident history, detour length, work zone speed, among other inputs. The tool estimates the monetary cost associated with road user travel time delays and safety impacts. The second tool is the Arkansas Statewide Travel Demand Model (AR STDm) which is a traditional four-step travel demand model for forecasting traffic volumes and travel times across the statewide roadway network. Using this model, we estimated 2,303 scenarios representing combinations of bridge closures (i.e., full and partial bridge closures that take into account one or both directions, single/multiple lanes, and day/night closures) including all the Mississippi River bridges in Arkansas (i.e., I-40, I-55, HWY 49, and HWY 82 bridges). The products of the RUC analysis and the AR STDm scenarios were used to produce an interactive web-based tool to conduct “what-if” analyses for decision-making purposes, whether for operation, maintenance, or planning activities.

Objective 1: Multimodal Impact Estimation

The first objective of this work is to estimate the multimodal impacts of bridge closures along the Mississippi River in Arkansas. Multimodal impacts include those for passenger vehicles, commercial and heavy-duty trucks and waterway traffic including barges and self-propelled vessels like tug and tow boats. This objective was carried out in three tasks:

1. State of the Art and State of the Practice review of methods to estimate multimodal impacts resulting from bridge closures.
2. Collection of transportation data such as traffic volumes, travel times, and trip origins and destinations to support the analysis of bridge closure impacts.
3. Multimodal impact estimation using scenario modeling approaches.

This work separates scenario impacts into two components: (1) Link-level impacts and (2) system wide impacts. Link-level impacts are estimated based on road user costs associated with work zones and road closures of the bridge. These impacts derive from congestion through the work zone and detouring requirements. Link-level impacts are estimated separately for each bridge and then combined for scenarios where more than one bridge is impacted (closed). System wide impacts consider the combined effects of concurrent bridge closures in terms of Vehicle Miles Travelled (VMT) and Vehicle Hours Travelled (VHT). The Link-level impacts are calculated dynamically in the background based on ARDOT's Road User Cost (RUC) templates, while the System-level impacts are estimated using ARDOT's Statewide Travel Demand Model (AR STDM).

Objective 2: Bridge Closure Scenario Analysis

The second objective of this work is to analyze bridge closure scenarios that were estimated through Objective 1. This outcome of work towards this objective was the development of an interactive application (tool) that allows the user to enter in closure details and output charts, maps, and summary tables of the impacts of a closure scenario. The report presents and discusses featured scenarios through the tool interface.

CHAPTER 2. ANALYSIS OF THE HERNANDO DE SOTO BRIDGE CLOSURE

This chapter showcases the impacts of the Hernando de Soto bridge closure that occurred in 2021 on roadway traffic patterns in Arkansas as observed using third-party probe data. In this context, roadway data encompasses various sources such as third-party probe-based data and stationary sensor-based data. The roadway data were used to analyze Origin-Destination (OD) traffic patterns for passenger and commercial vehicles during the bridge closure. In this section we include the Traffic Analysis Zone (TAZ) level OD flows, while **Appendix A** includes the origin-destination flows from each bridge to each TAZ for the closure period, and reference periods (before and after the closure by season and year).

DESCRIPTION OF DATA SOURCES AND ACQUIRED DATA

The purchased third-party probe data was acquired from two providers: StreetLight and Geotab. The geographic scope of the data includes select counties within and not within Arkansas to capture bridge flows as all bridges span across two states. For each of the probe datasets, we obtained data for the closure periods in 2021 and for the stable traffic flow periods in 2022 (Table 2) for the following time periods:

Closure Period

April 15-30, 2021 (Pre-Closure)
May 11-July 31, 2021 (Full Closure)
October 15-30, 2021 (Post Closure)

Stable Traffic Flow Period

January 15-30, 2022
April 15-30, 2022
July 15-30, 2022
October 15-30, 2022

Table 2. Geographic Scope of Probe Data by Bridge

Bridge Name	Geographic Scope by County
Interstate 40 (I-40) Hernando de Soto Bridge	Trips passing through the segment in Crittenden County, Arkansas and Shelby County, Tennessee with origins and destinations across the US
Interstate 55 (I-55) Memphis and Arkansas Bridge	Trips passing through the segment in Crittenden County, Arkansas and Shelby County, Tennessee with origins and destinations across the US
US Highway 49 (HWY 49) Helena Bridge	Trips passing through the segment in Phillips County, Arkansas and Coahoma County, Mississippi with origins and destinations across the US
US HWY 82/278 (HWY 82) Greenville Bridge	Trips passing through the segment in Chicot County, Arkansas and Washington County, Mississippi with origins and destinations across the US

ARDOT provided StreetLight OD data to the research team for the specified locations and time periods. StreetLight OD data provides insights into travel patterns by analyzing anonymized location data from mobile devices, GPS, and connected vehicles. It captures trip origins, destinations, routes, and travel times across different modes of transportation. StreetLight data

is comprised mostly of personal vehicles and was used to analyze passenger vehicle OD flows in this study. The StreetLight data provided by ARDOT included OD flows, but not traffic volumes by link. It is also important to note that the StreetLight data provided does not include out of state traffic flows.

Geotab OD data is derived from connected vehicle telematics collected through its fleet of GPS-equipped commercial vehicles. It provides detailed insights into trip patterns, including start and end points, travel routes, durations, and stop locations. This high-resolution data is valuable for freight analysis, traffic operations, and infrastructure planning, especially in understanding commercial vehicle behavior on regional and national networks.

Geotab data uses a custom journey definition and provides vocation, industry, and vehicle class filtering, and allows users to navigate and create zones to zero in on regions of interest through the Altitude web platform. A journey is defined as “when a vehicle starts moving until it stops with ignition turned off (or idles for 3 min 20 sec)”. Chained, consecutive trips define a journey. Journeys can be combinations of trips that are segmented by stops at gas stations and other short duration stops. In this case, a trip chaining factor, which is the minimum stop duration (time) threshold, can be set within the Altitude platform to string together trips to comprise a journey from origin to destination. However, trip chaining may unintentionally combine together trips for other types of vehicle activities.

In the context of Geotab commercial traffic volume, an "expansion factor" is a multiplier that, when applied to the observed volume, provides a reasonable estimate of the general commercial traffic volume. Utilizing the Federal Highway Administration (FHWA) traffic monitoring datasets for 2021 as population benchmarks, a set of discrete location expansion factors has been developed. These factors can scale Geotab commercial traffic volume to population commercial volumes at over 3,000 locations across the US. Additionally, a pilot set of state-level expansion factors was generated, derived using custom weighting on discrete location expansion factors.

ANALYSIS OF PASSENGER VEHICLE OD USING THIRD-PARTY PROBE DATA

This section describes the changes to OD traffic flow patterns of passenger vehicles observed through third-party probe data, specifically using StreetLight data, as a result of the Hernando de Soto bridge closure in 2021. A comprehensive set of maps for the time periods of the Hernando de Soto bridge closure as well as reference periods are shown in Appendix A. In this section we highlight a subset of those maps to illustrate the impact of the closure across the state's four Mississippi River Bridges.

During the closure period (May 11 through July 31, 2021), most of the passenger traffic shifted from the closed main I-40 route to the I-55 bridge. For illustrative purposes, we show the traffic from TAZs to the bridges in Figure 10 through Figure 13. Higher traffic volumes are observed on the I-55 bridge during the I-40 closure period. For the HWY 49 bridge we see a slight increase (5-50 vehicles per day) in vehicle volumes from the TAZs near I-40 midway between Little Rock and West Memphis. For the HWY 82 bridge, a slightly higher traffic volume (an increase of approximately 50 vehicles) is observed from Pine Bluff during the I-40 closure period before the closure. This is seen in the darker shading in the TAZs near Pine Bluff.

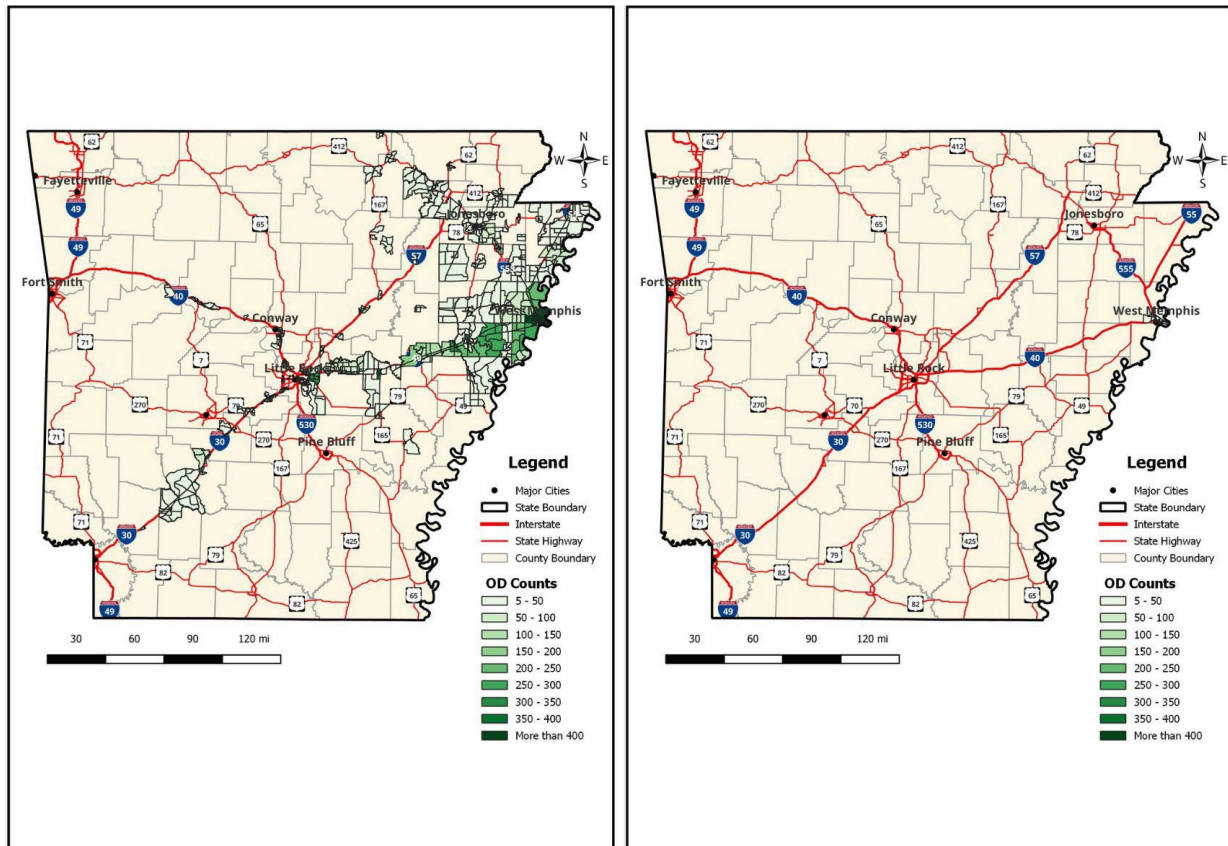


Figure 10. Comparison of Passenger Vehicle Flows from TAZs to the I-40 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 Bridge Closure

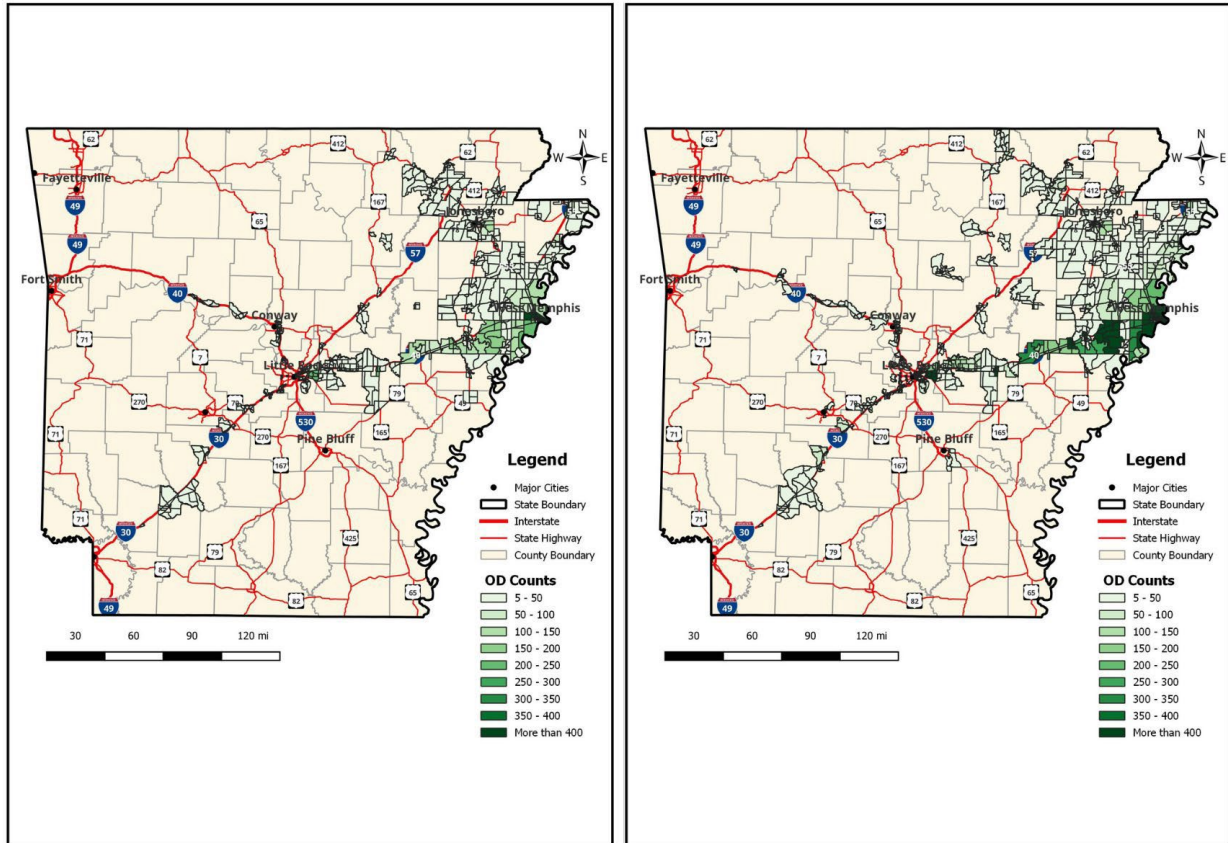


Figure 11. Comparison of Passenger Vehicle Flows from TAZs to the I-55 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 Bridge Closure

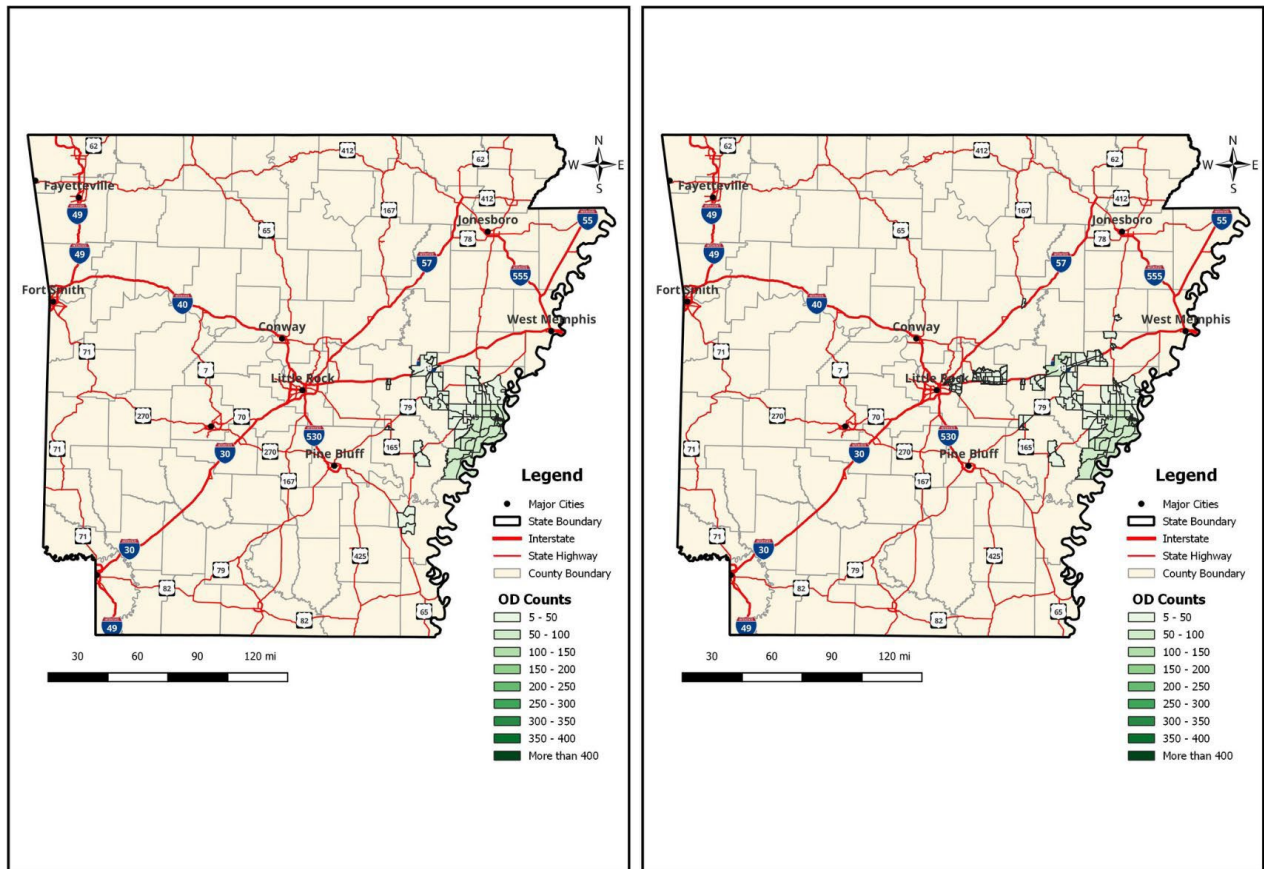


Figure 12. Comparison of Passenger Vehicle Flows from TAZs to the HWY 49 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 Bridge Closure

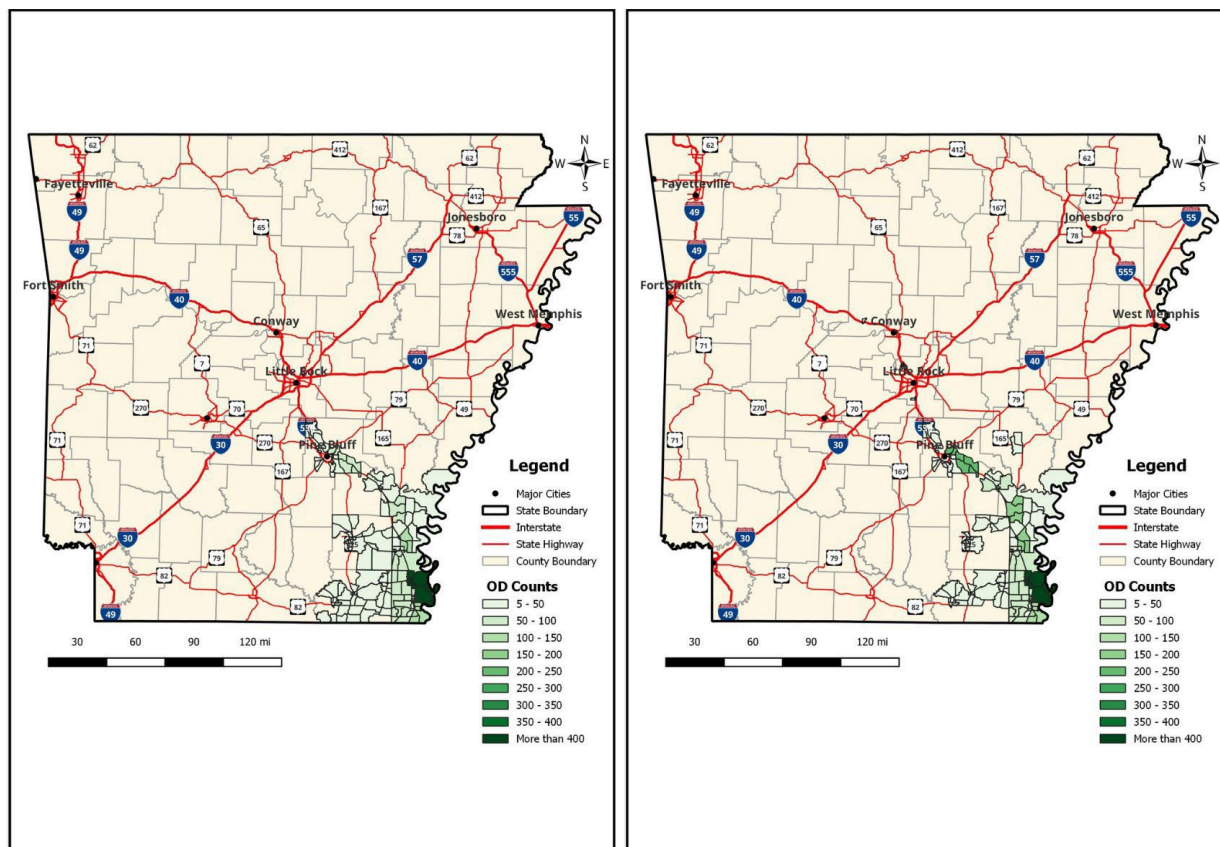


Figure 13. Comparison of Passenger Vehicle Flows from TAZs to the HWY 82 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 Bridge Closure

ANALYSIS OF COMMERCIAL VEHICLE OD USING THIRD-PARTY PROBE DATA

This section describes the changes to OD traffic flow patterns of commercial vehicles observed through third-party probe data, specifically using Geotab data, as a result of the Hernando de Soto bridge closure in 2021. A comprehensive set of maps for the time periods of the Hernando de Soto bridge closure as well as reference periods are shown in Appendix A. In this section we highlight a subset of those maps to illustrate the impact of the closure across the state's four Mississippi River bridges.

During the closure period (May 11 through July 31, 2021), commercial traffic shifted from the closed main I-40 route to each of the other three Mississippi River bridges. Inbound and outbound bridge flows exhibited the same trend. For illustrative purposes, we show the traffic from TAZs to the bridges in Figure 14 through Figure 17.

In each figure, we observe that during the closure of the Hernando de Soto bridge, each bridge captures a wider distribution of commercial traffic from across the state. As a validation of the data, we see that during the I-40 bridge closure, there is no traffic coming from any zone in the state (Figure 14). For I-55, during the closure of I-40, we see a higher volume of traffic coming from the I-30 corridor between Hot Springs and Texarkana and along HWY 64 in Northeast

Arkansas (Figure 15). For the HWY 49 bridge, we see a larger portion of flow coming from I-40 west of Little Rock, likely bypassing I-55 in favor of the HWY 49 bridge while the I-40 bridge was closed (Figure 16). For the HWY 82 bridge, we do not observe a significant portion of traffic shifting as a result of the closure of the I-40 bridge (Figure 17).

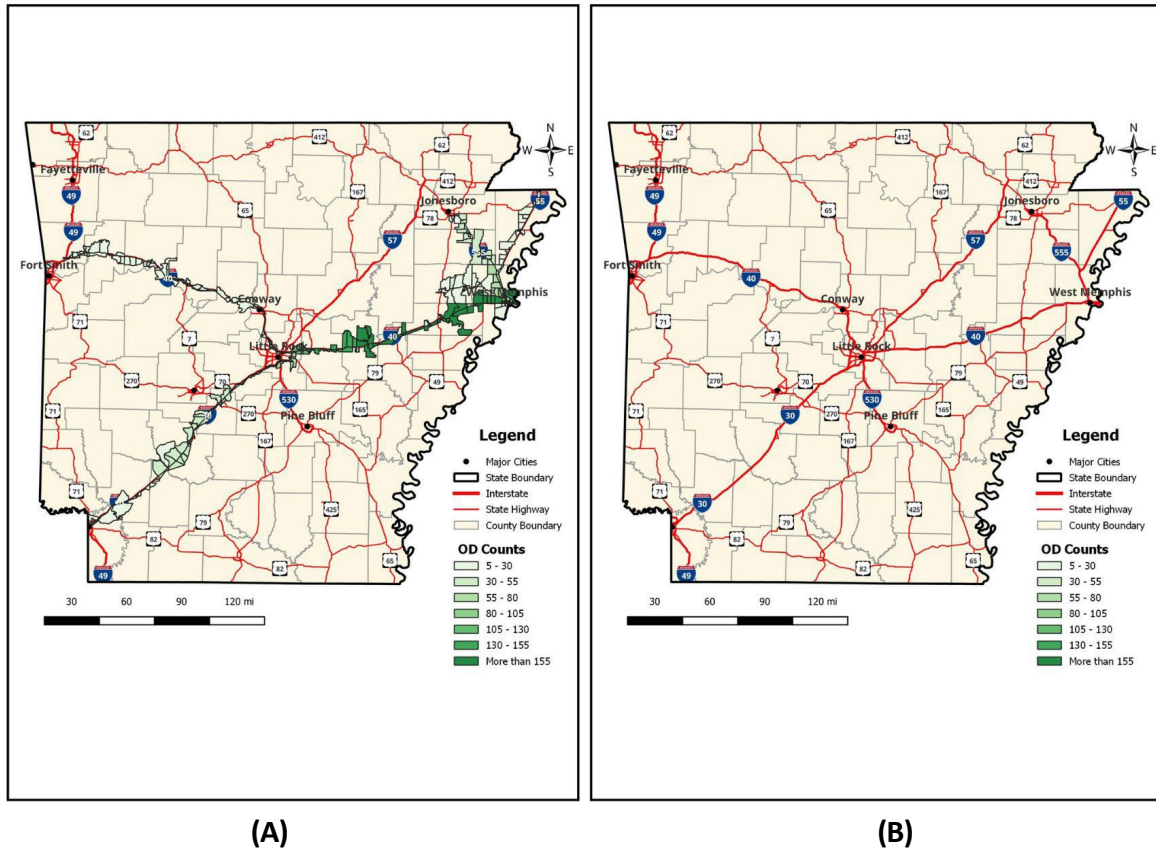


Figure 14. Comparison of Average Daily Commercial Vehicle Flows from TAZs to the I-40 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 bridge closure

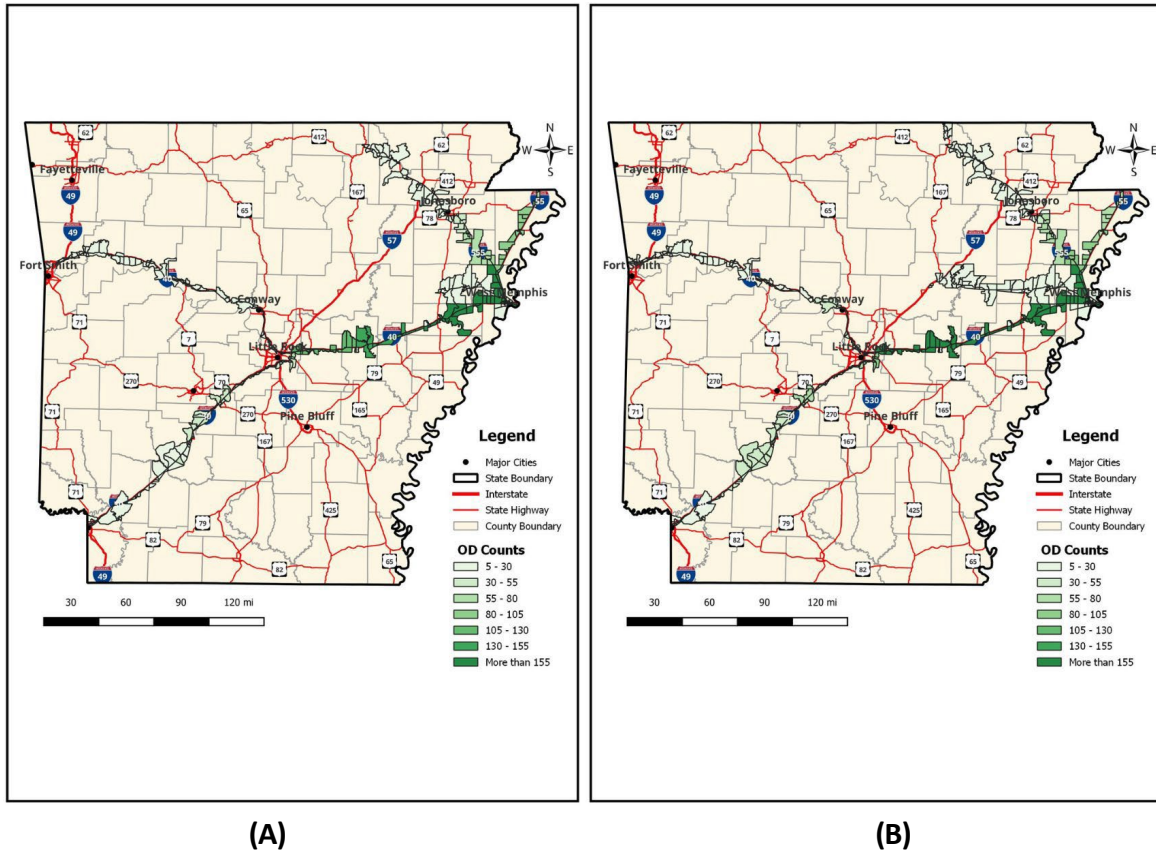


Figure 15. Comparison of Average Daily Commercial Vehicle Flows from TAZs to the I-55 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 bridge closure

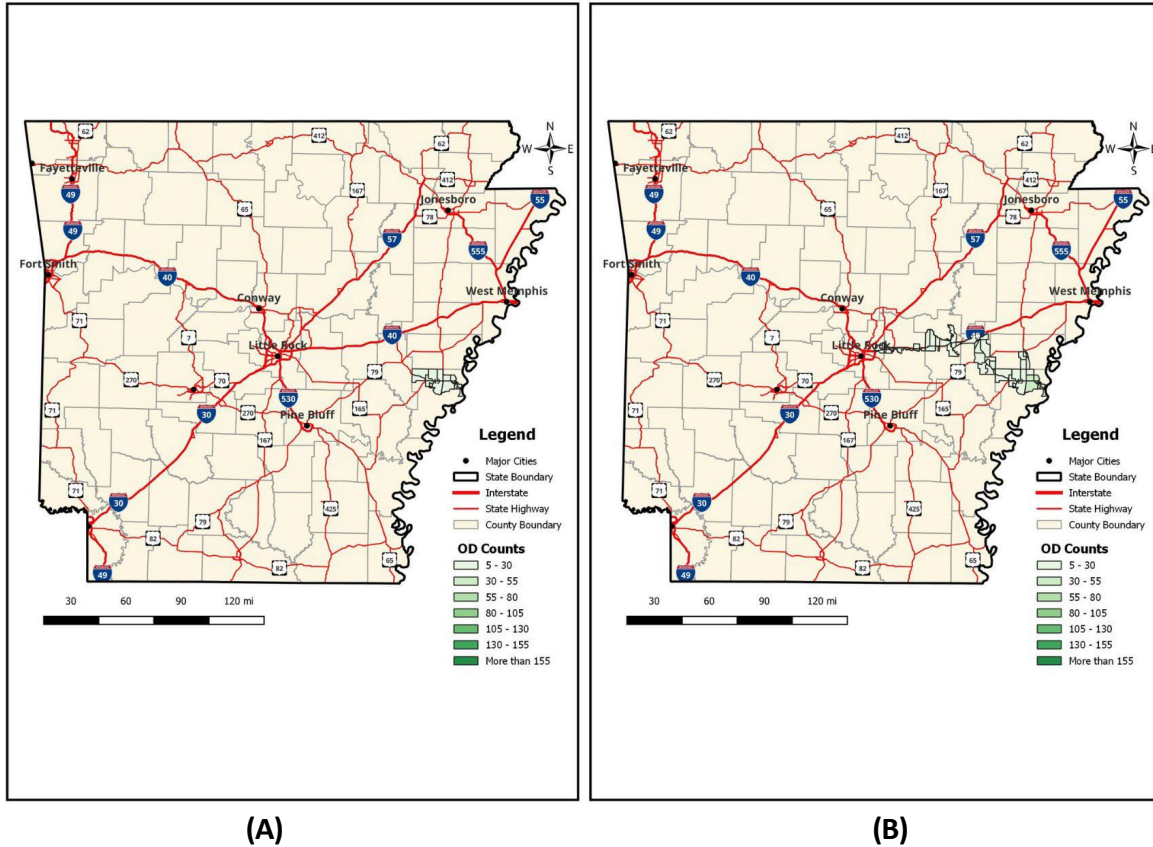


Figure 16. Comparison of Average Daily Commercial Vehicle Flows from TAZs to the HWY 49 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 bridge closure

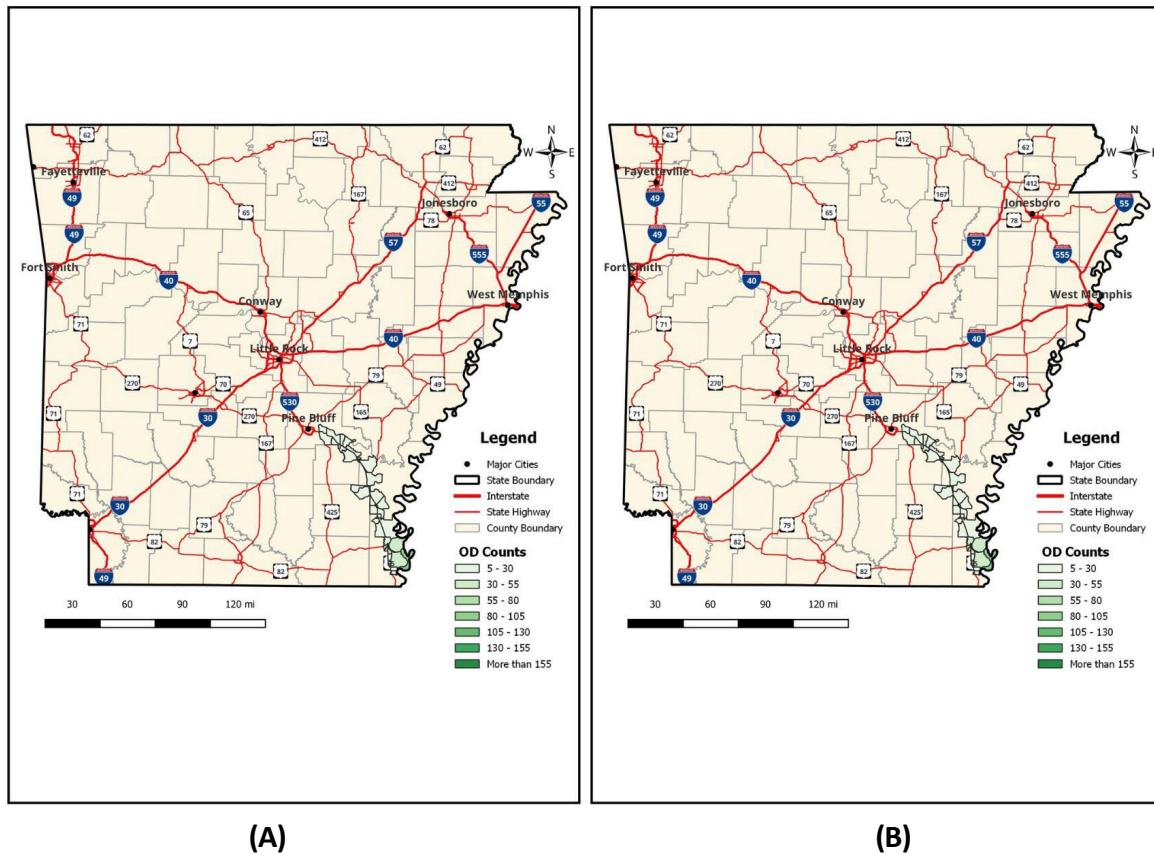


Figure 17. Comparison of Average Daily Commercial Vehicle Flows from TAZs to the HWY 82 bridge (A) before (April 15-30, 2021) and (B) during (May 11 through July 31, 2021) the I-40 bridge closure

CHAPTER 3. ANALYSIS OF POSSIBLE BRIDGE CLOSURE SCENARIOS

This chapter presents the analysis of bridge closure scenarios for the four bridges that cross the Mississippi River in Arkansas. The chapter is divided into three parts: (1) description of methods used to evaluate closure impacts, (2) analysis of roadway and waterway user impacts, and (3) summary of key contributions and findings.

METHODS ADOPTED FOR ARKANSAS BRIDGE CLOSURES

The methods adopted in this work to estimate the impact of bridge closures include Link-level impact estimation using Road User Costs (RUC), System-level impacts using the ARDOT Statewide Travel Demand Model (AR STDM), and a macro-level cost estimation for waterway delays. Each is described in this section. A detailed literature review of the methods used for impact analysis is included in **Appendix B**.

Link-level Impacts on Road User Costs (RUC)

The purpose of estimating RUC is to quantify the economic and safety impacts experienced by motorists and the broader community due to disruptions from work zone activities. These impacts are typically expressed as a daily dollar value. The RUC values presented in this report were calculated using a spreadsheet-based tool developed by ARDOT. This tool was created based on the methodology outlined in the Federal Highway Administration (FHWA) manual titled *Work Zone Road User Costs – Concepts and Applications*⁹, published in December 2011. It incorporates both economic costs (such as travel delay and vehicle operating costs) and safety costs (based on crash modification factors and crash rate changes in work zones). For ongoing and future 'what-if' scenario planning, this spreadsheet methodology was subsequently automated into the interactive web-based application delivered with this project.

The economic component of the RUC is calculated based on the traffic delays and vehicle operating costs. Delays are calculated based on queuing and queue dissipation, which are determined by analyzing lane capacity in relation to traffic demand. Vehicle operating costs consider various factors such as driver value of time (personal and commercial drivers) and vehicle depreciation. These variables are informed by economic indicators published by the U.S. Department of Labor, such as the Consumer Price Index (CPI), Employment Cost Index (ECI), and Producer Price Index (PPI). Using these indices, hourly dollar values are calculated to represent the economic cost per hour for different vehicle classes, including passenger cars, single-unit trucks, and tractor-trailers.

The safety component of RUC is estimated using crash modification factors (CMFs), CMFs are multiplicative values that estimate the proportion of crashes expected after implementing specific roadway changes or countermeasures¹⁰. To calculate the increased crash risk, the crash rate expected under work zone conditions is compared to historical crash data. This difference serves as a multiplier representing the heightened risk associated with the work zone. The safety cost is then calculated as the product of this increased crash risk and the

⁹ <https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop12005/>

¹⁰ <https://cmfclearinghouse.fhwa.dot.gov/>

typical crash cost. These crash costs vary by severity level and are sourced from the *FHWA: Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries* ¹¹.

The RUC spreadsheet is organized into the following tabs: Traffic, Economic Cost, Delay and Operational Cost, Detour Cost, Summary. The content of each tab is summarized below:

- **Traffic Tab:** Contains traffic volume data, vehicle classification, Passenger Car Equivalency (PCE) factors, and ADT inputs.
- **Economic Cost Tab:** Contains pre-set economic unit costs and indices used for delay and vehicle operating cost calculations.
- **Delay and Operational Cost Tab:** Conducts the main RUC calculations by integrating traffic, economic, and construction variables.
- **Detour Cost Tab:** Estimates additional costs due to detour length and travel time changes under full closure scenarios.
- **Summary Tab:** Consolidates output values for total economic and safety-related user costs.

These tabs collectively process the input data to estimate the total RUC under each bridge closure scenario. Video-based traffic counts were provided to the research team by ARDOT for each of the four bridges, except HWY 82. Video-based counts provide traffic volume in 15-minute increments for passenger cars and commercial vehicles. For HWY 82, no direct traffic data was available; however, due to its geometric and functional similarities with HWY 49 (both being two-lane rural highways), HWY 49's traffic counts were used as a proxy. Table 3 summarizes the facility type and the count date for each bridge. This chapter provides a summary of the key findings for RUC for full and partial closures. Full details of the RUC methodology, assumptions, and inputs are provided in Appendix C.

While these historical video counts provided the foundation for the 15-minute time-of-day traffic distributions, the actual daily volumes used in the final analysis are based on 2021/2022 data. To ensure the analysis reflects current conditions, raw volume outputs from the historical ARSTDM were not used directly. Instead, the model was used to calculate the relative percentage change in traffic distribution for each closure scenario compared to the model's baseline. These proportional shifts were then applied to the 2021/2022 Annual Average Daily Traffic (AADT) baseline values. This approach allows the interactive tool to dynamically simulate traffic redistribution for any user-configured closure condition.

Table 3. Traffic Data Collection Summary

Bridge	Facility Type	Traffic Count Data Time Period
I-40	Urban Interstate	Nov 15–16, 2022
I-55	Urban Interstate	Nov 15–16, 2022
HWY 49	Two-lane Rural Highway	May 27–28, 2021

¹¹ <https://www.fhwa.dot.gov/publications/research/safety/05051/>

HWY 82	Two-lane Rural Highway	<i>(15-minute traffic counts for HWY 82 were not available for this research, and HWY 49 counts were used as a proxy.)</i>
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Note: The AADT values presented here represent the 2021/2022 baselines. The interactive web tool developed for this project dynamically reallocates these volumes across the network to simulate specific bridge closure and detour scenarios.

System-level Impacts on Congestion and Delay

The Arkansas Statewide Travel Demand Model (ARSTDM) was used to estimate system-wide impacts of bridge closure scenarios. ARSTDM is a four-step model (trip generation, trip distribution, mode choice, and trip assignment) designed to estimate both passenger and freight movements. The freight component relies on TRANSEARCH freight data to estimate tonnage movements by 15 commodity groups and five transport modes (truck, rail carload, rail intermodal, air, and water). While originally developed in 2005 and not designed for hourly performance outputs, the model remains a useful tool for evaluating traffic impacts through scenario-based comparisons. The model is capable of estimating traffic volumes and travel times across four distinct time periods (Table 4).

Table 4. ARSTDM Time Periods

Period	Time	Time Period
Peak	AM Peak (AM)	6:30 AM – 8:30 AM
	PM Peak (PM)	2:30 PM – 6:30 PM
Off-Peak	Midday (MD)	8:30 AM – 2:30 PM
	Nighttime (NT)	6:30 PM – 6:30 AM

For this analysis, only the assignment step of the ARSTDM was run to evaluate traffic volumes and travel times across closure scenarios, while trip generation and distribution remained fixed under the assumption of unchanged travel demand. The network was modified to remove the links representing the bridge, and the assignment step was rerun.

Model runs included baseline (bridge fully open) and a disruption (bridge fully closed) scenarios. Model results were expressed as percentage changes in VHT to evaluate the broader impacts of the I-40, I-55, HWY 49, and HWY 82 bridges closure. The baseline represents normal conditions in which all roadways and bridges are fully operational. By comparing the full-closure scenario to this baseline, the model enables estimation of percentage changes in VHT, offering a practical and effective method for assessing the broader impacts of infrastructure disruptions, even with an older model structure.

While the ARSTDM allows traffic to reroute along detours that extend beyond Arkansas borders, the level of network detail varies by geography. Inside Arkansas, all roadway types are represented, allowing for detailed estimation of traffic volumes and travel times across the full

network. In contrast, outside the state, the model includes only major roadways, primarily interstates. As a result, while the model does estimate traffic flows and origin-destination (OD) patterns beyond Arkansas, it provides higher spatial resolution within the state. Despite this, the ARSTDM provides sufficient detail to evaluate both link-level and system-level changes in VHT for autos, SUT, and TTT within Arkansas and along primary interstate corridors in surrounding states, offering valuable insights into the broader impacts of major bridge closures, including I-40, I-55, HWY 49, and HWY 82.

The model outputs (Table 5) include the travel times and volumes for each roadway segment, identified by a link ID. Travel time and volume are reported for autos, SUT, and TTT. Free flow and congested travel times are reported for both directions of travel (A node to B node and B to A). The same variables are reported for the fully open and closed bridge scenarios, enabling a consistent basis for comparison.

Table 5. Data Set Variables (Applicable to Both Scenarios)

Variable	Description
link_id	Unique identifier for each road segment
Autos	Auto volume
Single Unit Trucks	Single unit truck volume
Tractor Trailer Trucks	Tractor trailer trucks volume
Congested Time	Congested travel time

The ARSTDM was created in 2005 and has not been updated. To provide reasonable estimates of congestion and delay, ARSTDM scenario results are presented as the percentage change in the performance measure over the base (e.g., free flow) condition. The base condition corresponds to a fully operational highway system in which all bridges (and other roads) are open and fully functional. This procedure was deemed most appropriate by our modeling expert consultant. Note that in the proposal, we outlined a process to use vehicle probe data before, during, and after the closure to update the model. Analysis of the probe data revealed several discrepancies that led to the decision to move to the percentage change approach as a solution handling the older ARSTDM model.

It should be noted that the structure of the zones in the ARSTDM allows traffic to reroute along detours that extend beyond the state borders. The model can be used to estimate the change in traffic volumes along routes that lead outside of the state. For example, traffic diverted from a potential closure of the I-55 or I-40 bridges in West Memphis could divert north to the I-155 bridge between Missouri and Tennessee. The portion of the detour in Arkansas along I-55 north through Blytheville can be represented using the ARSTDM approach with detail. However, the portion of the detour outside the Arkansas border, in Missouri, would simply be represented as an external zone. Lastly, the proposed approach will not capture trips that no longer enter Arkansas and choose to travel on I-20 (Louisiana) or I-70 (Missouri), for example, to avoid delays anticipated from a bridge closure. Doing so would require a regional or national

model for passenger and freight traffic. At this time, there is no regional model for freight, and no regional or national model for passenger traffic.

Impact of Closures on Waterway Traffic

We developed a methodology to estimate the direct costs of waterway freight delays resulting from bridge closures. The objective is to provide ARDOT with a transparent and consistent framework for estimating the financial impact of temporary waterway disruptions, using real-world data from past events and scalable assumptions. This methodology is grounded in publicly available information and past bridge closure events and is structured to allow flexible application to other sites through spatial scaling.

Key Inputs and Assumptions

To perform the analysis, we rely on a core set of inputs that describe the duration and scale of disruption, traffic volumes, and operating costs. Some of these inputs are derived from published data and reports from the I-40 Hernando de Soto Bridge closure in 2021¹² and the American Infrastructure Report Card published by the American Society of Civil Engineers (ASCE)¹³. The following serve as data inputs for the methodology:

- **Closure Duration (days):** The number of days the river is closed to commercial navigation due to a bridge incident.
- **Vessel Backlog:** Based on reports from the Bureau of Transportation Statistics, the nearly three-day closure of the I-40 bridge caused a backlog of 62 tugboats and 1,058 barges [1].
- **Average Daily Tugboat and Barge Counts:** From the reported backlog, we calculate:
 - Tugboats per day: $62 \div 3 = 20.7$
 - Barges per day: $1,058 \div 3 = 353$
- **Barges per Tugboat:** With 1,058 barges moved by 62 tugboats, we assume an average of 17 barges per tugboat.
- **Freight Volume (short tons/day):** According to the U.S. Army Corps of Engineers, the segment of the Mississippi River under the I-40 bridge moves 470,323 short tons of freight per day.
- **Cargo Distribution per Vessel:**
 - Short tons per tug: $470,323 \div 20.7 = 22,721$
 - Short tons per barge: $22,721 \div 17 = 1,337$

¹² "I-40 Bridge Failure Causes Multimodal Challenges | Bureau of Transportation Statistics." Accessed: Apr. 07, 2025. [Online]. Available: <https://www.bts.gov/data-spotlight/i-40-bridge-failure-causes-multimodal-challenges>

¹³ "Inland-Waterways-2021.pdf." Accessed: Jan. 03, 2024. [Online]. Available: <https://infrastructurereportcard.org/wp-content/uploads/2020/12/Inland-Waterways-2021.pdf>

- **Hourly Delay Cost per Tugboat:** Based on national estimates derived from the ASCE [2], we used a fixed cost of \$739 (maximum) per hour for tugboat delays.

These assumptions were used to define standard parameters for daily vessel throughput and per-vessel freight capacity.

AIS Data Acquisition and Insights

Vessel-tracking records were obtained from the U.S. Army Corps of Engineers' (USACE) Marine Cadastre AIS portal¹⁴. This interactive web tool allows users to draw a geographic bounding box around any area of interest and to specify a date range for which AIS messages are desired. Once the spatial and temporal filters are set, the portal generates a data request that can be submitted for download.

The resulting dataset includes timestamped position, speed, and heading information for all vessels within the box, which we then process to count monthly upstream and downstream crossings at each bridge screenline.

To convert this raw AIS data into meaningful traffic metrics, each vessel's discrete AIS points was connected to form continuous paths. Figure 18 illustrates this data processing method for a typical day's traffic at the I-40 bridge. The left panel shows the raw, scattered AIS points as they are received, while the right panel displays the reconstructed vessel trajectories. This reconstruction is essential for identifying unique vessel trips and determining their direction of travel as they pass under the bridge, allowing for an accurate count of upstream and downstream crossings.

Estimation process for Waterway Closure Costs

The estimation of waterway closure impacts as costs follows these steps:

1. **Estimate Daily Tugboat Throughput:** The daily tugboat throughput for each bridge location is directly defined by its specific AADT volume. These AADT values represent the average number of tugs and tows crossing at each site on a typical day (Figure 18).
2. **Estimate Total Delay Cost:** Multiply the AADT by the delay cost per hour and the duration of closure (hours)
3. **Estimate Disrupted Freight:** Multiply AADT by tonnage per tug (22,721) to estimate delayed cargo per day.
4. **Scale Across Bridges:** For each bridge, the total economic and freight impacts of a closure are calculated directly using its specific AADT. The total delay cost is estimated by multiplying the bridge's AADT by the delay cost per hour and the duration of the closure. Similarly, the total tonnage of disrupted freight is determined by multiplying the AADT by the average tonnage per tug. This approach ensures the estimated impacts are tailored to the unique traffic characteristics of each location.

¹⁴ "MarineCadastre.gov | Vessel Traffic Data." Accessed: Aug. 31, 2023. [Online]. Available: <https://marinecadastre.gov/ais/>



Figure 18. From raw data to vessel tracks at the I-40 bridge. The scattered points on the left are processed to create the clear vessel trajectories shown on the right

The methodology is intended to produce simple, transparent cost estimates based on historical data and national cost assumptions. However, it has limitations:

- The hourly delay cost per tugboat is a fixed average and does not reflect variation in vessel type, cargo, or market conditions.
- The estimates are based on a single event and assume similar vessel operating patterns at other bridge locations.
- The method focuses on direct delay costs and does not account for indirect economic impacts such as missed shipments, congestion, or inventory disruptions.
- It does not include costs related to environmental risks, public safety, or administrative responses.

Despite these limitations, the framework is designed for adaptability. Parameters can be updated as new data becomes available, and the structure allows scaling across different bridge locations. It fills an important gap in estimating waterway impacts from bridge closures and supports ARDOT's goal of building a complete picture of multimodal closure costs.

ANALYSIS OF MULTIMODAL IMPACTS FOR MISSISSIPPI RIVER BRIDGES IN ARKANSAS

In this section we present the impacts of individual bridge closures on Link-level road user costs and on System-level congestion and delay. There are four bridges included in the analysis.

Impacts of Bridge Closures on Roadway Users

This section presents an analysis of the impacts associated with closure of each bridge. The analysis considered: (1) a complete bridge closure (full closure) in which both directions of travel across the bridge are restricted from travel, and (2) a partial bridge closure in which one or more lanes are closed. Unlike previous static analyses, the automated RUC application can evaluate disproportional restrictions of capacity by direction (e.g., asymmetric lane closures) as well as full directional closures, seamlessly integrating these specific configurations into both the link-level RUC and system-level estimates.

The following assumptions apply to all bridges for the full closure scenario when estimating RUC using the automated application (which utilizes the underlying ARDOT templates):

- Flagging operations are only applicable when a single shared lane is used for alternating two-way traffic. Since a full closure detours all traffic and leaves no lanes open, flagging is not required, and flagging costs are excluded.
- Diversion costs are omitted as traffic is expected to follow designated detour routes without significant unplanned redistribution.
- Queueing costs are not included since a full bridge closure eliminates the need for time-of-day lane closures, meaning peak-hour congestion within the work zone is not a factor.
- Crash costs do not apply under the full-closure scenario because there is no active drive-through work zone.

The following assumptions apply to all bridges for the partial closure scenario when estimating RUC using the automated application (which utilizes the underlying ARDOT templates):

- In a partial closure, one lane is closed in each direction while the remaining lanes stay open, allowing continuous two-way traffic. Since alternating flow is not required, flagging operations are unnecessary, and flagging costs are excluded from the analysis.
- Diversion costs are omitted because at least one lane remains open in each direction, allowing traffic to continue flowing.
- Queueing costs are not included since the partial closure remains in place all day, and the analysis does not isolate peak-hour traffic congestion.
- Detour costs do not apply in the partial bridge closure scenario, as cars can still pass through the bridge.

I-40 Hernando de Soto Bridge

This section describes the daily financial impacts of full and partial closures on the I-40 Hernando de Soto Bridge. The I-40 bridge consists of 6 lanes, with 3 lanes in each direction.

Under a full closure scenario, both directions of travel on I-40 are completely restricted. Because no traffic can traverse bridge, the localized road user costs on I-40 drop to zero. The traffic demand is instead redistributed across the regional network based on the Arkansas

Statewide Travel Demand Model (ARSTDm) gravity distribution. The true cost of an I-40 full closure is measured by the additional friction placed on these detour routes, totaling \$198,625 per day. Table 6 details these daily RUC, specifically the added delay, added mileage, and the refined safety risks associated with the diverted traffic.

For partial closures, localized work zone costs are evaluated for the traffic remaining on I-40. When one lane is open in each direction (leaving 2 lanes closed), the total daily scenario cost rises sharply to \$2,382,823. The primary driver of this RUC is localized user delay caused by the severe work zone bottleneck, which accounts for \$2,217,214 of the total daily impact (Table 7).

Table 6. Network Detour Costs for I-40 Full Bridge Closure (Per Day)

Detour Route	Direction	Added Delay Cost	Added Mileage Cost	Added Safety Cost	Total Route Cost
I-55	EB	\$19,039	\$11,823	\$1,168	\$32,030
	WB	\$21,825	\$13,538	\$1,340	\$36,703
HWY 49	EB	\$33,200	\$29,249	\$2,497	\$64,946
	WB	\$33,200	\$29,249	\$2,497	\$64,946
HWY 82	-	-	-	-	-
	-	-	-	-	-
Total Scenario Cost					\$198,625

Table 7. Detailed User Costs for I-40 Partial Bridge Closure (Per Day)

Impact Category	Impact Type	Bridge	Direction	Delay	Operating	Crash	Total Daily Cost
Localized Work Zone (I-40)	User Costs	I-40	EB	\$785,760	\$28,893	\$10,300	\$824,953
		I-40	WB	\$1,431,454	\$47,173	\$10,300	\$1,488,927
				Added Delay	Added Mileage	Added Safety	Total Daily Cost
Detour Routes (System-wide)	Added Costs	I-55	EB	\$46	\$29	\$3	\$78
			WB	\$53	\$33	\$3	\$89
		HWY 49	EB	\$17,579	\$15,487	\$1,322	\$34,388
			WB	\$17,579	\$15,487	\$1,322	\$34,388
Total Scenario Cost							\$2,382,823

I-55 Memphis-Arkansas Bridge

This section describes the daily financial impacts of full and partial closures on the I-55 Memphis-Arkansas Bridge. The I-55 bridge has four lanes, with two lanes in each direction.

Under a full closure scenario, both directions of travel on I-55 are completely restricted, causing localized road user costs on the bridge itself to drop to zero. Instead, traffic redistributes to alternate routes across the network. The estimated total daily cost for an I-55 full closure is \$250,691. As shown in Table 8, the nearby I-40 bridge absorbs the entirety of these added detour costs, with specific impacts on travel delay, vehicle mileage, and normalized safety risk.

For a partial closure, the analysis evaluated closing one lane in each direction, leaving a single lane open each way. This scenario splits the financial impact into two categories: a portion of the traffic remains on I-55 and experiences localized work zone friction, while the remaining traffic detours to alternate routes to avoid the bottleneck. Table 9 summarizes these combined impacts, showing a total daily Road User Cost (RUC) of \$915,416. The largest contributor to this total remains the localized user delay on I-55, representing \$859,168 per day due to severe traffic queuing at the single-lane work zone.

Table 8. Detailed User Costs for I-55 Full Bridge Closure (Per Day)

Detour Route	Direction	Added Delay Cost	Added Mileage Cost	Added Safety Cost	Total Route Cost
I-40	EB	\$62,424	\$48,705	\$5,698	\$116,827
	WB	\$71,559	\$55,769	\$6,536	\$133,864
HWY 49	-	-	-	-	-
	-	-	-	-	-
HWY 82	-	-	-	-	-
	-	-	-	-	-
Total Scenario Cost					\$250,691

Table 9. Detailed User Costs for I-55 Partial Bridge Closure (Per Day)

Impact Category	Impact Type	Bridge	Direction	Delay	Operating	Crash	Total Daily Cost
Localized Work Zone (I-55)	User Costs	I-55	EB	\$132,003	\$10,024	\$5,959	\$147,986
		I-55	WB	\$727,165	\$29,536	\$5,959	\$762,660
				Added Delay	Added Mileage	Added Safety	
Detour Routes (System-wide)	Added Costs	I-40	EB	\$1,188	\$927	\$108	\$2,223
			WB	\$1,362	\$1,061	\$124	\$2,547
Total Scenario Cost							\$915,416

HWY 49 Helena Bridge

This section describes the daily financial impacts of a full closure on the HWY 49 Helena Bridge, which carries an average daily traffic volume of 3,900 vehicles. The bridge has two lanes, with one in each direction. Because of this, a partial closure is not an option. Any maintenance on a lane requires a full directional closure, forcing all traffic to use a detour.

Under a full closure scenario, road user costs on the bridge itself drop to zero because no traffic can pass through the work zone. The traffic demand is instead reassigned to the remaining Mississippi River crossings at I-40, I-55, and HWY 82. Table 10 details the daily Road User Costs (RUC) incurred by this diverted traffic.

The total estimated cost for a HWY 49 full closure is \$19,927 per day. The financial impact is driven by the added delay and mileage costs accumulated over the long detour routes. These costs are distributed across the alternate routes to I-40, I-55, and HWY 82, with the safety component representing the crash risk associated with the increased travel distance.

Table 10. Detailed User Costs for HWY 49 Full Bridge Closure (Per Day)

Detour Route	Direction	Added Delay	Added Mileage	Added Safety	Total Route
I-40	EB	\$3,194	\$2,802	\$328	\$6,324
	WB	\$3,661	\$3,208	\$376	\$7,245
I-55	EB	\$1,143	\$1,032	\$102	\$2,277
	WB	\$1,310	\$1,182	\$117	\$2,609
HWY 82	EB	\$377	\$340	\$19	\$736
	WB	\$377	\$340	\$19	\$736
Total Scenario Cost					\$19,927

HWY 82 Greenville Bridge

This section describes the daily financial impacts of a full closure on the HWY 82 Greenville Bridge. Similar to the HWY 49 bridge, HWY 82 consists of only two lanes with one lane in each direction. Because a partial lane closure is not feasible without completely halting a direction of travel, any lane restriction requires a full closure and detours all traffic.

Under a full closure scenario, no vehicles can pass through the HWY 82 work zone, meaning localized road user costs drop to zero. The traffic demand instead redistributes to alternate crossings, pushing the financial impact onto the detour routes. Table 11 details the daily Road User Costs (RUC) incurred by this diverted traffic.

The total estimated cost for a HWY 82 full closure is \$994,762 per day. As shown in the table, the diverted traffic relies heavily on the Highway 49 bridge. The largest financial contributors to this daily RUC are the added delay and added mileage costs, representing \$490,826 and \$464,300 per day respectively. Added safety costs make up the remainder of the detour penalty at \$39,636 per day.

Table 11. Detailed User Costs for HWY 82 Full Bridge Closure (Per Day)

Detour Route	Direction	Added Delay Cost	Added Mileage Cost	Added Safety Cost	Total Route Cost
HWY 49	EB	\$245,413	\$232,150	\$19,818	\$497,381
	WB	\$245,413	\$232,150	\$19,818	\$497,381
Total Scenario Cost					\$994,762

Impacts of Bridge Closures on System Performance

This section outlines the results of the ARSTDM model runs on bridge closure scenarios. In total, 2,303 scenarios were evaluated. The scenarios include all combinations of full and partial closures across the four Mississippi River bridges in Arkansas. The scenarios include evaluating the AM, midday, PM, and off-peak periods. All scenarios and time periods can be explored dynamically in the interactive web tool associated with this project. In this section we present key findings that include full closure scenarios for each bridge during the most impactful time period and the most impactful scenarios for combinations of bridges. The evaluation was conducted for personal vehicles (autos), single-unit trucks (SUT), and tractor-trailer trucks (TTT), with results centered on the most critical time period identified for each scenario. Altogether, 15 scenarios are presented here: the worst-case time period for each bridge full closure across three vehicle types (12 scenarios) plus the overall worst-case scenario for each vehicle type (3 scenarios).

Study Area

To capture the effects of the bridges closure beyond their immediate area and to understand their broader regional implications, the study area includes adjacent and surrounding states (Figure 19): Mississippi (MS), Missouri (MO), Kansas (KS), Louisiana (LA), Texas (TX), Oklahoma (OK), Alabama (AL), Kentucky (KY), Ohio (OH), Indiana (IN), Illinois (IL), Georgia (GA), Florida (FL), South Carolina (SC), North Carolina (NC), Virginia (VA), and West Virginia (WV). These states were selected for two key reasons: first, their geographic proximity to Arkansas positions them along major detour routes when any of the Mississippi River bridges are closed; second, preliminary analyses revealed that several links beyond the immediately adjacent states exhibited notable percentage increases in VHT during the bridge closure scenarios.

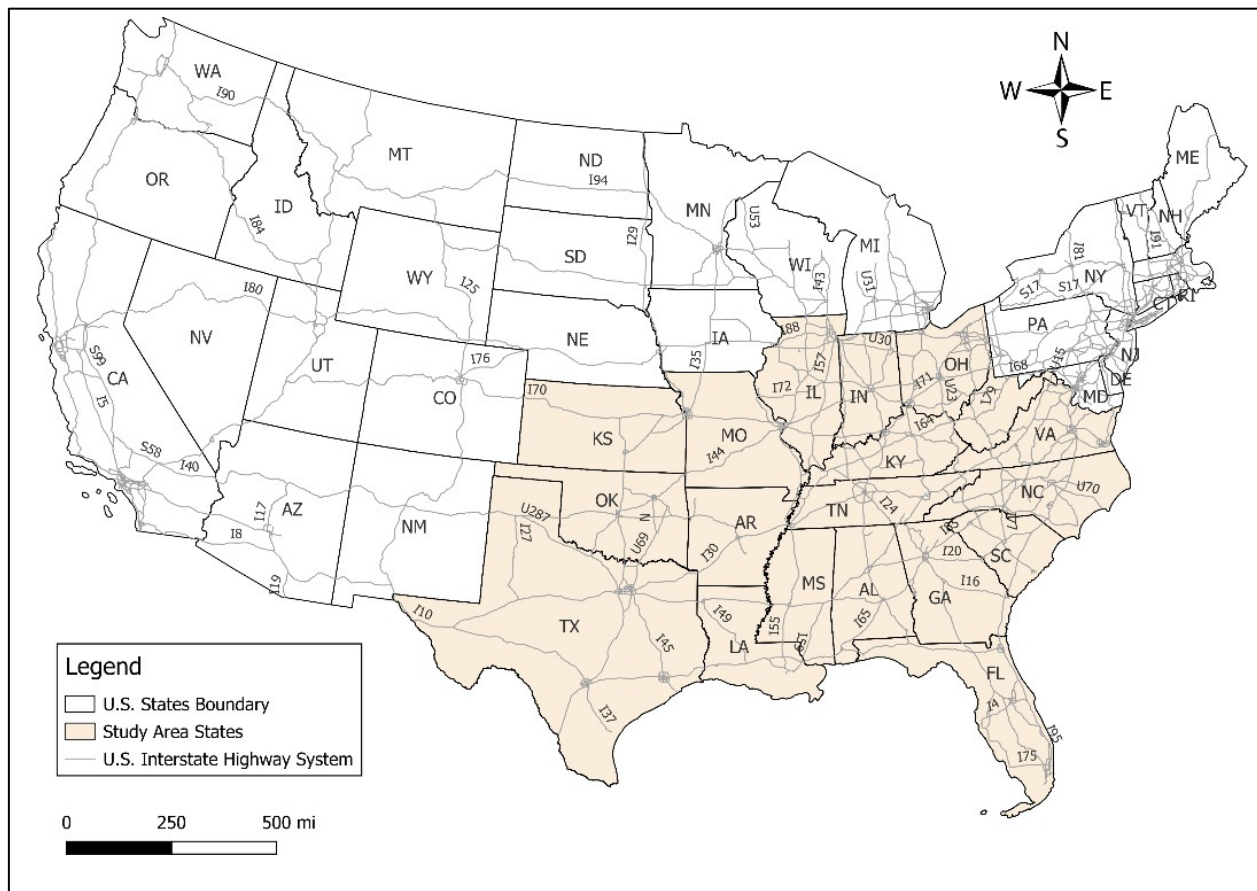


Figure 19. Study Area States Selected to Assess the I-40, I-55, HWY 49, and HWY 82 Bridges

Scenarios Considered

A total of six scenarios were modeled to evaluate the impacts of Mississippi River bridge closures on VHT. These include the baseline scenario, in which all bridges are fully open, and four scenarios where each of the study bridges (I-40, I-55, HWY 49, and HWY 82) is completely closed. In addition to these full-closure cases, one additional scenario with a different lane-closure configuration was also modeled. This structure ensures that the analysis captures both bridge-specific disruptions and the most critical impacts by vehicle type at the System-level.

The table below summarizes directional lane availability for each scenario presented in this report. Each row represents a different scenario, while each column corresponds to a bridge segment in one direction. The last scenario listed (e.g., 1350) reflects the worst case (highest VHT impact) scenario with the following lane configuration: HWY 49 eastbound fully open with westbound fully closed, HWY 82 fully open, I-40 eastbound with two lanes open and westbound fully closed, and I-55 fully closed.

- A green check (✓) indicates the segment is fully open.
- A yellow warning (⚠) indicates partial availability (e.g., only one or two lanes open).
- A red cross (✖) indicates a full closure in that direction.

Scenario	HWY 49 EB	HWY 49 WB	HWY 82 EB	HWY 82 WB	I-40 EB	I-40 WB	I-55 EB	I-55 WB
I-40 Fully Closed (1223)	✓	✓	✓	✓	➡	➡	✓	✓
I-55 Fully Closed (2287)	✓	✓	✓	✓	✓	✓	➡	➡
Hwy 49 Fully Closed (2266)	➡	➡	✓	✓	✓	✓	✓	✓
HWY 82 Fully Closed (1133)	✓	✓	➡	➡	✓	✓	✓	✓
Full System Functional (2303)	✓	✓	✓	✓	✓	✓	✓	✓
Worst Case Scenario (1350)	✓	➡	✓	✓	➡	➡	➡	➡

Selection of Time Periods for Presentation in Report

The PM peak period was consistently the most critical across all full bridge closure scenarios on each vehicle type, producing the largest increases in VHT at the System-level. However, when the analysis was disaggregated by vehicle type the worst-case closure configuration for autos, single-unit trucks (SUT), and tractor-trailer trucks (TTT) occurred during the AM period under Scenario 1350. Based on these findings, the analysis focused only on the worst-case conditions by selecting the most critical time period for each scenario. The selected period was then used as the basis for VHT computation and spatial visualization.

VHT was then calculated for each vehicle type (Autos, SUT, and TTT) and direction of travel by multiplying vehicle volume by congested travel time (Equation 1). Separate calculations were performed for autos, SUT, and TTT in both directions (A→B and B→A). Directional values were then summed to obtain the total VHT for each vehicle type (Equation 2).

$$VVVVV_{dd,tt} = VVVVVVVVVV_{dd,tt} \times CCVV_{dd} \quad (1)$$

$$VVVVV_{tt} = VVVVV_{AAA,tt} + VVVVV_{AAA,tt} \quad (2)$$

Where:

d = Direction of travel: AB (from point A to B) or BA (from point B to A)

t = vehicle type (Auto, SUT = Single Unit Trucks, and TTT = Tractor Trailer Trucks)

VHT _{d, t} = Vehicle Hours Traveled for vehicle type t in direction d

Volume $_{d,t}$ = Volume for vehicle type t in direction d

CT _{d} = Congested travel time in direction d

VHT _{t} = Total VHT for vehicle type t summed over both directions

Once VHT was computed for the most critical time period and scenario, the percentage change in VHT between the open-bridge baseline and the full-closure scenario was calculated separately for each vehicle type (Equation 3).

$$\% \Delta VHT = \frac{VHT_{closed} - VHT_{open}}{VHT_{open}} \times 100 \quad (3)$$

Where:

% Δ VHT = Percentage change in VHT between scenarios

VHT_{closed} = Total VHT under the bridge closure scenario

VHT_{open} = Total VHT under the fully open scenario

This metric reflects the relative change in vehicle travel time across roadway segments due to each bridge closure. To assess regional impacts of each bridge closure, a spatial analysis was conducted using the percentage differences in VHT for each roadway segment.

Cumulative distribution plots were generated for each of the vehicle types to identify a consistent threshold for distinguishing the most affected segments. The cumulative distribution used to establish this threshold was generated from the I-40 full-closure scenario (Scenario 1223) on the PM period. The I-40 crossing was selected because it carries the highest average daily traffic (ADT) among the four bridges, producing the widest range of network impacts and the most representative distribution of VHT changes. This threshold was applied consistently across all bridges and vehicle types to allow comparable results across the study.

The cumulative distribution plot (Figure 20) shows that most roadway links experienced relatively small percentage increases in VHT, as indicated by the steep initial rise of the curve. Beyond approximately 4%, the slope of the curve begins to flatten, meaning that additional links contributing to higher percentage increases represent only a small share of the total network mileage. In other words, the plot demonstrates that links exceeding the 4% threshold fall within the long, flat tail of the distribution, capturing only the most severely impacted roadway segments.

Using this threshold, a spatial visualization was created in QGIS to map the geographic distribution of impacted roadway segments. The mapping was performed only for the most critical time period identified in each scenario rather than for all four periods. Segments with percentage increases in VHT below 0% were excluded, as they represent improved travel conditions. The remaining segments were categorized into the following impact levels: 0%, 0–1%, 1–2%, 2–3%, 3–4%, and greater than 4%. Segments exceeding the 4% threshold represented where each vehicle type traffic was most disrupted due to the bridge closure.

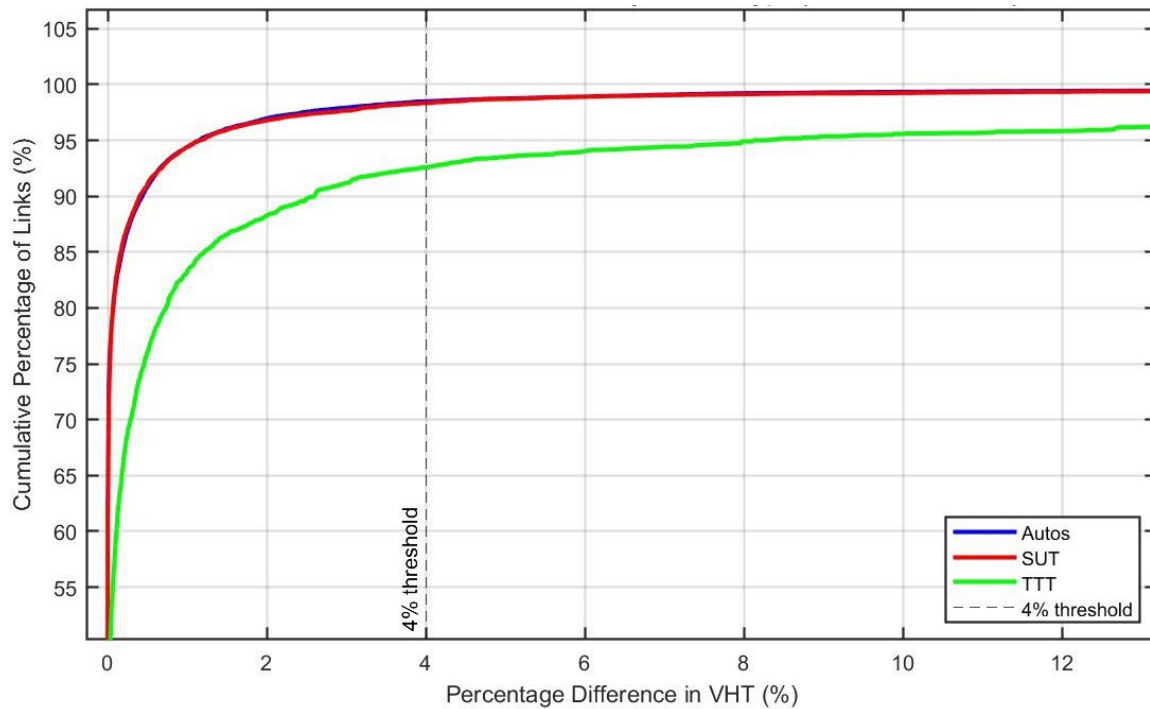


Figure 20. Cumulative Distribution of Percentage Change in VHT Across Each Vehicle Type on Scenario 1223, I-40 Full Bridge Closure

VHT Impacts by Bridge Closure Scenario

This section presents the results of the spatial visualization of the VHT analysis under full-closure scenarios for the four study bridges. For each bridge, results are shown separately for autos, SUT, and TTT, focusing on the most critical time period identified in the methodology. In addition, this section presents the results of the VHT analysis for the worst-case scenarios by vehicle type. Mileage values reported in the map legends correspond to the entire modeled network across the study area states, even when the visualization is focused on Arkansas.

I-40 Closure Scenario

In this section we present the results for autos, SUT, and TT during the PM period for the full closure scenario of I-40.

Autos

Under the I-40 full closure scenario during the PM peak period, most roadway segments in Arkansas showed 1% change or no change in VHT for autos. Out of the total network, approximately 57,078 miles of roadway showed no difference in VHT between the open and closed bridge conditions, while about 13,117 miles experienced increases of less than 1%. Because the roadway mileage in the broader study area exhibited 0% change in VHT, a map of the entire study area is not provided; instead, the results focus on Arkansas and adjacent corridors where impacts were concentrated.

Although the legend mileage values apply to the entire network, the spatial visualization highlights that the most pronounced auto impacts were geographically concentrated in Arkansas, particularly around the I-40 corridor near West Memphis, in central Arkansas near Little Rock, and in Northwest Arkansas. This suggests that while the overall regional network

impact for autos was mostly 1% change or no change in VHT, certain key cities in Arkansas experienced congestion effects due to the I-40 Hernando de Soto Bridge closure.

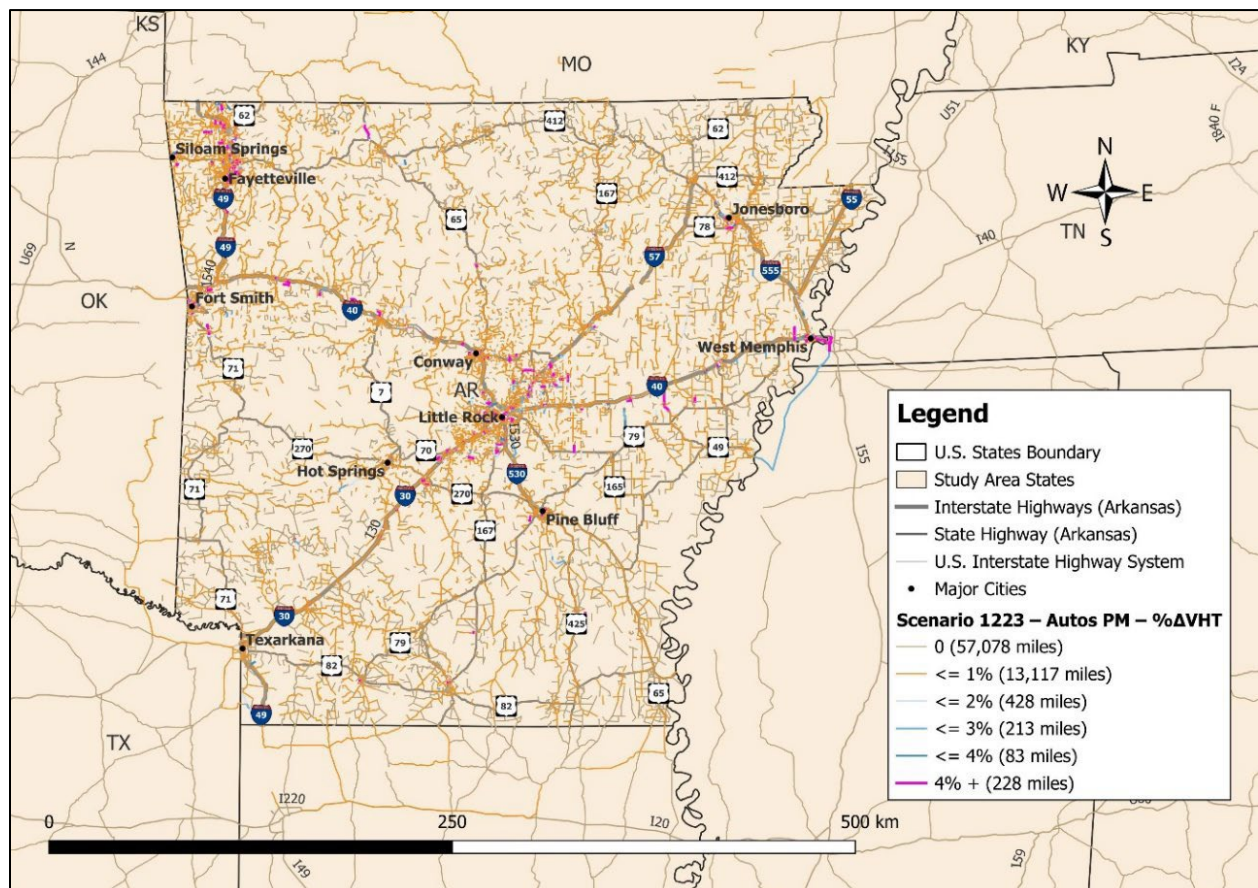


Figure 21. Percentage Difference in VHT for Autos During the PM Period Under a Full Closure of the I-40 Bridge

Single Unit Trucks

In the I-40 full-closure scenario during the PM peak period, the majority of roadway mileage across the study area network experienced 1% change or no change in VHT for SUT. Approximately 57,353 miles were unaffected, while about 13,059 miles recorded increases of less than 1%, indicating low impacts for most of the network.

The overall pattern for SUT was similar to autos, with most of the network unaffected and the highest concentration of impacts occurring along the I-40 corridor near West Memphis, Little Rock, and Northwest Arkansas.

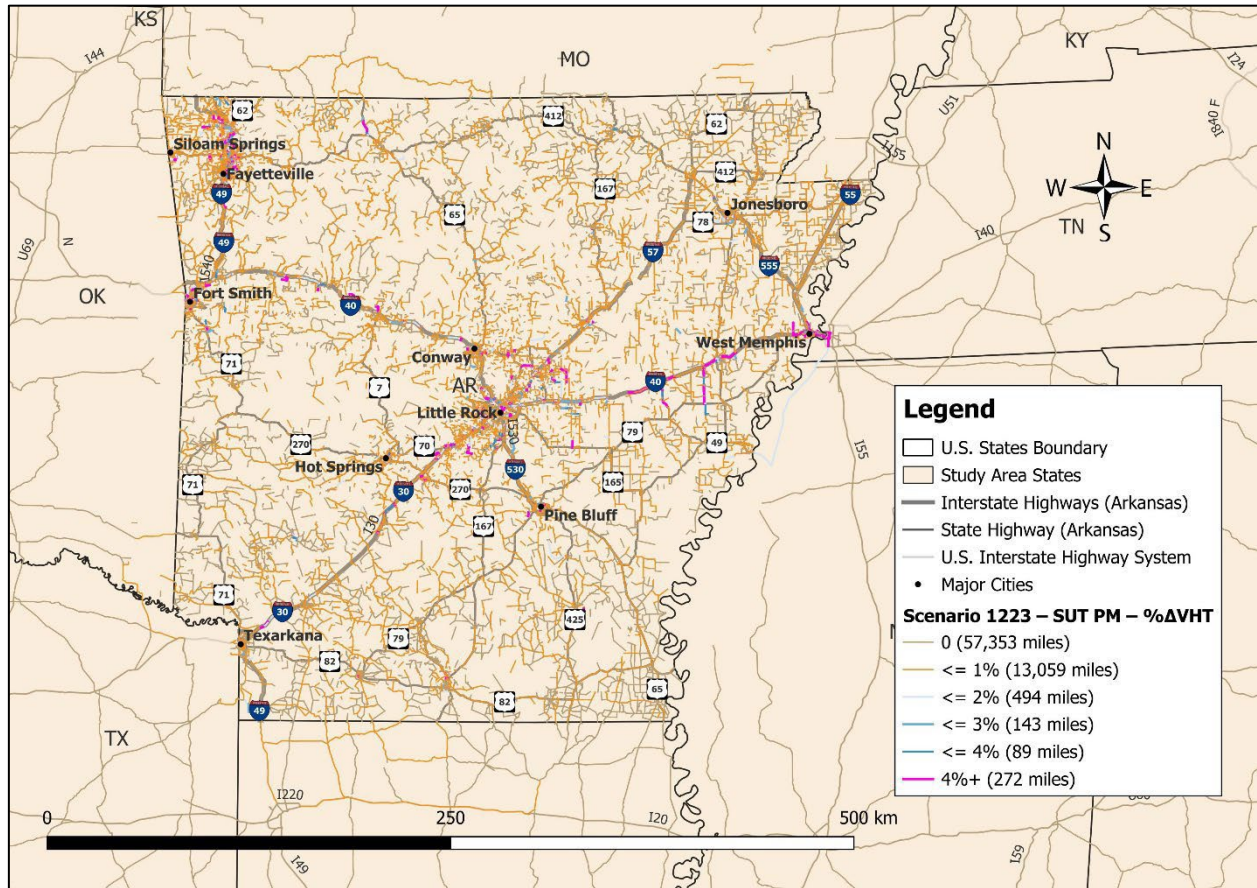


Figure 22. Percentage Difference in VHT for SUT During the PM Period Under a Full Closure of the I-40 Bridge

Tractor Trailer Trucks

TTT experienced greater VHT impacts than autos and single-unit trucks, both within Arkansas and across the broader study area. Across the full study area network, only 17,274 miles showed no difference in VHT, while links exceeding the 4% threshold totaled 6,902 miles; far higher than the mileage observed for autos (228 miles) and SUT (272 miles).

At the Arkansas level (Figure 23), high-impact segments were concentrated along the I-40 corridor, Little Rock, and Northwest Arkansas (Figure 24). Disruptions also extended beyond Arkansas, affecting major interstate freight routes across the South and Midwest. Corridors with over 4% increases in VHT included I-60/I-70 starting in Virginia, continuing through Kentucky and Missouri, and connecting westward into Kansas via I-70. In the South, I-20 from Georgia to Texas also experienced 4% or more increases in VHT. The widespread nature of these impacts on major freight corridors highlights the importance of the I-40 crossing, with tractor-trailer flows rerouting to parallel interstate corridors hundreds of miles away from the closure point.

Overall, the results confirm that tractor-trailer trucks experienced the most extensive and severe disruptions of all vehicle types due to the I-40 bridge closure, with impacts not only concentrated within Arkansas but also spread across the broader freight network.

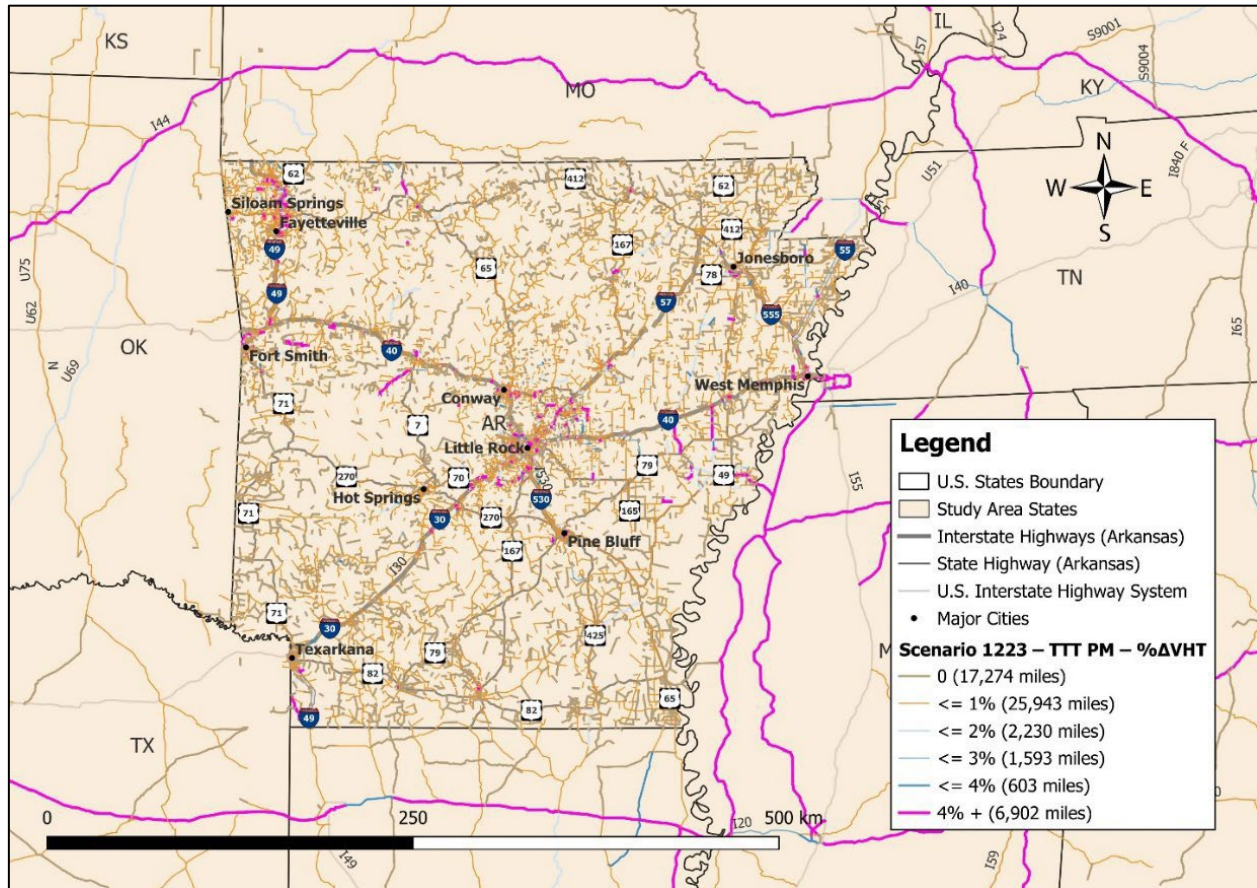


Figure 23. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the I-40 Bridge (Arkansas View)

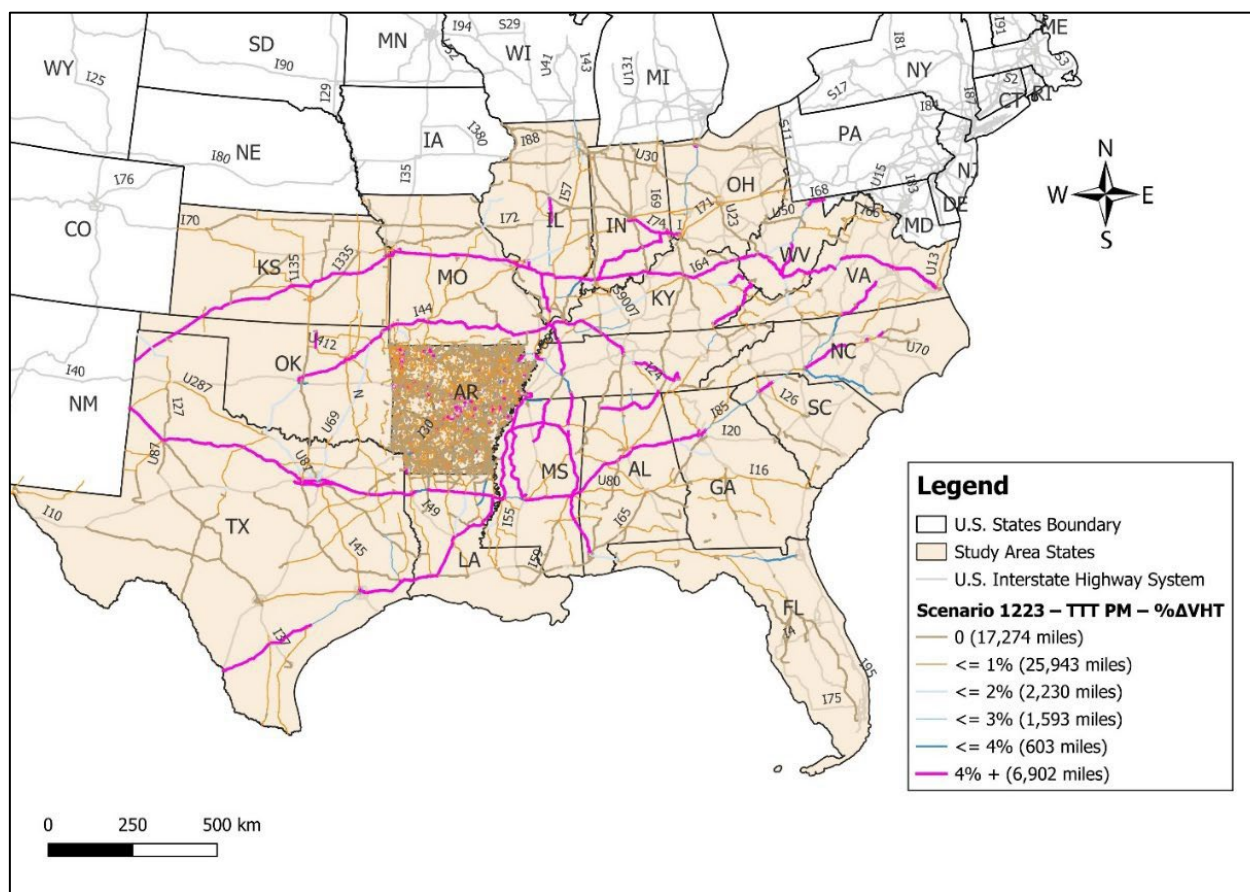


Figure 24. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the I-40 Bridge (Whole Study Area View)

I-55 Closure Scenario

In this section we present the results for autos, SUT, and TT during the PM period for the full closure scenario of I-55.

Autos

In the I-55 full closure scenario, 53,463 miles of the roadway mileage across the full study area experienced no change in VHT for autos, while 260 miles exceeded the 4% threshold, representing the most impacted corridors.

Because the roadway mileage in the broader study area exhibited 0% change in VHT, a map of the entire study area is not provided; instead, the results focus on Arkansas and adjacent corridors where impacts were concentrated (Figure 25). Within Arkansas, high-impact segments were observed primarily along the I-40 corridor near West Memphis, as autos rerouted to alternative crossings. Additional disruptions were visible in Little Rock and Northwest Arkansas.

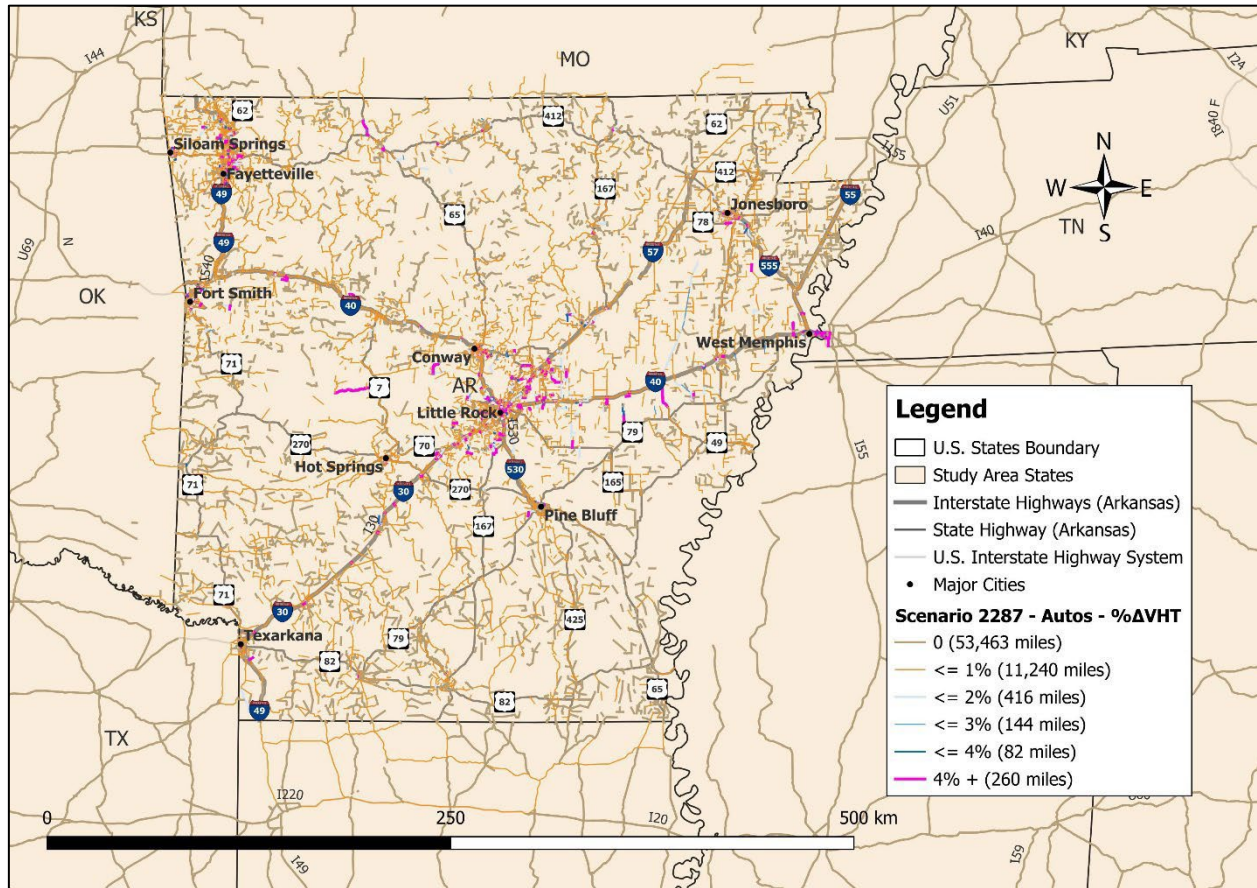


Figure 25. Percentage Difference in VHT for Autos During the PM Period Under a Full Closure of the I-55 Bridge

Single Unit Trucks

In the I-55 full-closure scenario, the majority of roadway mileage across the study area network experienced 1% change or no change in VHT for SUT. 54,390 miles were unaffected, while about 11,776 miles recorded increases of less than 1%, indicating low impacts for most of the network.

The overall pattern for SUT was similar to autos, with most of the network unaffected and the highest concentration of impacts occurring along the I-40 corridor near West Memphis, Little Rock, and Northwest Arkansas.

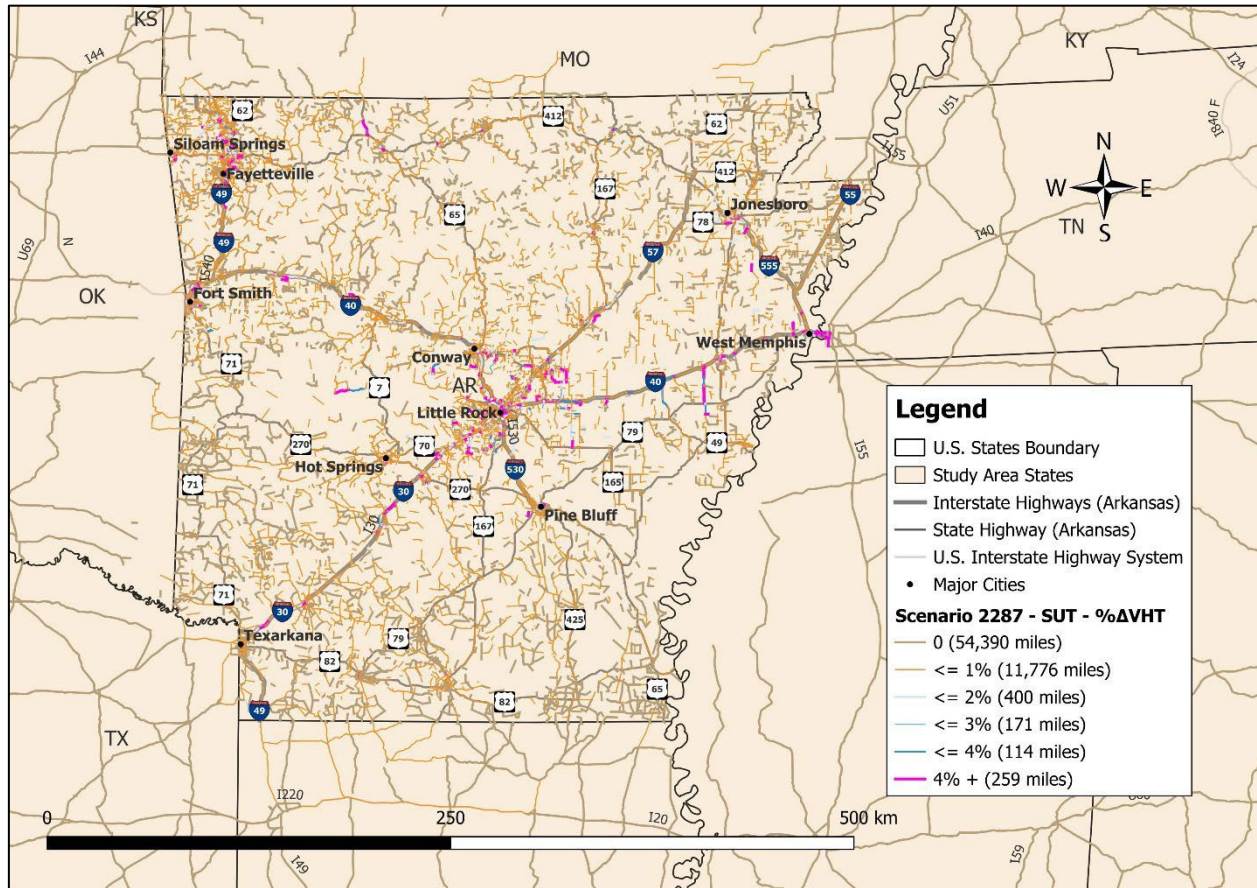


Figure 26. Percentage Difference in VHT for SUT During the PM Period Under a Full Closure of the I-55 Bridge

Tractor Trailer Trucks

Tractor-trailer trucks were the most affected vehicle type during the I-55 full-closure scenario in the PM peak. Across the full study area network, only 16,304 miles showed no difference in VHT, which is approximately 1,000 miles fewer than under the I-40 bridge closure for TTT. Links exceeding the 4% threshold totaled 2,313 miles, about 30% fewer than in the I-40 closure scenario for TTT.

At the Arkansas level (Figure 27), high-impact corridors were concentrated along I-40 near West Memphis, through Little Rock, and extending westward toward Fort Smith and Fayetteville.

At the regional level (Figure 28), disruptions were notable in Mississippi, Alabama, Virginia, West Virginia, Ohio, Indiana, and Tennessee. While the extent of affected corridors was smaller compared to the I-40 closure, the I-55 closure still disrupted freight mobility hundreds of miles from the bridge, though not at the same scale as the I-40 disruption.

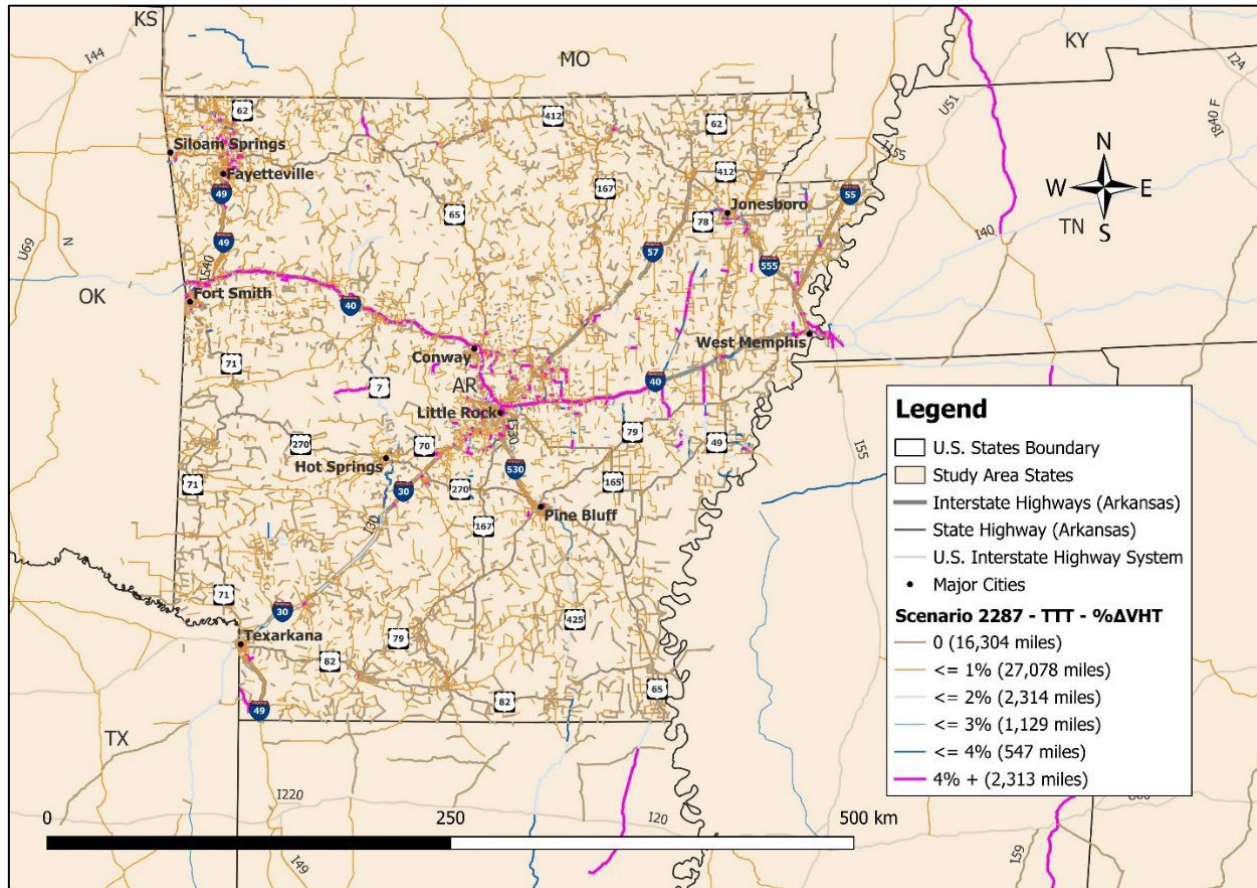


Figure 27. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the I-55 Bridge (Arkansas View)

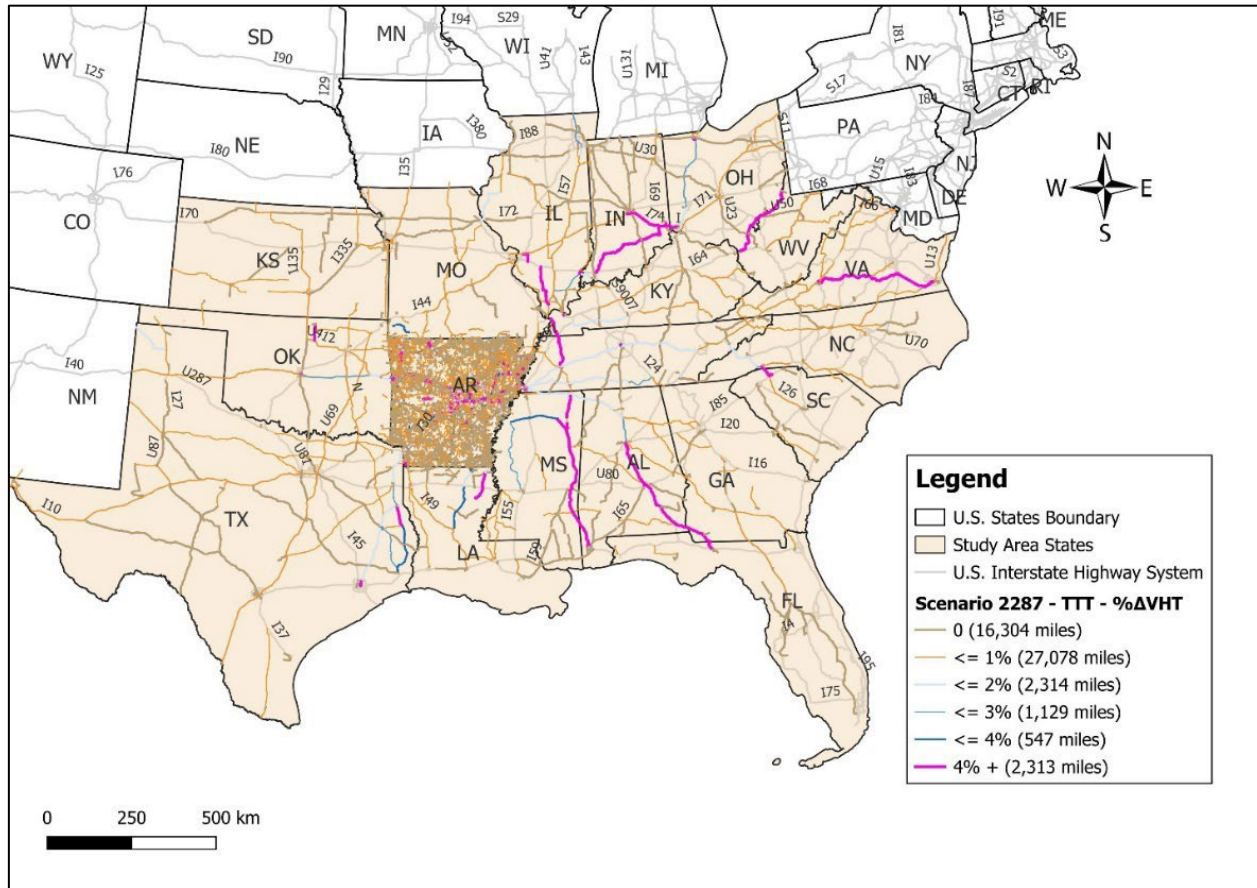


Figure 28. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the I-55 Bridge (Whole Study Area View)

HWY 49 Closure Scenario

In this section we present the results for autos, SUT, and TT during the PM period for the full closure scenario of Hwy 49.

Autos

In the HWY 49 full-closure scenario, 57,219 miles showed no difference in VHT, while only 169 miles exceeded the 4% threshold, approximately 20% fewer than in the I-40 closure (228 miles) and 35% fewer than in the I-55 closure (260 miles) for autos. Segments exceeding the 4% threshold were primarily located in Little Rock and Northwest Arkansas. Near the HWY 49 bridge itself, roadway segments exhibited only 0% or less than 1% changes, indicating minimal local impacts. Because most of the roadway mileage in the broader study area exhibited 0% change in VHT, a regional map is not provided.

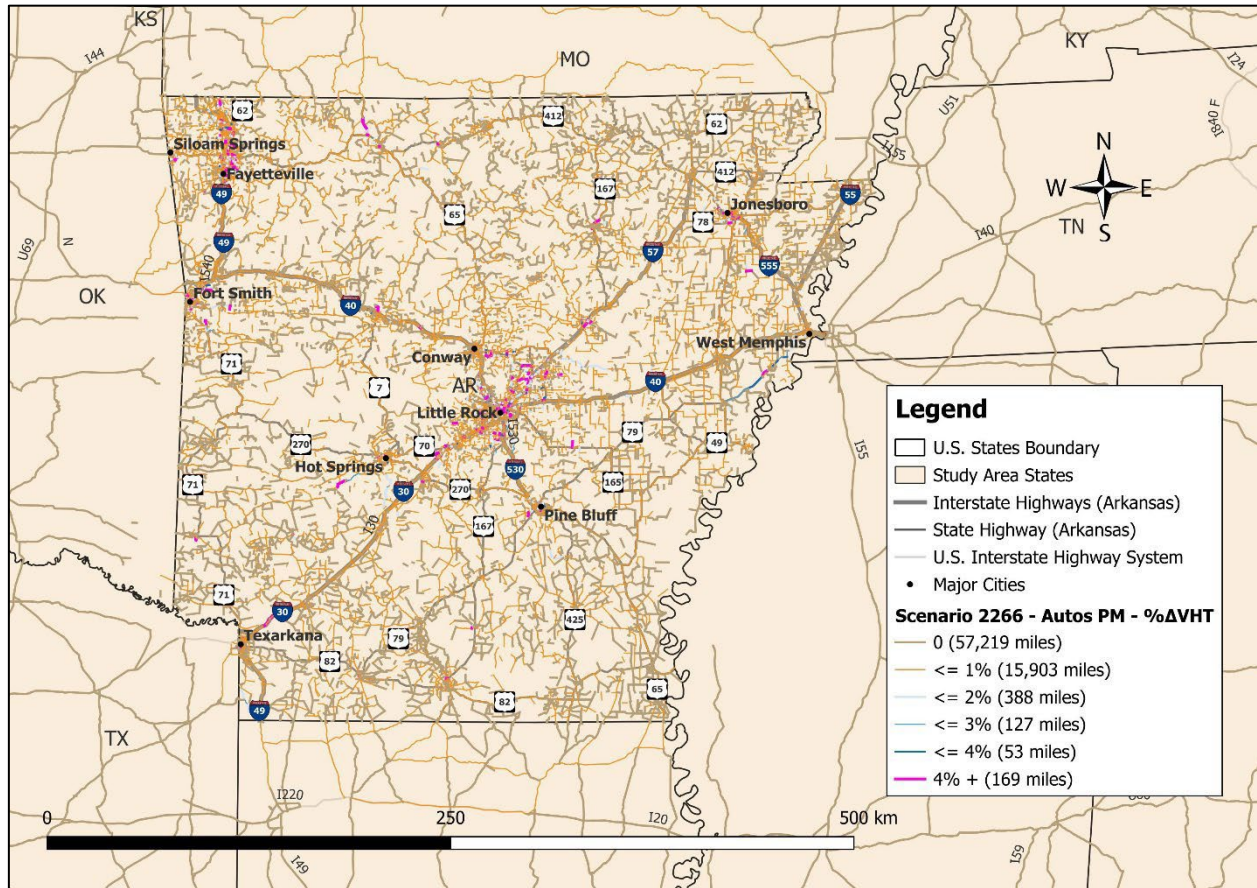


Figure 29. Percentage Difference in VHT for Autos During the PM Period Under a Full Closure of the HWY 49 Bridge

Single Unit Trucks

Impacts on SUT were similar compared to I-40 and I-55 closures. Across the full study area network, 57,194 miles showed no difference in VHT, while 220 miles exceeded the 4% threshold. This value is 25% higher than that observed for autos (169 miles) under the same closure. The segments exceeding the 4% threshold were again concentrated in Little Rock and in Northwest Arkansas, similar to the spatial pattern observed for autos. In addition, near the HWY 49 crossing itself and roadway segments on US 79 that go north to West Memphis also experienced a 4% or more increase in VHT. The roadway mileage across the broader study area experienced 0% change in VHT.

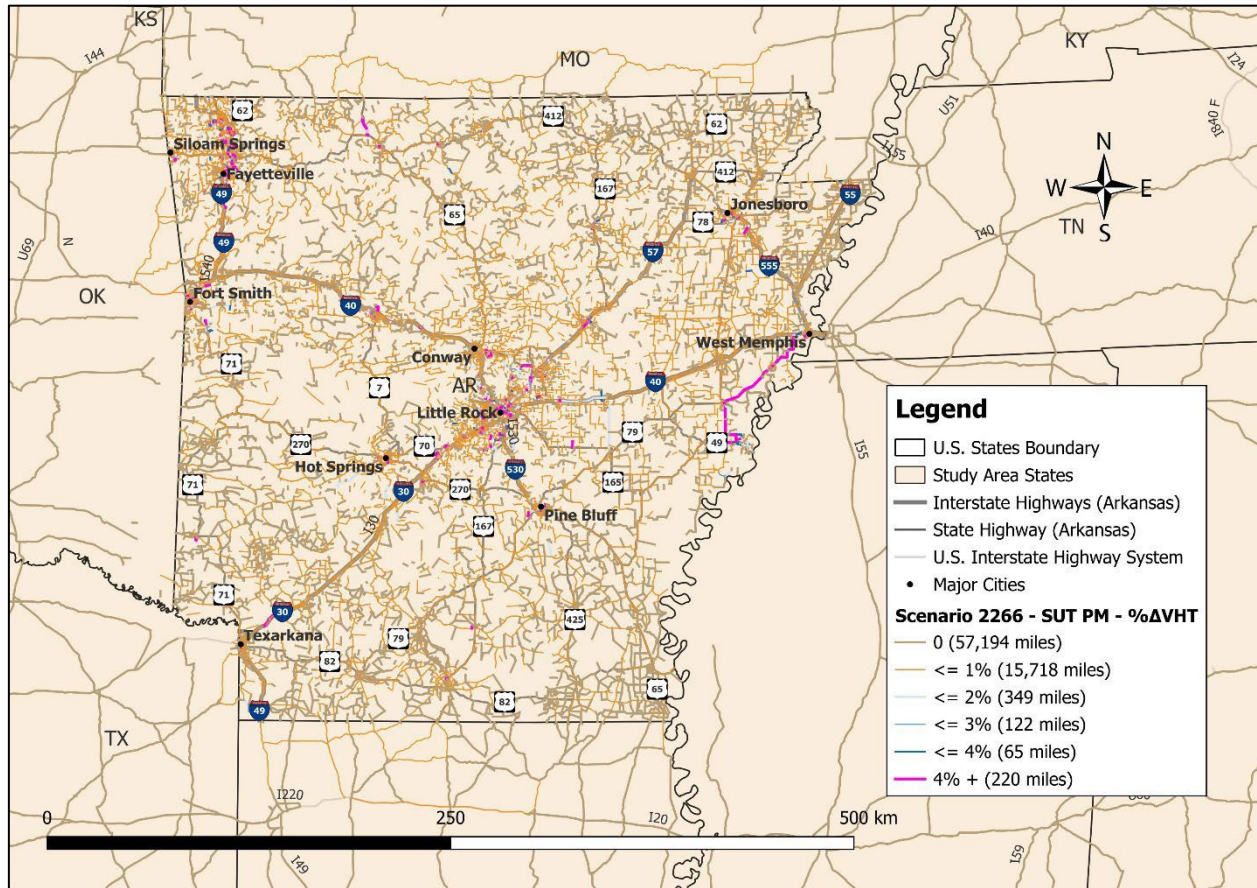


Figure 30. Percentage Difference in VHT for SUT During the PM Period Under a Full Closure of the HWY 49 Bridge

Tractor Trailer Trucks

TTT exhibited broader impacts compared to autos and SUTs. Across the full study area network, 17,998 miles of roadway showed no difference in VHT, while 784 miles exceeded the 4% threshold which is 70% higher than that observed for SUT.

At the Arkansas level (Figure 31), high-impact corridors were visible in Little Rock, Northwest Arkansas, and most notably near the HWY 49 bridge itself. At the regional level (Figure 32), disruptions extended to the states adjacent to Arkansas, particularly along Louisiana, Mississippi, Alabama and Georgia. In northern Louisiana and Mississippi, several links experienced 3% or more increases in VHT, while in Alabama and Georgia, most impacted links experienced just 2% or less increases.

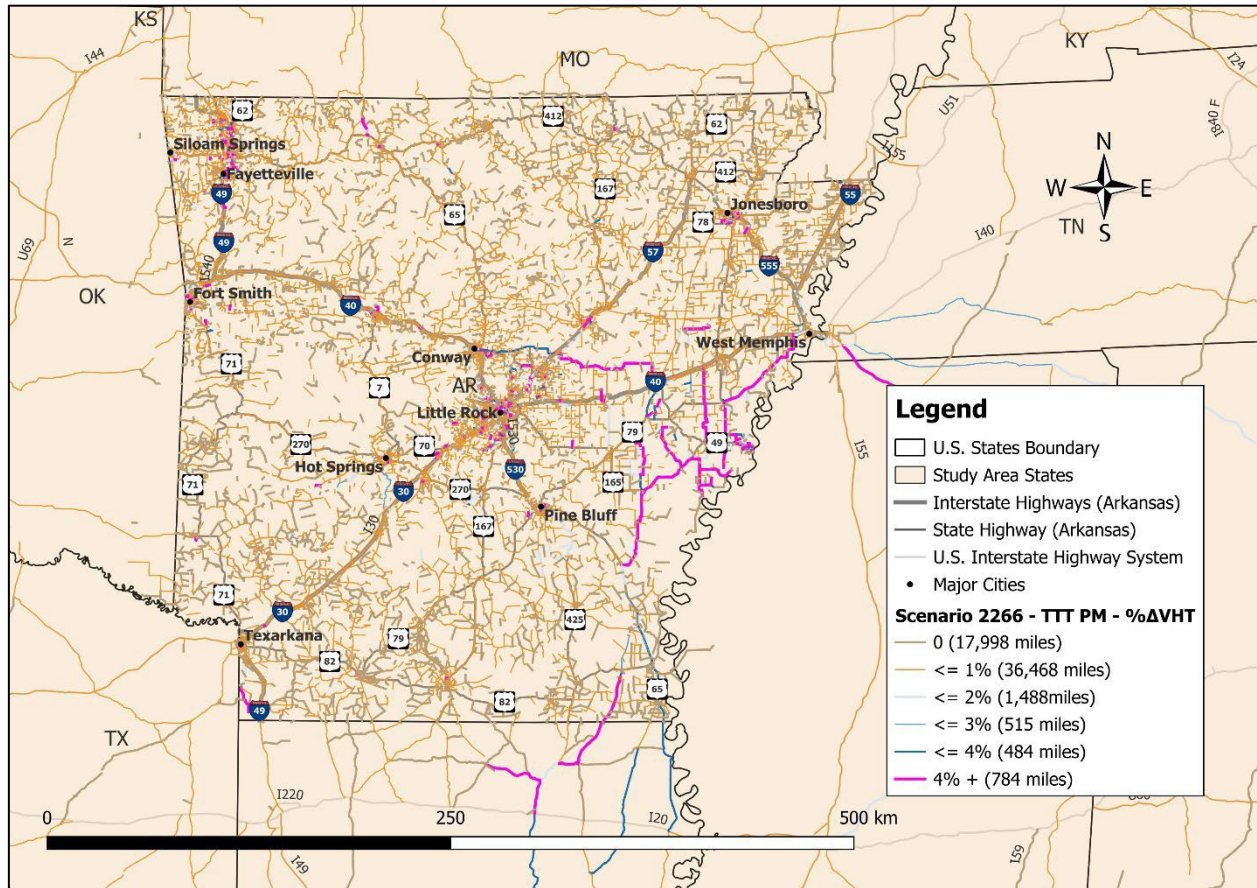


Figure 31. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the HWY 49 Bridge (Arkansas View)

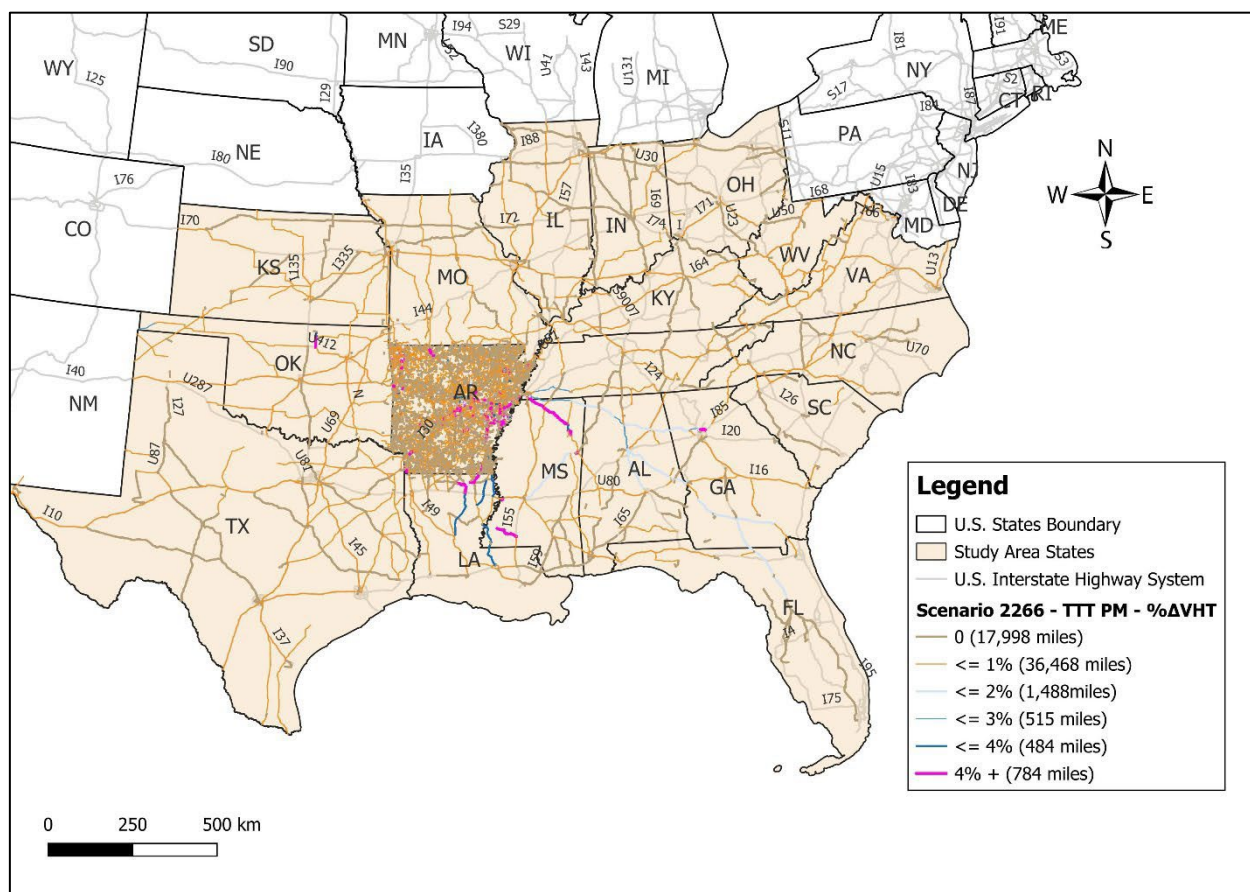


Figure 32. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the HWY 49 Bridge (Whole Study Area View)

HWY 82 Closure Scenario

In this section we present the results for autos, SUT, and TT during the PM period for the full closure scenario of HWY 82.

Autos

In the HWY 82 full-closure scenario, 56,718 miles of roadway showed no difference in VHT, while 742 miles exceeded the 4% threshold. This value is approximately 70% higher than in the I-40 closure (228 miles), I-55 (260 miles), and HWY 49 (169 miles) closures for autos, highlighting that the HWY 82 closure had the largest auto impact among the four bridges.

High-impact corridors were visible primarily in South Arkansas, particularly near the HWY 82 bridge and along roadway segments extending north toward HWY 49 bridge from the Mississippi side via MS-1. Increases of 4% or more also spread across northern Louisiana, specifically along I-20 and several U.S. highways branching northward into Arkansas. Additional impacts are also located in Little Rock and Northwest Arkansas area.

Overall, the HWY 82 closure primarily disrupted southbound and east-west traffic flows near the Louisiana and Mississippi borders. Other states within the broader study area, not shown on the map, exhibited 0% change in VHT.

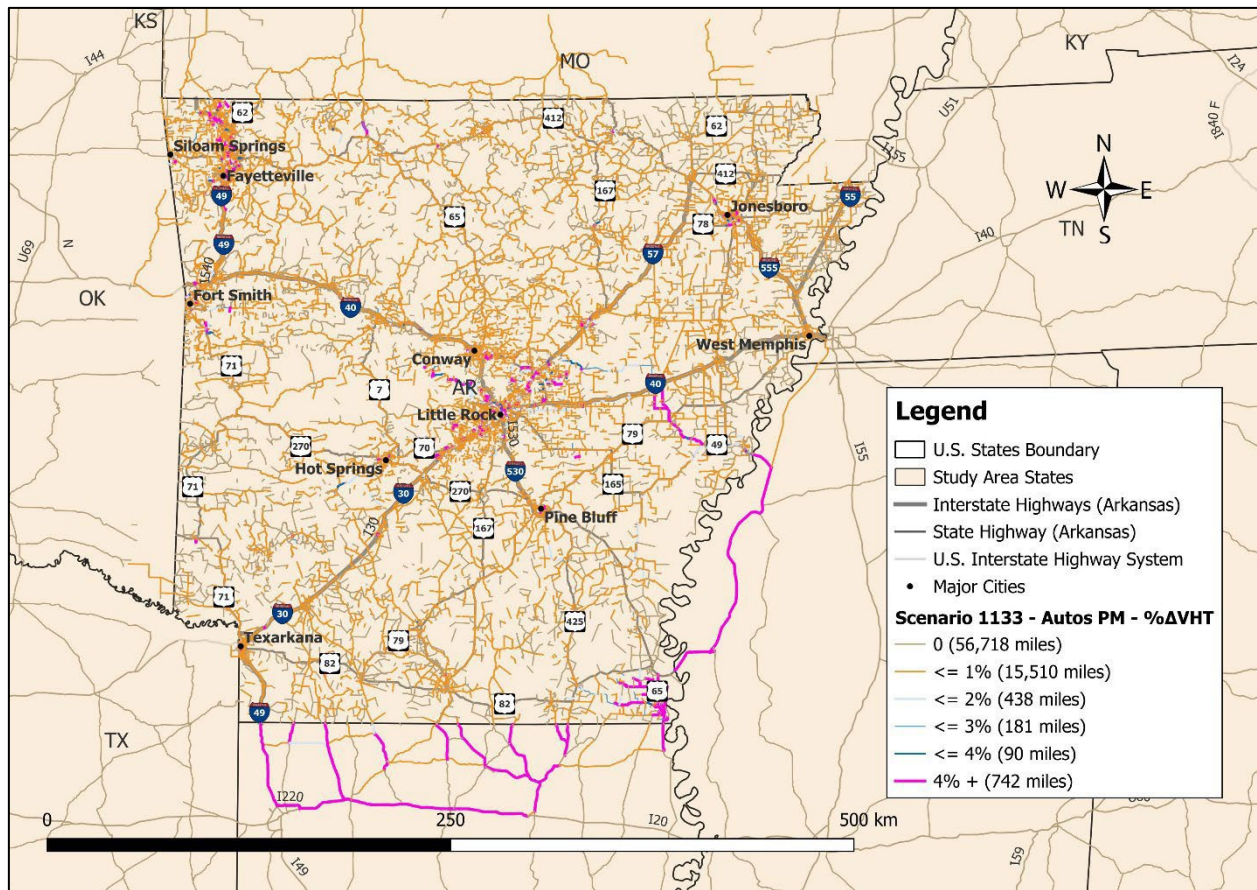


Figure 33. Percentage Difference in VHT for Autos During the PM Period Under a Full Closure of the HWY 82 Bridge

Single Unit Trucks

In the HWY 82 full-closure scenario for SUT, 56,718 miles of roadway showed no difference in VHT, while 742 miles exceeded the 4% threshold. Similar to autos, this represents approximately 70% more mileage than in the I-40 (272 miles), I-55 (220 miles), and HWY 49 (220 miles) closures for SUT, making HWY 82 the most disruptive bridge closure for this vehicle class.

High-impact corridors were visible primarily in South Arkansas, particularly near the HWY 82 bridge and along roadway segments extending north toward HWY 49 bridge from the Mississippi side via MS-1 and from the Arkansas side via US-165. Increases of 4% or more also spread across northern Louisiana, specifically along I-20 and several U.S. highways branching northward into Arkansas. Additional impacts are also located in Little Rock and Northwest Arkansas area.

Overall, the HWY 82 closure primarily disrupted southbound and east-west traffic flows near the Louisiana and Mississippi borders. Other states within the broader study area, not shown on the map, exhibited 0% change in VHT.

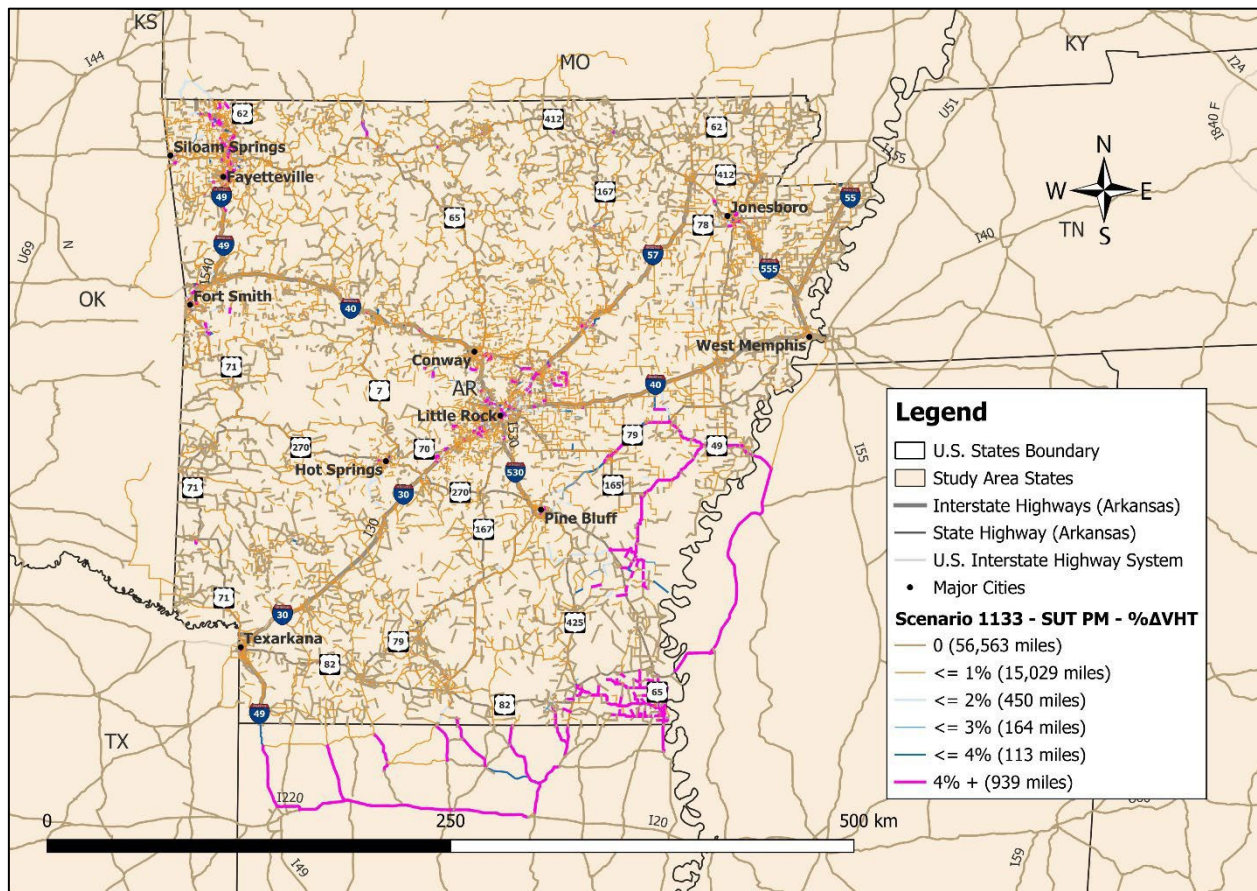


Figure 34. Percentage Difference in VHT for SUT During the PM Period Under a Full Closure of the HWY 82 Bridge

Tractor Trailer Trucks

In the HWY 82 full-closure scenario for TTT, 17,611 miles of roadway showed no difference in VHT, while only 301 miles exceeded the 4% threshold. Compared to the HWY 49 bridge closure, this represents approximately 60% fewer miles affected, and nearly 95% less than in the I-40 closure, highlighting that the HWY 82 disruption generated relatively lower regional impacts for heavy trucks.

At the Arkansas level (Figure 35), high-impact corridors were concentrated mostly around Little Rock and a few impacted areas in Northwest Arkansas. Notably, no highly impacted areas were observed near the HWY 82 bridge itself. At the regional level (Figure 36), the results show a predominance of links experiencing only 1% or less increases in VHT.

This reduced level of disruption for tractor-trailer trucks may be explained by the characteristics of the HWY 82 bridge. Unlike the I-40 and I-55 crossings, HWY 82 is located in a more rural area and provides only one lane in each direction. As a result, it is likely less convenient for heavy freight flows, which tend to concentrate along higher-capacity interstate facilities to the north.

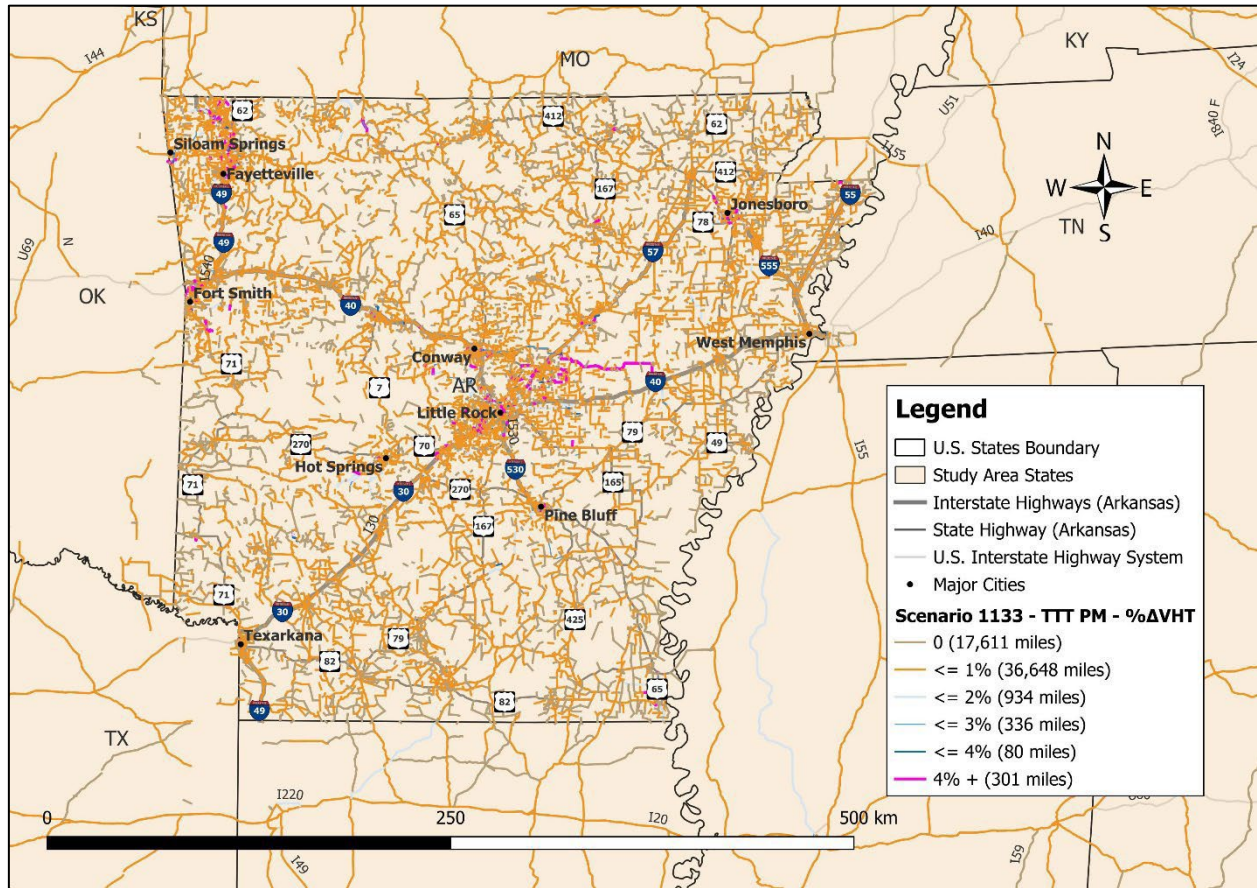


Figure 35. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the HWY 82 Bridge (Arkansas View)

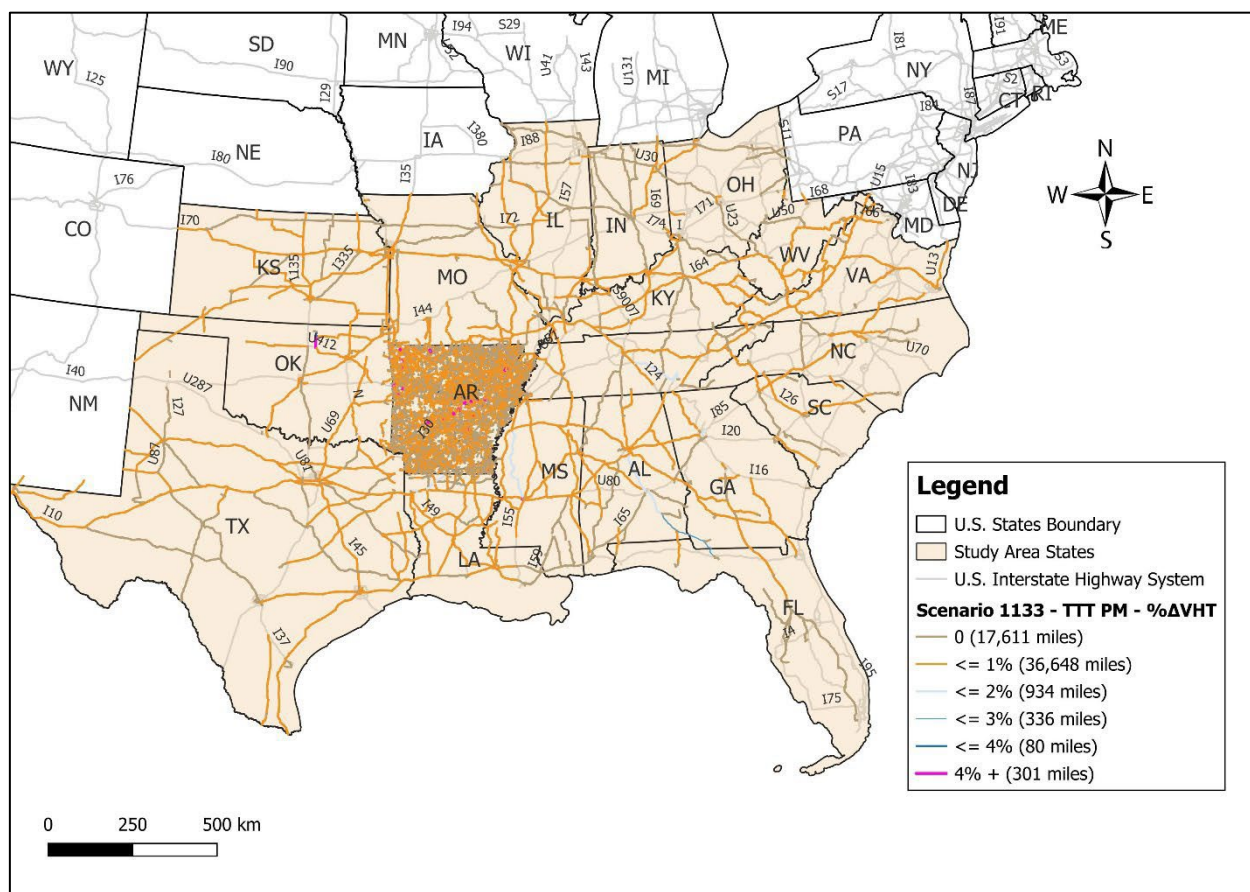


Figure 36. Percentage Difference in VHT for TTT During the PM Period Under a Full Closure of the HWY 82 Bridge (Whole Study Area View)

VHT Impacts by Combinations of Bridge Closure Scenarios

Scenarios for all possible combinations of closures were evaluated using the AR STDM. For example, a scenario may include the full closure of I-40 and I-55 bridges while HWY 49 and HWY 82 remain open. All 2,303 scenarios are available for evaluation and visualization in the implementation tool discussed at the end of this report. In this section we present the “worst case scenario” for a bridge closure.

Results show that the most critical scenario across all vehicle types occurred during the AM period under the following lane configuration: I-40 eastbound with two lanes open and westbound fully closed, I-55 fully closed, HWY 49 eastbound fully open with westbound fully closed, and HWY 82 fully open (Scenario #1350).

Autos

‘Scenario 1350’ during the AM period represents the worst-case condition for autos (Figure 37). A large share of roadway mileage (100,371 miles) experienced no change in VHT while approximately 5,042 miles of roadway showed increases greater than 4%. This represents about 2,111% more mileage compared to the I-40 bridge closure for autos. The impacts of this lane configuration were widespread across the state, with notable increases of 4% or more in VHT observed in Little Rock and its surrounding areas, West Memphis and areas east of West

Memphis, south of Jonesboro, and Northwest Arkansas. Additional impacts extended beyond the state, including northern Louisiana (particularly along I-20 and U.S. highways branching northward into Arkansas) and southern Missouri (notably along I-49 and nearby U.S. highways). Other states within the broader study area, not shown on the map, exhibited 0% change in VHT.

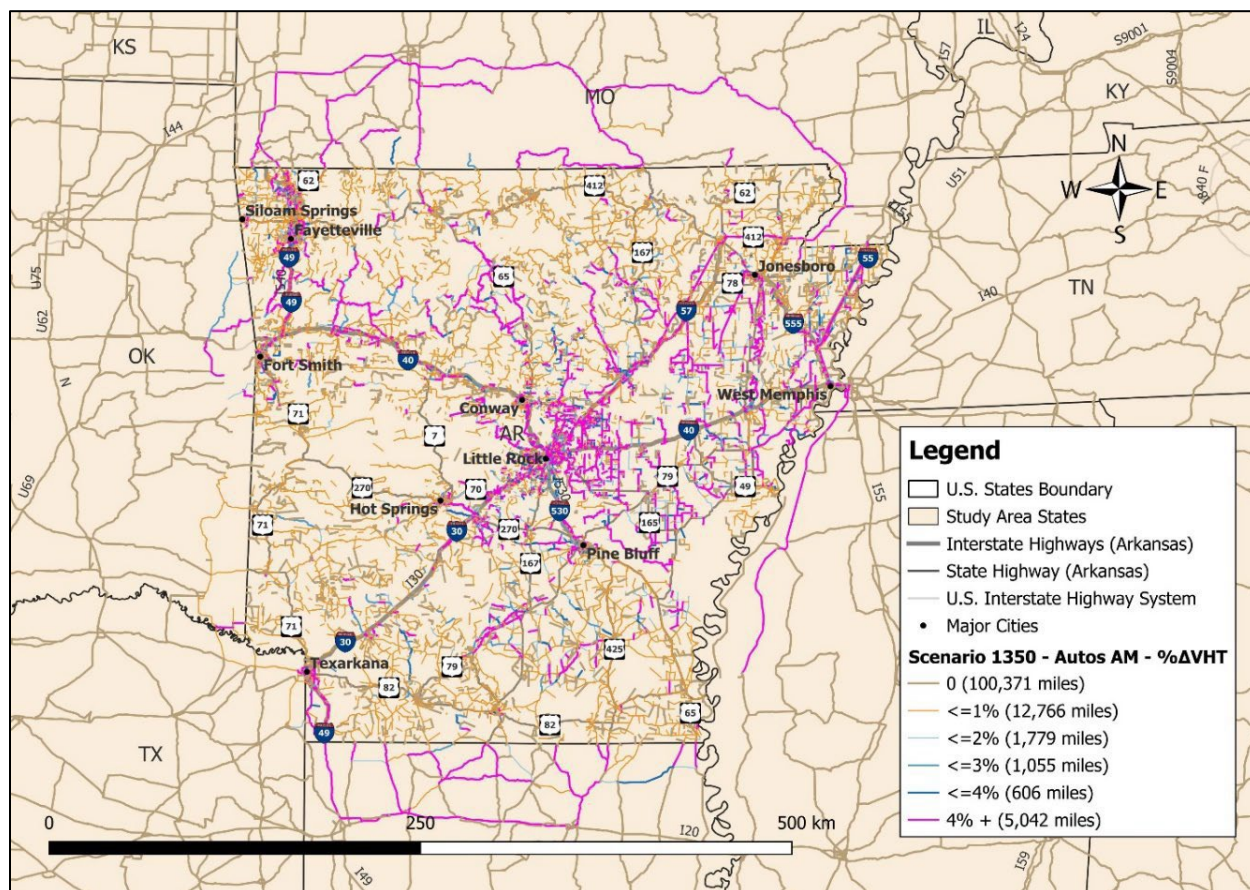


Figure 37. Scenario 1350 – Percentage Difference in VHT for Autos During the AM Period

Single Unit Trucks

‘Scenario 1350’ during the AM period represents the worst-case condition for SUT (Figure 38). A large share of roadway mileage (101,138 miles) experienced no change in VHT while approximately 3,876 miles of roadway showed increases greater than 4%. This represents about 1,325% more mileage compared to the I-40 bridge closure for SUT. The impacts of this lane configuration were widespread across the state, with notable increases of 4% or more in VHT observed in Little Rock and its surrounding areas, West Memphis and areas east of West Memphis, south of Jonesboro, and Northwest Arkansas. Additional impacts extended beyond the state, including northern Louisiana (particularly along I-20 and U.S. highways branching northward into Arkansas) and southern Missouri on nearby U.S. highways. Other states within the broader study area, not shown on the map, exhibited 0% change in VHT.

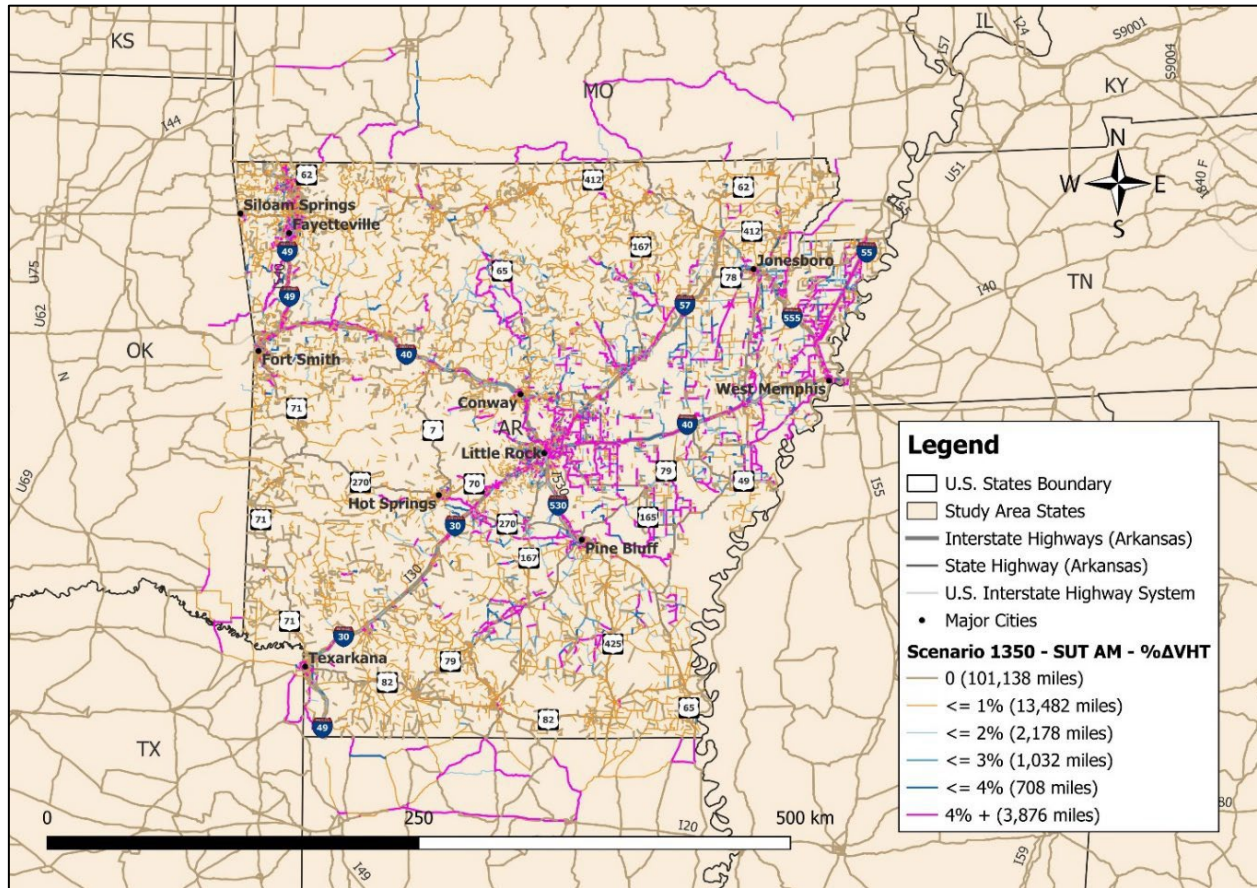


Figure 38. Scenario 1350 – Percentage Difference in VHT for SUT During the AM Period

Tractor Trailer Trucks

‘Scenario 1350’ during the AM period represents the worst-case condition for TTT (Figure 39 and Figure 40). A total of 6,263 miles of roadway showed no difference in VHT, while 18,838 miles exceeded the 4% threshold. Compared to the I-40 bridge closure, this represents a 173% increase in impacted mileage.

At the Arkansas level (Figure 39), high-impact corridors were concentrated around West Memphis, Jonesboro, Little Rock, Northwest Arkansas, and their surrounding areas, particularly along major interstate highways such as I-30, I-40, and I-49, as well as several state highways. Notably, high-impact areas were also observed in the vicinity of each of the four bridges. At the regional level (Figure 40), disruptions extended across all states in the study area. Major corridors with over 4% increases in VHT included I-64/I-70 beginning in Virginia, continuing through Kentucky and Missouri, and extending westward into Kansas via I-70, along with other principal U.S. highways adjacent to these routes. In the South, I-10 from Florida to Texas and I-20 from Georgia to Texas also experienced 4% or greater increases in VHT, along with additional connected corridors.

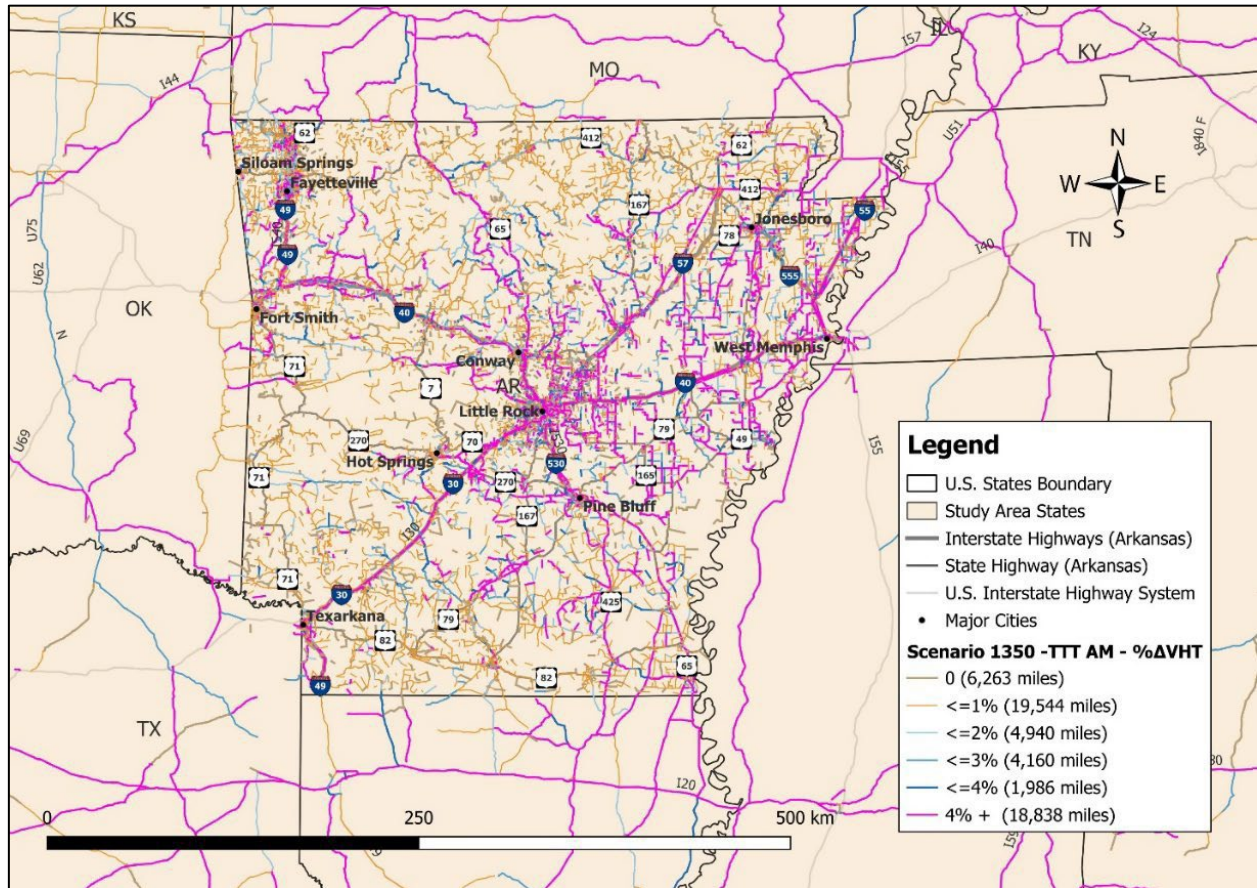


Figure 39. Scenario 1350 – Percentage Difference in VHT for TTT During the AM Period (Arkansas View)

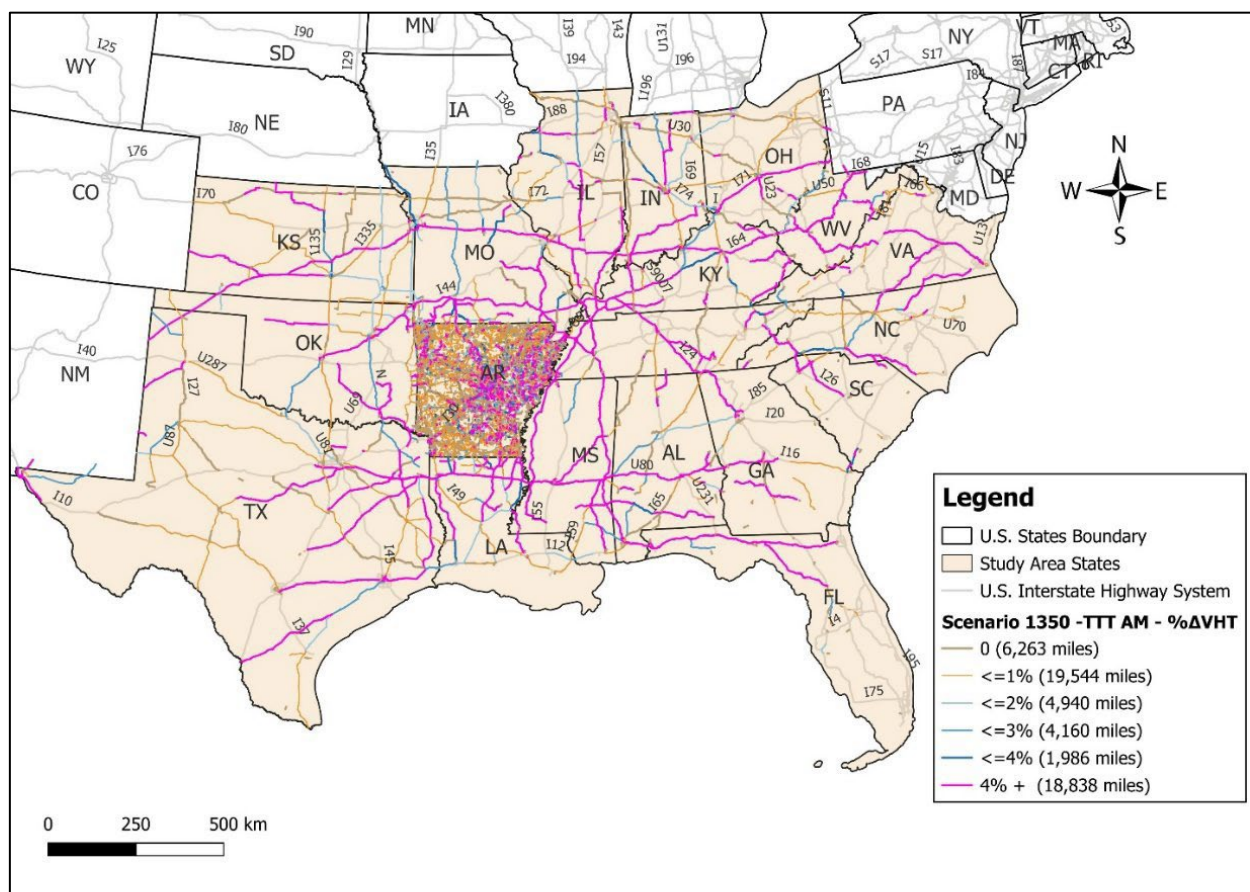


Figure 40. Scenario 1350 – Percentage Difference in VHT for TTT During the AM Period (Study Area View)

Impacts of Bridge Closures on Waterway Traffic

The following sections present the estimated waterway closure costs per day for each of the four study bridges following the methodology previously described along with an analysis of vessel flows by bridge location and month.

Waterway Closure Costs

According to the Bureau of Transportation Statistics, the nearly three-day waterway closure led to a queue of 62 tugboats and 1,058 barges. The segment of the Mississippi River passing beneath the bridge moves over 470,000 short tons of freight per day.

Using this data and the derived vessel AADT (average daily tug/tow crossings) for the Hernando de Soto Bridge in 2021, we established the following:

- Vessel AADT = 23
- Delay cost per day: $23 \times \$739 \times 24 = \$407,928$

This estimated cost represents direct operational losses for delayed waterway freight traffic, excluding broader supply chain effects for 24 hours. For closures affecting other locations, use the AADT for that specific location for the calculations.

To reflect both historical and recent vessel-flow conditions, we developed two sets of 24-hour closure cost estimates (Table 13). 2021 estimates are based on published 2021 delay-and-economic-impact values calibrated to I-40, then scaled to each bridge. For the 2024 estimates, we updated using 2024 AIS-derived vessel volumes.

Table 13. Estimated 24-hour waterway closure cost by bridge for 2021 and 2024

Bridge	Estimate for 2021 (\$)	Estimate for 2024 (\$)
I-40	\$407,928	\$407,928
I-55	\$425,664	\$407,928
HWY 49	\$461,136	\$461,136
HWY 82	\$70,944	\$195,096
Total	\$1,365,672	\$1,472,088

By presenting both 2021 and 2024 estimates, we capture the evolution of traffic-induced impacts over time. Stakeholders can thus see how rising vessel volumes translate into higher disruption costs, and planners can apply the appropriate estimate depending on whether they wish to reference possible pandemic-related (2021) conditions or current (2024) operational realities. Notably, from 2021 to 2024, the average daily traffic for tugs and tows increased by 8%, which resulted in a directly proportional 8% increase in the total economic cost of a one-day river closure across all four bridges.

Waterway Traffic Activity by Location and Time

Monthly vessel crossing volumes, upstream, downstream, and total, at four Mississippi River bridges (I-40, I-55, HWY 49, and HWY 82) from January to December for the years 2021 and 2024 are illustrated in the figures below. The year 2021 reflects traffic conditions during the bridge closure event, while 2024 represents the most recent available data. The traffic growth rate observed from the AIS data from the year 2021 to 2024 is 8%. Each figure shows the number of AIS-derived vessel crossings by direction, with dotted lines indicating 2021 traffic levels and solid lines representing 2024 volumes. Overall, the HWY 49 bridge recorded the highest AADT for tug and tow traffic in 2021 and was tied with the I-40 bridge for the highest in 2024. The most significant change occurred at the HWY 82 bridge, which saw its AADT nearly double between the two years (Figure 41).

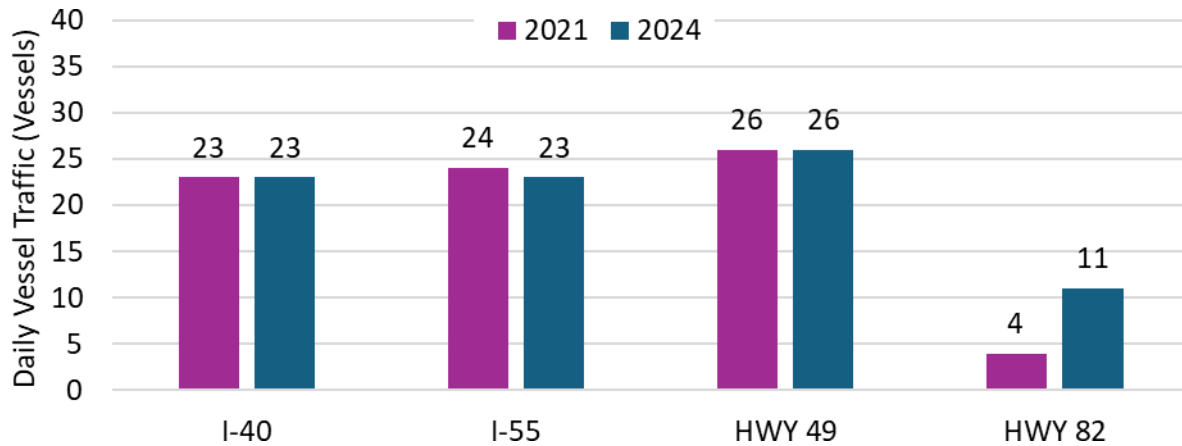


Figure 41. AADT for vessels at four bridge locations, comparing volumes for 2021 and 2024

I-40 Bridge Vessel Traffic

The vessel traffic on I-40 was higher in 2021 than in 2024 in most months (Figure 42), with the 2021 series showing larger fluctuations that reached a low point in February and peaked in the fall, reaching its high in November at about 800 vessels and a near-peak in October. By contrast, 2024 followed a steadier path that climbed from January to a March high just under 800 vessels, dipped into July, then rebounded in August and again in late fall.

When comparing directions, 2021 shows downstream (red dashed) slightly above upstream (blue dashed) in many months, though upstream edges ahead in October and November; in 2024 the two move closely together through the first half of the year, with upstream briefly leading in March and downstream modestly higher in September and November.

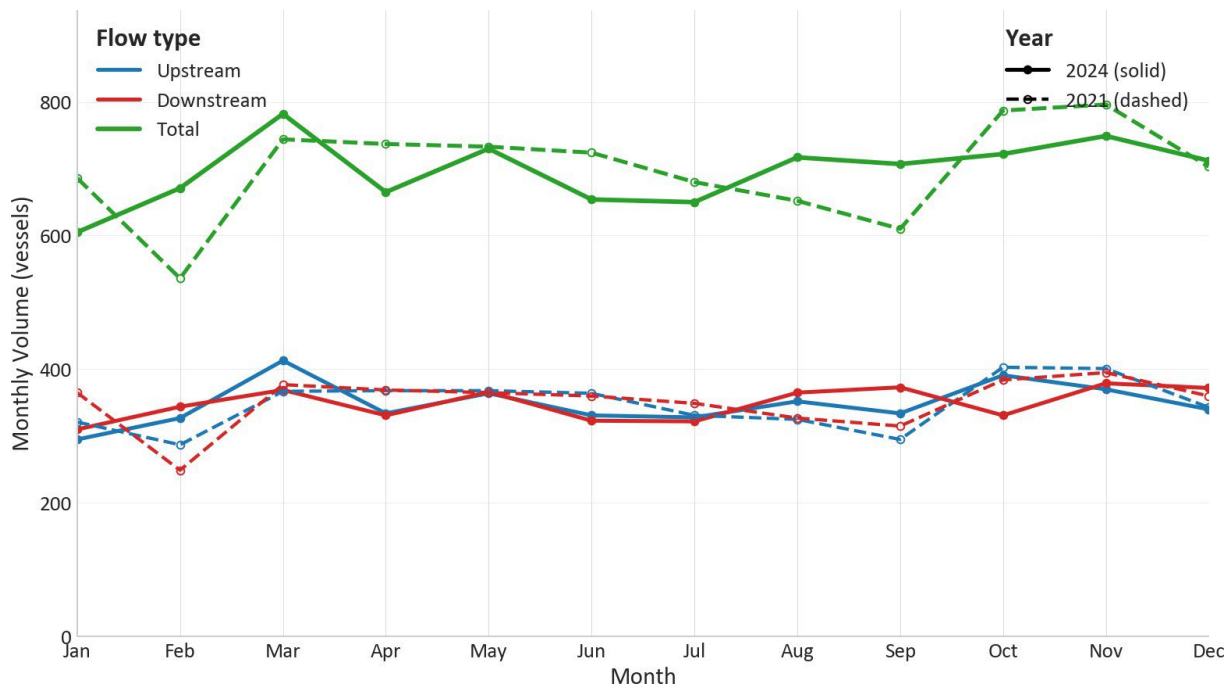


Figure 42. I-40 Vessel Traffic by Month for 2021 and 2024

I-55 Bridge Vessel Traffic

The total tug and tow traffic on I-55 was generally higher in 2021 than in 2024 in most months (Figure 43), with 2021 showing wide variability that started below 700 vessels, dropped further in February, then surged to a March high near 900 and remained elevated again in October and November; 2024 followed a similar shape at lower levels, peaking in March at about 785 vessels, easing through July, rebounding in August, dipping in September, and rising again in October and November, with 2024 exceeding 2021 in February, August, September, and December.

When examining directions, the 2021 series shows upstream (blue dashed) and downstream (red dashed) moving closely together, with downstream slightly higher in most months and both hitting their low in February, while upstream edges ahead in February, May, October, and November; in 2024 the two directions again track closely, peaking in March with upstream above downstream, slipping to a midsummer low, then downstream leading in August and September, upstream briefly leading in October, and downstream higher in November and December.

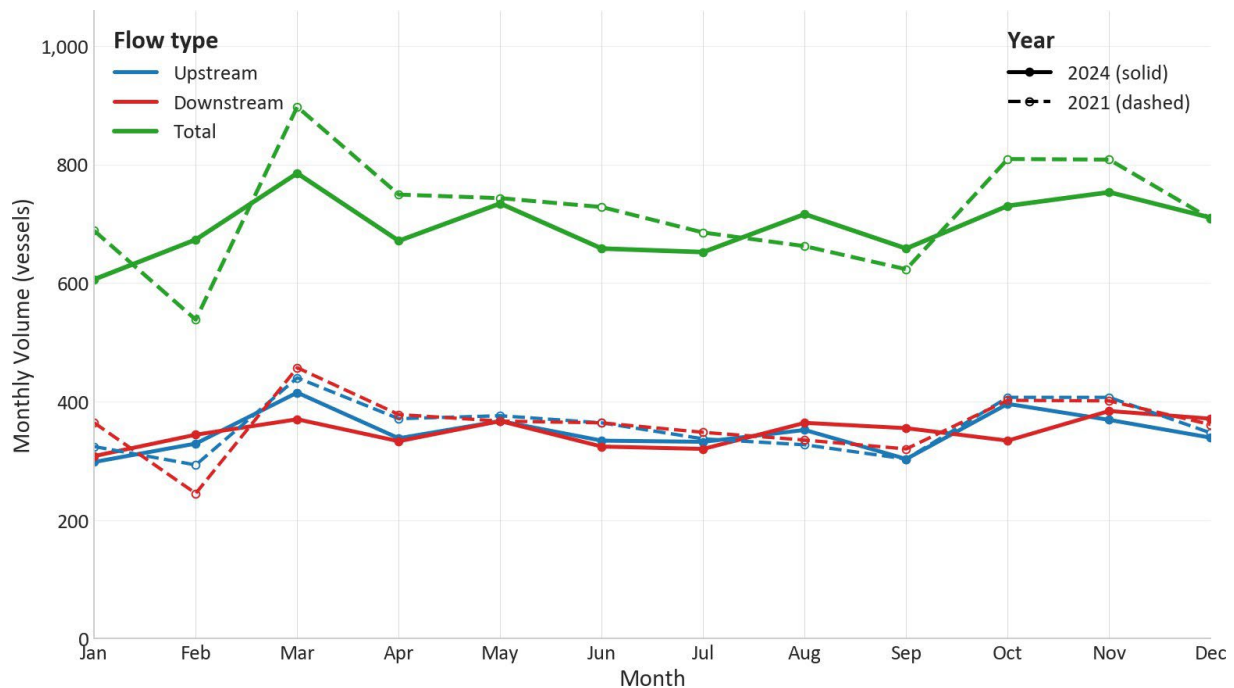


Figure 43. I-55 Vessel Traffic by Month for 2021 and 2024

HWY 49 Bridge Vessel Traffic

The total tug and tow traffic on HWY 49 shows a mixed pattern between 2021 and 2024 (Figure 44). In 2021 totals started higher in January, fell to a February low near 640 vessels, then climbed, with a sharp October spike to about 1,005 vessels which was the highest month in either year, before easing slightly in November and December. In 2024 totals were below 2021 in January, exceeded 2021 in February and March, declined to a June low around 680, then rebounded through the fall, reaching the mid-840s in October and November, and finishing

above 2021 in December; overall, 2024 was higher in February, March, May, August, September, and December, while 2021 led in January, April, June, July, October, and November.

Looking at directions, in 2021 upstream and downstream moved together with upstream (blue dashed) consistently above downstream (red dashed); both reached their low in February and shared a strong peak in October. In 2024 the two series again followed the same general shape, yet upstream (blue solid) remained higher throughout the year, with the largest gaps in March and October when upstream approached 500 vessels while downstream was in the mid-300s; both directions lifted from summer lows and stayed elevated into the year's end.

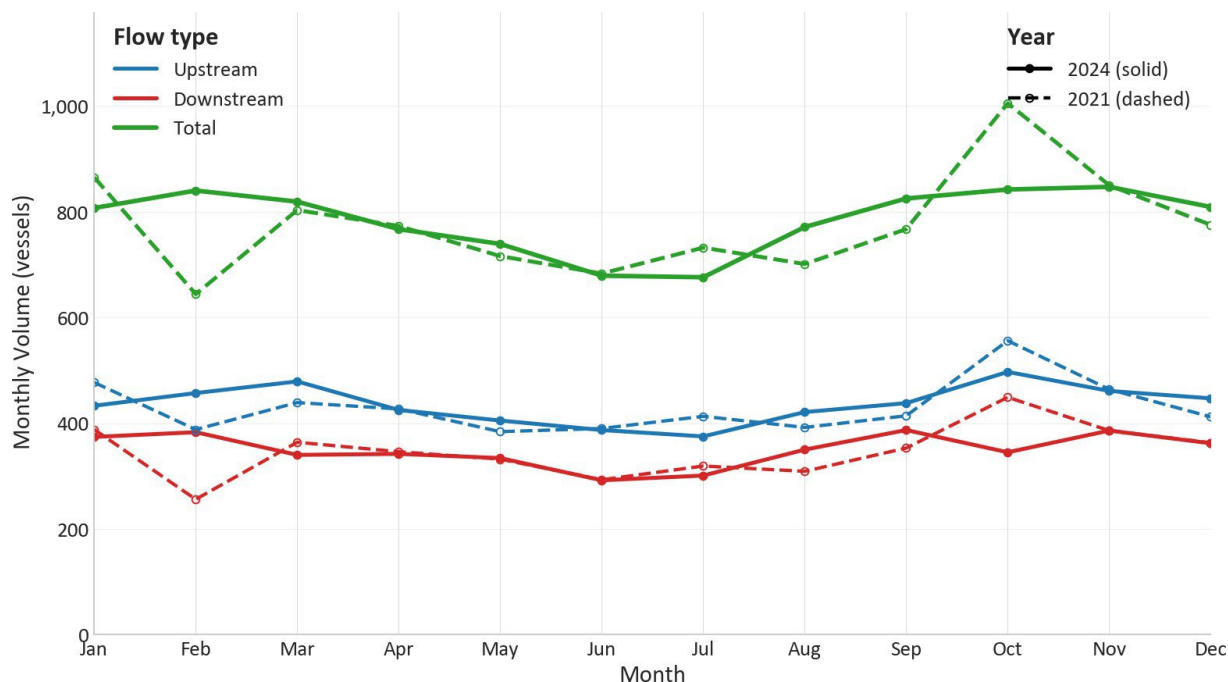


Figure 44. HWY 49 Vessel Traffic by Month for 2021 and 2024

HWY 82 Bridge Vessel Traffic

The total tug and tow traffic on HWY 82 was much higher in 2024 than in 2021 for most of the year (Figure 45), with 2021 exceeding 2024 only in January and March; the difference widened from May forward as 2024 jumped from about 150 vessels in April to 302 in May, reached 466 in June, stayed near or above 450 through November with highs around 523 in September and 522 in November, then eased to about 329 in December, while 2021 remained low throughout the year with a February minimum near 41 and a modest August peak just over 200.

Examining directions, 2021 upstream and downstream volumes were both very low and moved closely together with mild bumps in April and August; in 2024 both directions increased sharply, with downstream showing pronounced surges in June, September, and November, and upstream rising more steadily with highs in August and October, leaving each direction well above 2021 from spring through late fall.

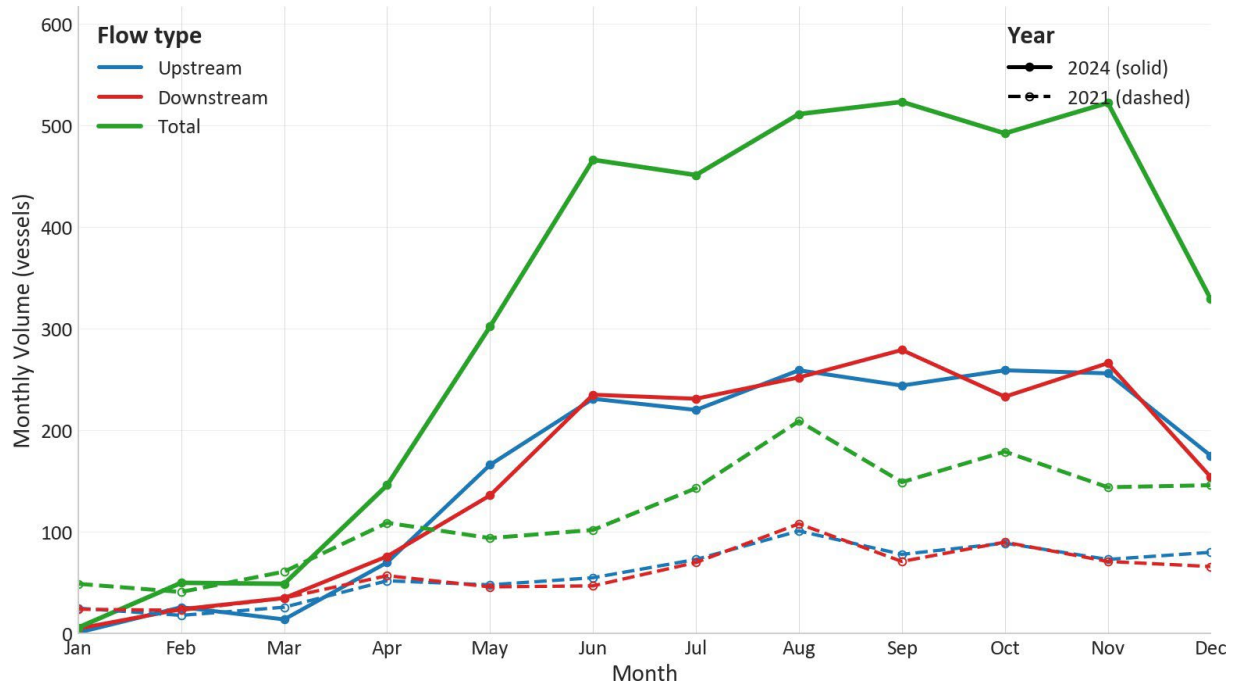


Figure 45. HWY 82 Vessel Traffic by Month for 2021 and 2024

SUMMARY OF FINDINGS

This section presents a summary of results relating to Link-level and System-level road user impacts as well as the impacts to commercial traffic on the waterways.

Link-level Impacts

This work used an automated Road User Cost (RUC) framework developed by ARDOT paired with a travel demand model to estimate the daily impacts of full and partial bridge closures. While the Arkansas Statewide Travel Demand Model (ARSTDm) provides the total traffic volume increases on alternate routes during a closure, it does not distinguish the specific source of those diverted vehicles. For instance, if I-40 and HWY 49 are closed simultaneously, the I-55 bridge will absorb a significant volume of traffic from both facilities. To estimate the percentage of traffic that comes from each closed bridge, this work applied a proportional approach (also referred to as a gravity method). This approach helps predict these proportions by assigning a weight to each closed bridge based on its baseline traffic volume and its distance to the open crossing. By distributing the total traffic increase according to these weights, the application can accurately allocate diverted volumes to their respective origins to calculate precise detour costs.

The costliest scenario evaluated is the partial closure of the I-40 Hernando de Soto bridge, with an estimated daily cost of \$2,382,823. A key finding from this analysis is that RUC framework causes partial closures on high volume facilities to generate significantly higher daily costs than full closures. When the I-40 bridge is restricted to a single lane in each direction, the severe localized bottleneck produces massive user delay. Conversely, a full closure of the same bridge forces all traffic to detour to alternate crossings. While a full closure adds detour mileage and

safety risks to the trip, the alternate routes often have sufficient capacity to keep vehicles moving. As a result, the full closure of I-40 drops the daily RUC to \$198,625. This same pattern holds true for the I-55 Memphis-Arkansas bridge, where a partial closure costs \$915,416 per day compared to \$250,691 for a full closure. This is a result of the logic in the RUC framework and should be further examined.

Table 14. Summary Estimated Daily Road User Costs for Full and Partial Closures

Bridge	Lanes per Direction	AADT (vehicles per day)	Truck Percentage (approximate truck count)	Approx. Driving Distance to Next Bridge	Full Closure Daily Costs	Partial Closure Daily Costs
I-40, Hernando de Soto Bridge	3	48,200	29% (12,000)	12 miles to I-55	\$198,625	\$2,382,823
I-55, Memphis-Arkansas Bridge	2	41,200	35% (16,000)	12 miles to I-40	\$250,691	\$915,416
HWY 49, Helena Bridge	1	3,900	20% (880)	143 miles to I-55	\$19,927	<i>Not evaluated</i>
HWY 82, Greenville Bridge	1	7,100	24% (1,728)	241 miles to HWY 49	\$994,762	<i>Not evaluated</i>

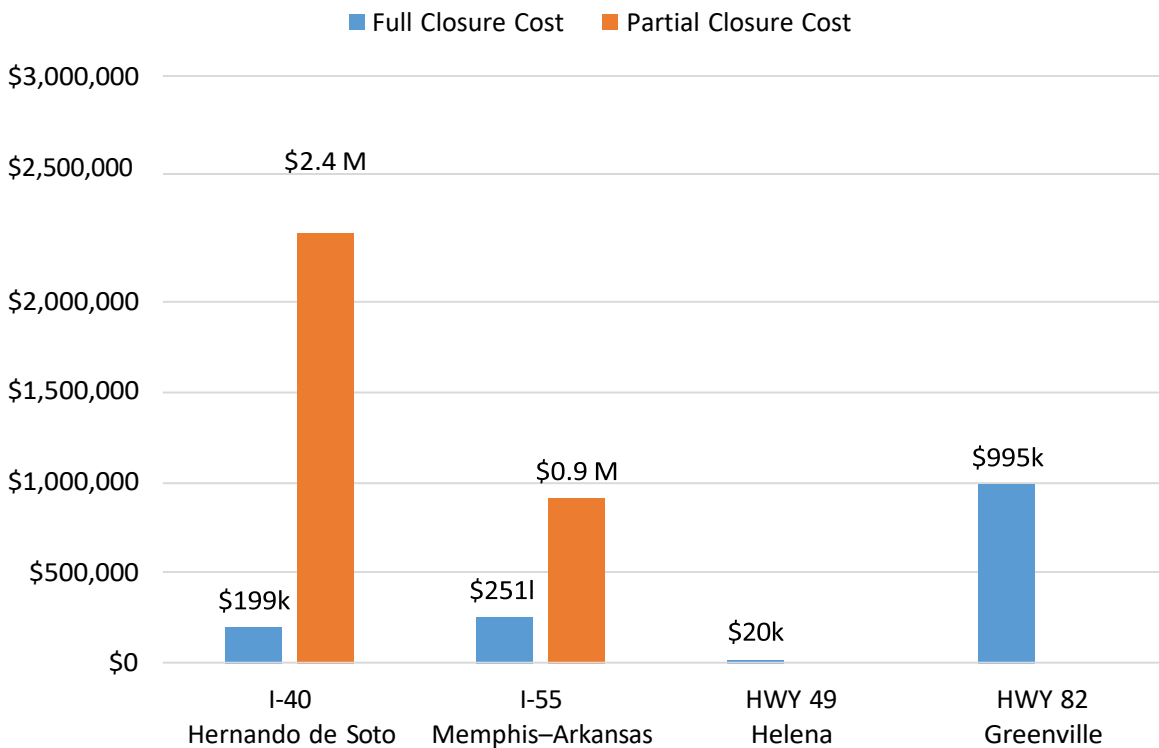


Figure 46. Summary of Road User Costs by Bridge and Closure Type

The RUC framework suggests that full closures generally result in lower daily costs compared to partial closures for high-traffic facilities like the I-40 and I-55 bridges. Other seemingly counterintuitive results should be highlighted. While the AADT on I-40 is 12 times higher than HWY 49 and almost 7 times higher than HWY 82, the full closure cost of I-40 (\$198,625) is lower than the HWY 82 rural bridge (\$994,762). This occurs because the detour distance between I-40 and I-55 is only 12 miles. By contrast, closing HWY 82 forces traffic onto a regional detour of 241 miles to the closest bridge in Arkansas, making it the most expensive full closure scenario evaluated.

The distance to the next available bridge plays a major role in detour-related costs. Bridges like HWY 82, which require a detour of approximately 241 miles to the closest bridge within Arkansas, experience high delay and mileage penalties compared to bridges located closer together. Opening the analysis to bridges outside of Arkansas would allow shorter detours in the case of HWY 82 for which the I-20 bridge in Vicksburg, MS is approximately 85 miles away. Similarly, for the case of I-40 and I-55 closures, the I-155 bridge connecting Missouri and Tennessee is approximately 10 miles away, compared to 143 miles to the HWY 49 bridge.

Figure 47 and Figure 48 illustrate the estimated road user costs by length of the closure period by bridge under full and partial closure scenarios. In the full closure scenario, the HWY 82 bridge consistently shows the highest cumulative road user costs across all closure durations, primarily due to its extreme detour distance. As expected, cumulative road user costs increase linearly with the number of days the bridge remains closed. In contrast, for the partial closure scenarios, the I-40 bridge experiences the most severe RUCs.

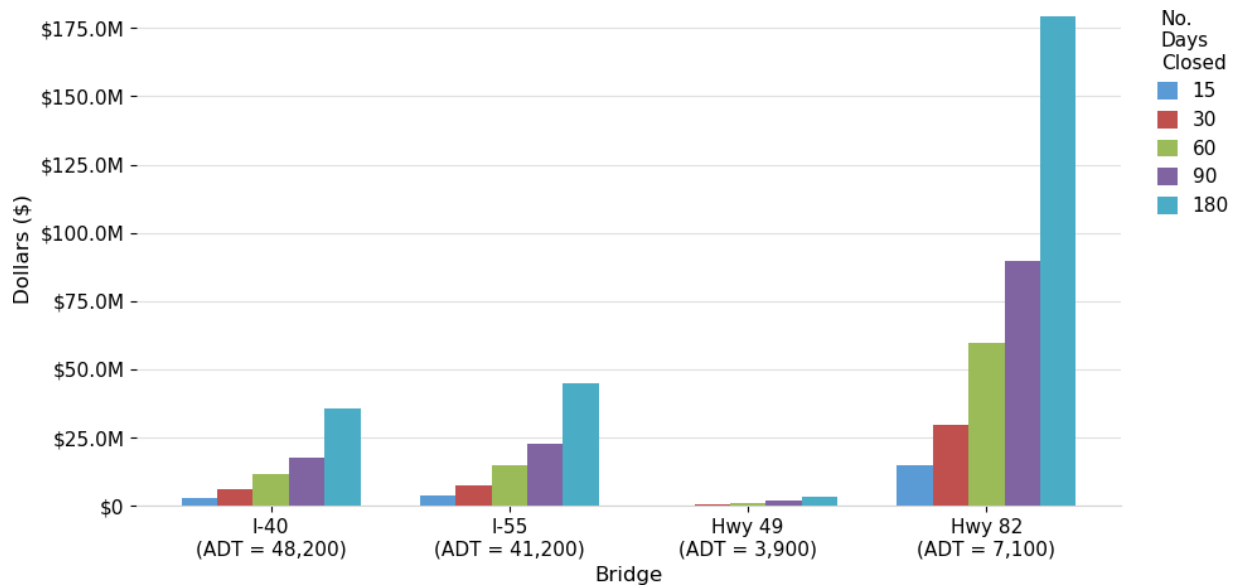


Figure 47. Estimated Road User Costs by Bridge and Closure Duration under Full Closure Scenario

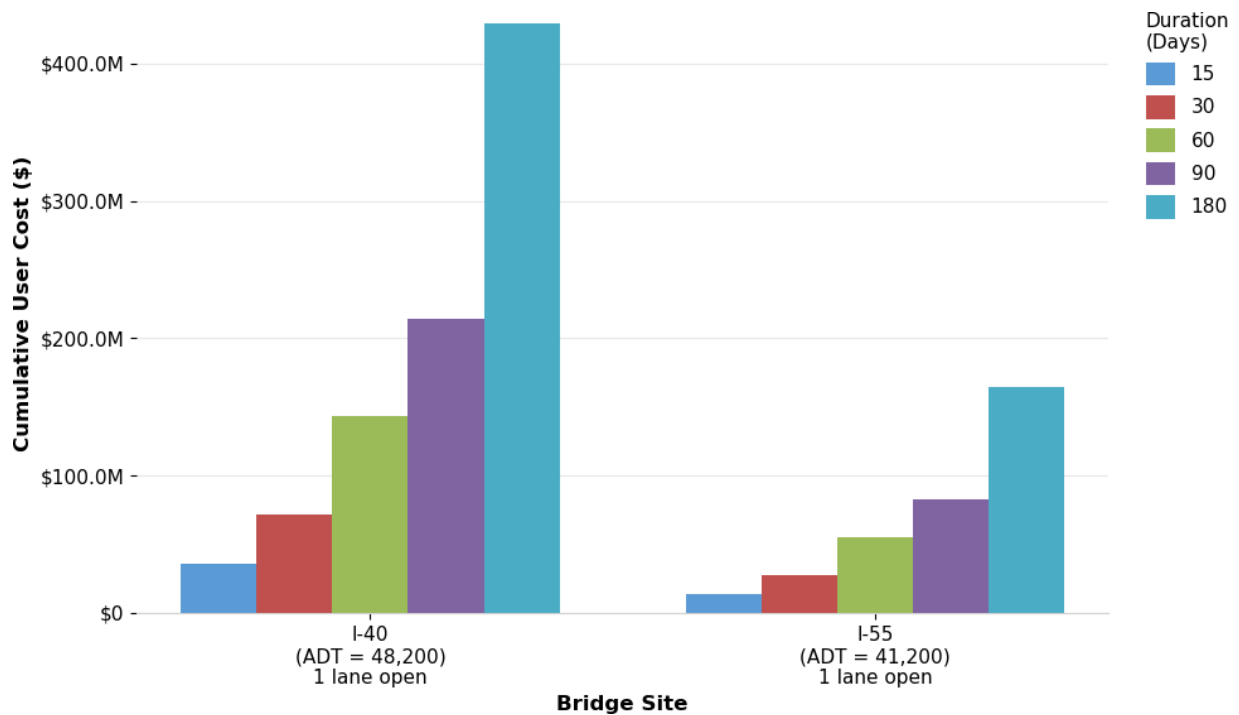


Figure 48. Estimated Road User Costs by Bridge and Closure Duration under Partial Closure Scenario

Figures 49 and 50 present the breakdown of delay, operational, and safety (crash) costs by bridge under full and partial closure scenarios over a 30-day period. In the full closure scenario, all costs are driven by the friction of the detour routes. Because the interstate bridges (I-40 and I-55) have short, highly capable detour routes of only 12 miles, their cumulative 30-day costs remain relatively low at approximately \$5.9 million and \$7.5 million, respectively.

Conversely, closing the rural bridges forces traffic onto large regional detours. For HWY 82, the 241-mile detour to the HWY 49 Helena Bridge makes 'Added Delay' and 'Added Operating' costs dominate, resulting in a 30-day impact of nearly \$29.8 million. For HWY 49, the costs are also led by 'Added Delay' and 'Added Mileage' costs, with the safety component contributing \$28,830 to the 30-day total. In the partial closure scenario, the financial profile shifts. Because the interstates remain partially open, traffic is forced through a localized work zone bottleneck. As a result, User Delay becomes the primary contributor to the total road user costs for both interstates. For I-40, this localized delay generates RUC of over \$66.5 million over 30 days. While localized work zone crash costs are present in this scenario, totaling \$697,500 for the month, they are dwarfed by the economic cost of the traffic queuing. This contrast highlights that for high-volume facilities, the efficiency of the detour route often outweighs the benefit of keeping a single lane open, according to the RUC framework.

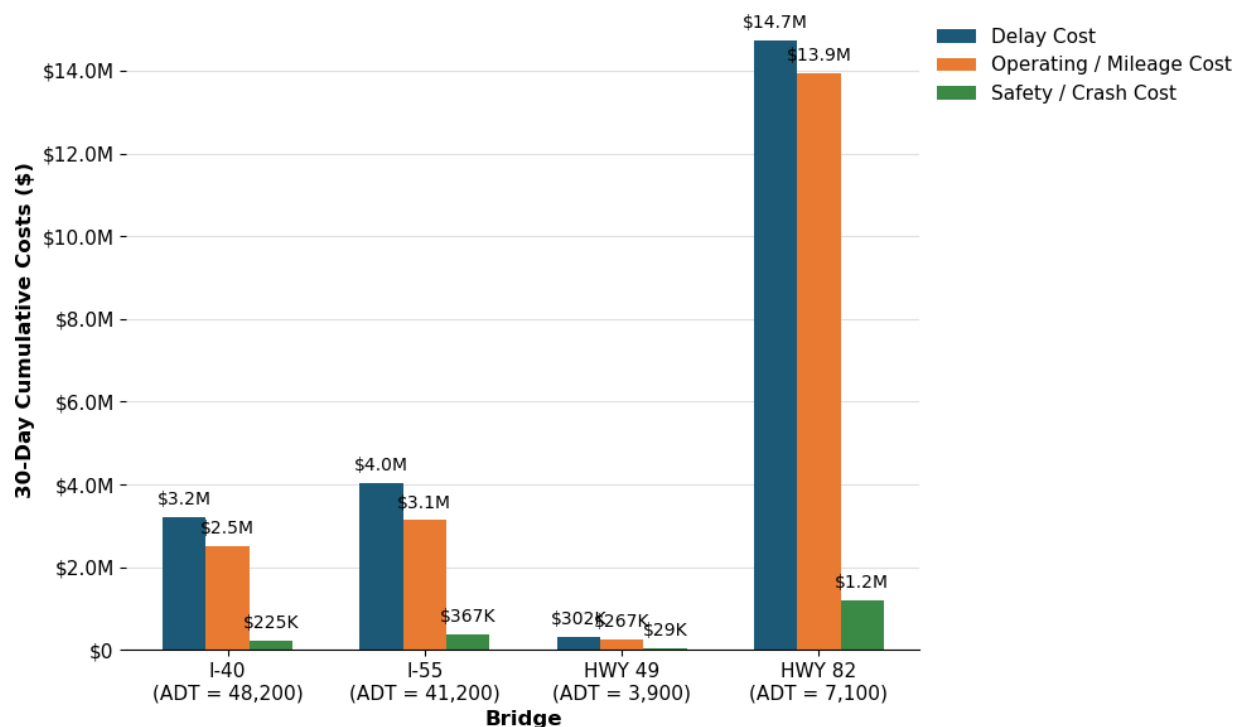


Figure 49. 30-Day Delay, Operational, and Detour Costs by Bridge under Full Closure Scenario

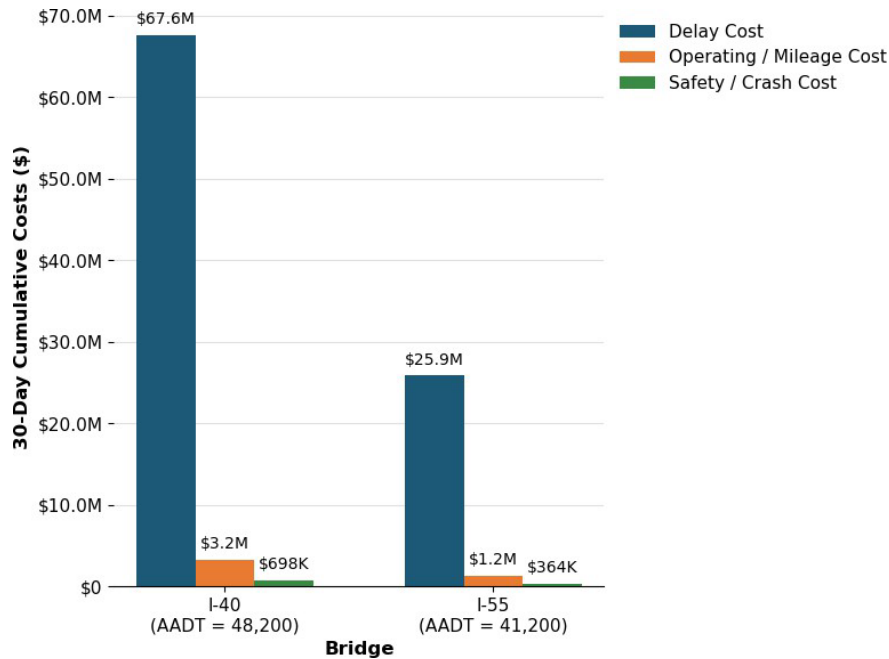


Figure 50. 30-Day Delay, Operational, and Detour Costs by Bridge under Partial Closure Scenario

System Impacts

The analysis of full-closure scenarios for the four Mississippi River bridges (*I-40, I-55, HWY 49, and HWY 82*) during the PM peak period, together with Scenario 1350 during the AM period (*HWY 82 fully open, I-40 eastbound with two lanes open and westbound fully closed, I-55 fully closed, and HWY 49 eastbound fully open with westbound fully closed*) demonstrates that travel impacts vary by bridge location, vehicle type, and time period.

Among the individual bridge closures, the I-40 Hernando de Soto Bridge generated the most widespread disruptions, particularly for TTT, with links exceeding the 4% threshold totaling 6,902 miles. While autos and SUT showed mostly localized increases in VHT near West Memphis, Little Rock, and Northwest Arkansas, tractor-trailers experienced significant rerouting across the South and Midwest, with corridors such as I-64/I-70 and I-20, along with other principal U.S. highways adjacent to these routes. The I-55 closure produced similar but less extensive freight disruptions, with 2,313 miles exceeding the 4% threshold, while the HWY 49 closure generated only localized impacts in Arkansas. By contrast, the HWY 82 closure showed a unique pattern: autos and SUT had approximately 700–900 miles of roadway exceeding the 4% threshold, but tractor-trailer impacts were minor, with only 301 miles exceeding 4%. This reflects the bridge’s rural location, limited capacity, and lower importance for long-haul freight.

When analyzing worst-case conditions by vehicle type, Scenario 1350 (*HWY 82 fully open, I-40 eastbound with two lanes open and westbound fully closed, I-55 fully closed, and HWY 49 eastbound fully open with westbound fully closed*) during the AM period emerged as the most disruptive across the network. This lane-closure configuration forced widespread detours that amplified VHT increases far beyond those observed under any single bridge closure. Autos and

SUT exhibited significant increases in impacted mileage, 2,111% and 1,325% higher than under the I-40 closure, while TTT impacts were also severe, increasing by 173%. These results confirm that while freight vehicles are generally the most sensitive to bridge closures, mixed-vehicle lane restrictions can also trigger system-wide disruptions that surpass those caused by single bridge failures.

Overall, the study highlights the critical role of the Mississippi River crossings in Arkansas for maintaining both regional mobility and national freight flows. The findings reinforce the importance of prioritizing resiliency in bridge infrastructure, particularly for high-capacity crossings such as I-40 and I-55.

Waterway Impacts

Between 2021 and 2024, vessel traffic across the four Mississippi River bridges in Arkansas rose by about 8 percent, with notable differences by location. The section of river under HWY 49 saw the most tug and tow traffic in 2021 and remained the busiest in 2024, ahead of sections of river under the I-40 and I-55 bridges. The biggest change occurred at HWY 82, where average daily traffic more than doubled, reflecting a significant increase in river-based freight activity. The section of river under the I-55 bridge saw slightly lower totals in 2024 than in 2021, while keeping a similar seasonal pattern with peaks in early spring and late fall. Monthly variations show distinct directional and seasonal dynamics.

To reflect both historical and recent vessel flow conditions, closure cost estimates are presented for 2021 (year of the Hernando DeSoto bridge closure) and the year 2024. In 2021, estimated daily waterway disruption costs across the four Mississippi River bridges totaled \$1,365,672, with HWY 49 the highest at \$461,136. By 2024, the total increased to \$1,472,088 (about 8% higher). HWY 49 remained \$461,136, I-40 was unchanged at \$407,928, HWY 82 rose from \$70,944 to \$195,096, and I-55 decreased from \$425,664 to \$407,928.

CHAPTER 4. IMPLEMENTATION

This chapter provides an overview of the implementation tool for analyzing bridge closure scenarios, highlights key findings and presents general recommendations for mitigating closure impacts.

BRIDGE CLOSURE IMPACT ANALYSIS TOOL

To allow for a more robust and comprehensive review of scenarios and maps, this project developed the *Bridge Closure Impact Analysis Tool*, a web-based application designed to estimate the comprehensive impacts of bridge closures in Arkansas. The tool provides a streamlined, user-friendly interface for calculating Road User Costs (RUC) and system-wide traffic impacts associated with full and partial closures of four critical Mississippi River bridges: I-40 (Hernando de Soto Bridge), I-55 (Memphis–Arkansas Bridge), HWY 49 (Helena Bridge), and HWY 82 (Greenville Bridge).

Purpose of the Tool

The primary objective of this tool is to automate and simplify the quantification of economic and safety-related impacts on motorists and freight carriers. It achieves this by serving as an interactive front-end to a series of sophisticated backend calculations and data models. The tool's architecture integrates a Python-based calculation engine with a suite of Microsoft Excel workbooks that contain the core RUC estimation logic. This logic is based on the Federal Highway Administration's *Work Zone Road User Costs – Concepts and Applications* (2011) methodology. Users can configure various closure scenarios by adjusting parameters such as the number of open lanes, work zone duration, and detour routes. The tool then programmatically interacts with the appropriate Excel files and travel demand model scenario runs to compute two primary categories of impacts:

1. **Link-Level Impacts:** These include direct daily Road User Costs (RUC) for each bridge, separated into localized work zone friction (User Delay, User Operating, and Crash Cost) and regional detour friction (Added Delay, Added Mileage, and Added Safety). The tool also calculates the specific impacts of closures on waterway traffic, estimating the number of disrupted tugs and barges and the associated economic cost.
2. **System-Level Impacts:** These provide a broader view of how a closure scenario affects the entire regional road network. The tool calculates changes in Vehicle Miles Traveled (VMT) and Vehicle Hours Traveled (VHT) across different road types (e.g., freeways, arterials), specifically separating commercial and heavy truck delays to highlight freight impacts. It then visualizes these changes through interactive charts and geospatial maps.

By automating these complex calculations, the *Bridge Closure Impact Analysis Tool* enables planners and engineers to rapidly test different scenarios, compare the costs of full versus partial closures, and make more informed decisions to prioritize future maintenance projects and justify incentive/disincentive clauses. A full implementation guide is provided as a

standalone document. The guide provides a comprehensive overview of the tool's workflow, user interface, underlying calculation methodologies, and results interpretation.

Key Capabilities of the Tool

The tool provides a comprehensive framework for analyzing the impacts of bridge closures and work zones. It supports both single-bridge and multi-bridge analyses, which is essential for capturing regional dynamics since a closure on one bridge, such as I-40, directly alters congestion and traffic distribution on nearby facilities like I-55. Users can configure a wide range of closure scenarios (Figure 51) with a high degree of control, including full closures that divert all traffic to designated detours and partial closures that allow limited traffic flow through the work zone at reduced capacity. In addition, the tool fully automates Road User Cost (RUC) calculations by programmatically running the official ARDOT spreadsheets, producing detailed results for both localized friction and added detour penalties (Figure 52).

In addition to roadway impacts, the tool extends its analysis to waterways, estimating the economic disruption caused by bridge closures on commercial navigation along the Mississippi River. It quantifies total costs and provides metrics such as the number of tugs, barges, and short tons of freight affected. At the System-level, the tool captures network-wide effects by measuring shifts in Vehicle Miles Traveled (VMT) and Vehicle Hours Traveled (VHT), offering insight into how closures redistribute traffic across Arkansas. To make these results accessible, an interactive dashboard presents high-level metric cards, bar charts that break down RUC components, and a dynamic geospatial map of the road network, color-coded to clearly highlight where travel times increase most severely as a result of the closures (Figure 53).

The screenshot displays the 'ARDOT Bridge Closure Impact Analysis Tool' interface. It is divided into two main sections: 'Step 1: Scenario lane configurations' on the left and 'Network Traffic Redistribution' on the right. The left section includes a dropdown for 'Select bridge(s) to analyze' (currently showing 'I-40'), a section for 'Set lane closures for selected bridges' with 'Eastbound Status' and 'Westbound Status' both set to 'Fully Closed', and a red button labeled 'Confirm Configurations & Fetch Traffic Data'. The right section shows 'Active ARSTDM Model: Scenario 1223' and four traffic volume cards: 'I-40 Daily Traffic' (48,200, No Change), 'I-55 Daily Traffic' (73,844, +32,644 (+44.2%)), 'US 49 Daily Traffic' (4,646, +1746 (+37.6%)), and 'HW 83 Daily Traffic' (7,100, No Change). A 'Deploy' button is visible in the top right corner.

Bridge	Daily Traffic	Change
I-40	48,200	No Change
I-55	73,844	+32,644 (+44.2%)
US 49	4,646	+1,746 (+37.6%)
HW 83	7,100	No Change

Figure 51. Interface for configuring single- and multi-bridge closure scenarios to analyze regional traffic redistribution.

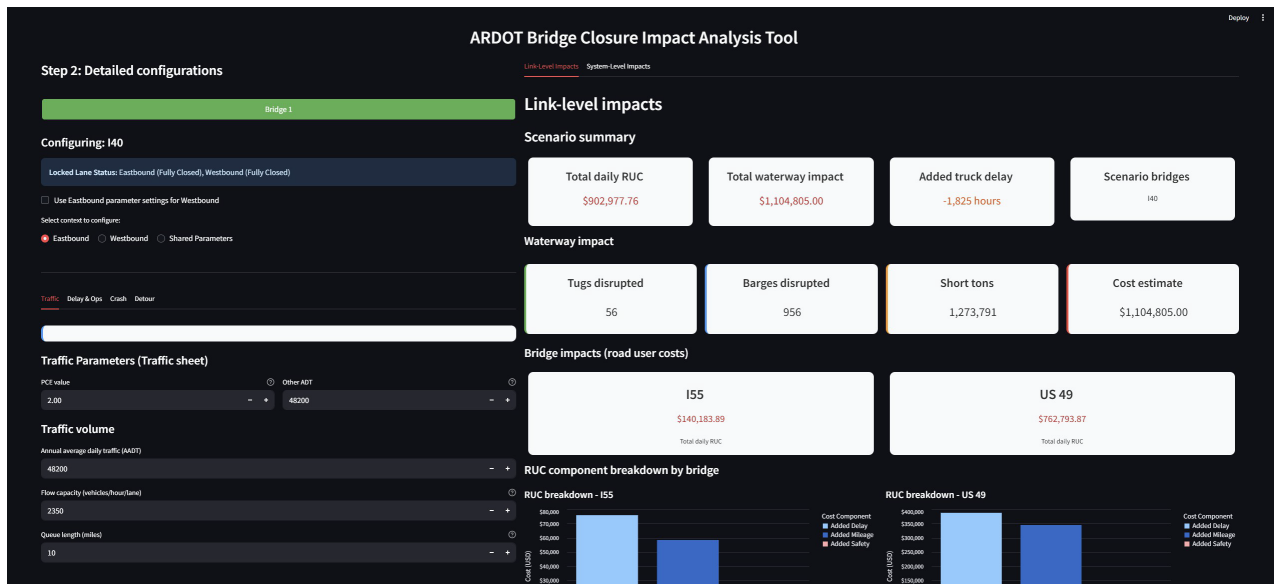


Figure 52. Screenshot of the "Summary" page of the Bridge Closure Impact Assessment Tool.

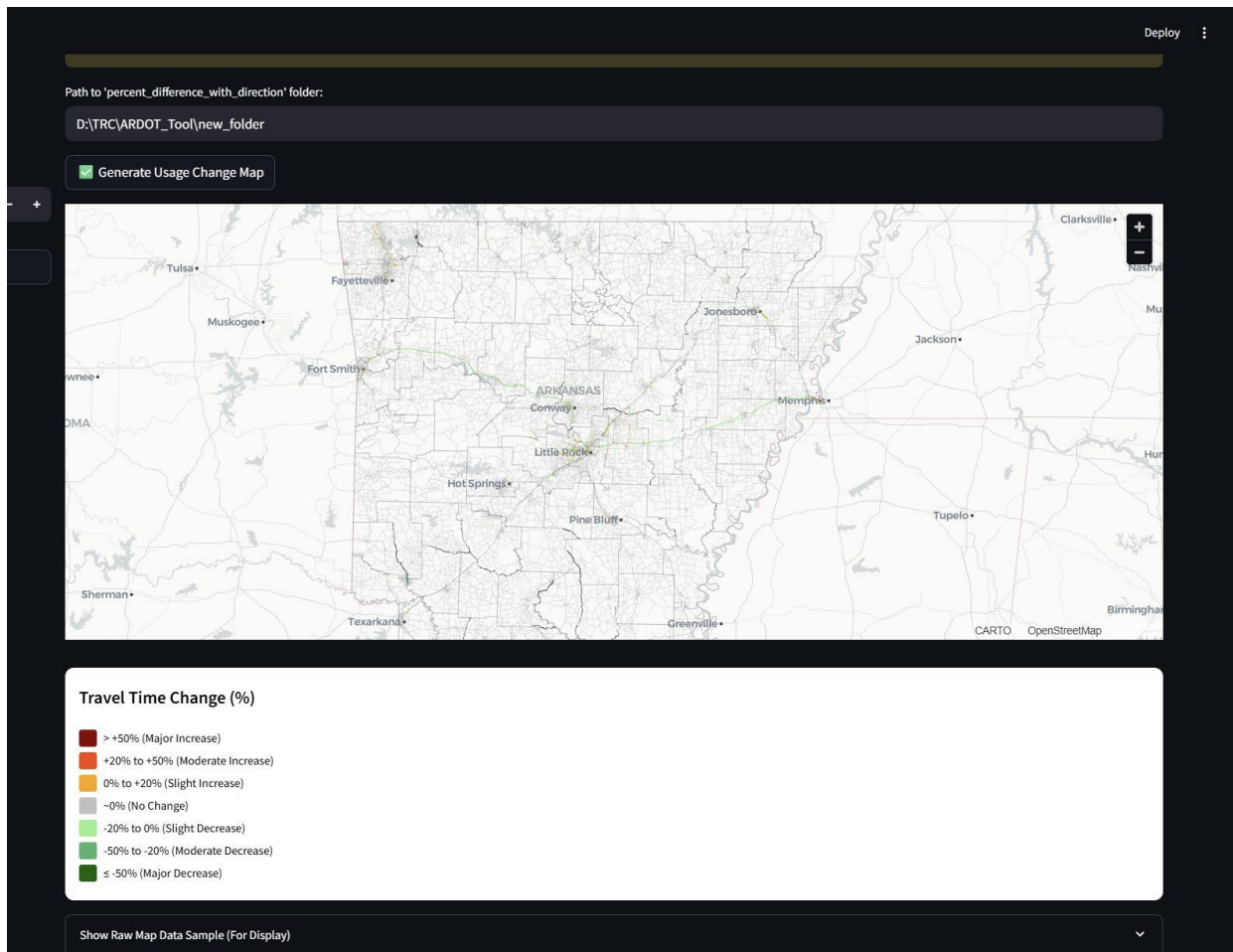


Figure 53. Screenshot of the dynamic and interactive map within the Bridge Closure Impact Assessment Tool.

MITIGATIVE SOLUTIONS FOR MINIMIZING THE IMPACT OF CLOSURES

Mitigating bridge and roadway closure impacts is a critical first step in reducing disruptions to the transportation system. There are generally three categories of mitigative solutions: operational, maintenance, and planning. The operational solutions are usually implemented during the closure or construction phases and are aimed at informing the road users during the event. The maintenance and the planning solutions are pre-closure methods where the road infrastructure and the analysis are conducted before an actual event of road closure. Maintenance involves knowledge of the road assets whereas planning involves an idea of foreseeing the future and preparing to mitigate the impact of the event. The following section discusses some of the most common mitigative solutions applied to road closures with focus on bridge closures.

Operational Mitigative Solutions

Operational practices for mitigative solutions of road closures usually involve Intelligent Transportation Systems (ITS) (Table 15). Previous studies identified methods like the dynamic lane merge indicators where the road users were requested to merge onto a different lane during partial closure of traffic lanes or using a live webpage to inform the road users about the current road closures (Charlotte, n.d.). Other measures involve systematic and strategic placement of the Maintenance Of Traffic (MOT) symbols along the detours has been found to help the road users by making them better informed so that they can be guided to move along the roadway network (Mwamba et al., 2021). Data-driven operational parameters have also been found to be an effective way to mitigate alternative roadways during road closure events (Wang et al., 2016).

Table 15. Categories of operational mitigative solutions to roadway closures

Model/Method	Reference	Event	Asset on the transportation system
Dynamic Lane Merge using traffic sensors	(Robinson & others, 2001)	Lane Expansion in Michigan	Workzone
Strategic use of MOT	(Mwamba et al., 2021)	Construction and road closures in Indiana	Roadways
Web-based application of road closures	(Charlotte, n.d.)	Live webpages	Roadways
Next Road Rerouting	(Wang et al., 2016)	Road closure due to extreme congestion	Roadways

Maintenance-based Mitigative Solutions

Maintenance-based mitigative solutions are more structurally oriented for roadway closures (Table 16). The three main categories of maintenance-related mitigative solutions are driven by the resilience of the structures holding the roadway segment, life-cycle estimation of the structures, and construction-based practices. These principles are applied to roadways or

assets, followed by a ranking-based method for identifying vulnerable locations along the roadways. Resilient-based analysis can be computed by identifying the independent pathways that can be undertaken during network disruption so that the retrofitting projects can be prioritized (Fitzsimmons et al., 2014; W. Zhang & Wang, 2016). Such studies identify the resilience of the road networks at their vulnerable location – bridges (Capacci et al., 2022). Conducting a life-cycle benefit-to-cost ratio analysis for the road infrastructure and then applying it to the different road assets can help agencies prepare a list of locations that require imminent attention (Padgett & Tapia, 2013; N. Zhang & Alipour, 2021; Cheng & Gao, 2023). Different construction-based practices like Structural Health Monitoring (Thöns & Stewart, 2019) can also improve this process by preparing such a list of locations for the agencies. Another way to mitigate the impact of road closures can be by following a set of best practices laid by the federal, state, and local governments, which will involve some kind of training and knowledge transfer technology (Keller, 2002). Though these methods have been found to be useful in the past, the transportation and traffic division would require experts from construction departments to assist them in such evaluations.

Table 16. Categories of maintenance-based mitigative solutions to roadway closures

Model/Method	Reference	Event	Asset on the transportation system
Resilience	(W. Zhang & Wang, 2016)	Simulation (hypothetical disruption)	Bridges
	(Capacci et al., 2022)	Past studies	Bridges
	(Fitzsimmons et al., 2014)	Simulation (hypothetical disruption) in Kansas	Bridges
Life Cycle	(N. Zhang & Alipour, 2021)	Flooding Events (hypothetical disruption) in Iowa	Roadways
	(Padgett & Tapia, 2013)	Simulation (hypothetical disruption) in South Carolina	Bridges
	(Cheng & Gao, 2023)	Simulation (hypothetical disruption) in New Jersey	Bridges
Construction	(Thöns & Stewart, 2019)	Simulation (hypothetical disruption) in UK	Bridges
	(Keller, 2002)	Flooding Events in North America	Rural Roadways

Planning-based Mitigative Solutions

Mitigation through planning is the most common solution identified in the literature (Table 17). The process involves analysis and planning in using various categories involving probabilistic modeling, scenario-based analysis, and judicious scheduling of roadway closures. Scheduling the closing time and duration for road closures is an important strategy that has been helping

mitigate the impact of bridge closures since the past century (Sinha & Jha, 1996). A recent study improved the strategy by incorporating the productivity of the maintenance crew to determine the planning strategy for road closures (Chien et al., 2016). This has further been improved by using deep reinforcement learning to schedule the different projects for road closures (Esmaeilzadeh Seilabi et al., 2022). Planning and scheduling can also be used by emergency vehicles for searching and rescuing the people affected by an earthquake. By planning the routes beforehand, the transportation agencies and first responders can work hand in hand to better serve a locality being affected by a disruption (Y. Wu & Chen, 2023). The mitigation applications to freight transportation and planning is equally important as the passenger vehicles. A recent study for an island near Seattle, Washington identified planning strategies to mitigate the short-term and long-term impacts of the bridge closure (Goodchild et al., 2021). The study identified some short-term measures such as granting special permission to local businesses, and parcel carriers, hosting storage containers for storing freight, and promoting zero-emission vehicles. On the other hand, long-term strategies involved shared freight movement and storage facilities. The mitigation strategies were found to be a bit different for road closure events for all vehicles in the islands of Hawaii, where long-term planning was identified to be elevated construction practices and hardened infrastructure (K. Kim et al., 2019).

Historical and scenario-based analysis has also been found to be popular in past literature as researchers can adopt hypothetical scenarios and make planning changes and adjustments according to them (Waterway, 2014; B. Kim et al., 2018; Quagliarini et al., 2018; K. Kim et al., 2019). These studies usually calculate various what-if scenarios based on road closures at bridges or vulnerable locations. Studying this can be found to be one of the most useful planning methods as the agencies can emulate such work and be better prepared when such events strike them.

A risk assessment probabilistic modeling of road closures was also found to be a useful mitigative option for transportation agencies across the globe in case of an impending natural calamity where a major road might need to be closed for an event such as volcanic eruption, earthquake, and others (Dalziell & Nicholson, 2001; Ertugay et al., 2016; Nicholson & Dalziell, 2001). Some of the earlier works were further progressed by conducting a benefit-to-cost ratio for each event (snow, volcanic eruption, and others) and then planning for each separate event accordingly (Nicholson & Dalziell, 2003).

With regard to waterway closure the mitigation techniques have usually been based on planning and simulation-based approach where the impact is analyzed through a scenario-based analysis of a waterway closure (Kanerla et al., 2019) or through a scheduling of the waterway closure to see which time and what duration will be the most favorable one (Rahimikelarijani et al., 2017).

These findings suggest that ARDOT would benefit from adopting a broader set of what-if scenarios to prepare for future roadway closures.

Table 17. Categories of planning-based mitigative solutions to roadway closures

Model/Method	Reference	Event	Asset on the transportation system
Search-and-rescue (SAR) activity	(Y. Wu & Chen, 2023)	Tennessee (Earthquake)	Intersections
Freight Mitigation Plan	(Goodchild et al., 2021)	Seattle bridge closure	Bridge Closure
Probabilistic Risk Assessment	(Dalziell & Nicholson, 2001; Nicholson & Dalziell, 2001, 2003)	Natural calamities in New Zealand	Roadways
Probabilistic Risk Assessment	(Ertugay et al., 2016)	Natural Events in Greece	Roadways
Historical and Scenario Analysis	(K. Kim et al., 2019)	Volcanic Eruption and flood in Hawaii	Roadways
Historical and Scenario Analysis	(B. Kim et al., 2018)	Flood in South Korea	Bridges
Historical and Scenario Analysis	(Waterway, 2014)	Bridge Closure in Canada	Bridges
Historical and Scenario Analysis	(Twumasi-Boakye & Sobanjo, 2018)	Hurricane in Florida	Bridges
Historical and Scenario Analysis	(Kanerla et al., 2019)	Waterways closure in Texas	Waterways
Historical and Scenario Analysis	(Quagliarini et al., 2018)	Earthquake in Italy	Roadways
Scheduling of closures	(Sinha & Jha, 1996)	Work zones in Indiana	Roadways
Scheduling of closures	(Chien et al., 2016)	Work Zone in New Jersey	Roadways
Scheduling of closures	(Esmaeilzadeh Seilabi et al., 2022)	Road closures in Indiana	Roadways
Scheduling of closures	(Rahimikelarijani et al., 2017)	Temporary waterway closures in Texas	Waterways

CHAPTER 5. CONCLUSIONS

This study quantifies the economic and mobility impacts resulting from full and partial closures of four critical Mississippi River bridges in Arkansas: I-40 (Hernando de Soto Bridge), I-55 (Memphis–Arkansas Bridge), HWY 49 (Helena Bridge), and HWY 82 (Greenville Bridge). The analysis integrates Road User Cost (RUC) estimation, system-level congestion modeling, and waterway disruption assessments to evaluate the consequences for passenger vehicles, freight carriers, and commercial vessels.

Using an automated RUC application paired with a travel demand model, daily economic impacts were calculated for both full and partial closure scenarios of the four Mississippi River Bridges. The gravity model is used to assign traffic fractions when multiple crossings are restricted. For example, if I-40 and HWY 49 are closed, the model predicts how much of the added traffic on I-55 originates from each bridge based on their baseline volumes and distances.

The RUC framework used by ARDOT leads to estimates that show partial closures on high-volume facilities generated higher daily Road User Costs than full closures. Restricting the I-40 bridge (ADT 48,200) to a single open lane creates a severe localized bottleneck, driving its partial closure cost to \$2,382,823 per day. Similarly, a partial closure on I-55 (ADT 41,200) operating with one lane open costs \$915,416 per day. Partial closures are not applicable for HWY 49 and HWY 82 because each bridge has only one lane in each direction, leaving no practical excess capacity for a lane-reduction scenario.

Under full closure scenarios, the rural bridges bear higher financial impacts relative to their traffic volumes. Because traffic redistributes easily between the closely spaced I-40 and I-55 bridges, their full closure costs are lower at \$198,625 and \$250,691 per day, respectively. In contrast, HWY 82 incurs a high full closure RUC of \$994,762 per day. While HWY 49 has a lower daily cost of \$19,927, its impact is still significant given its low baseline volume. These costs are driven by remote locations that force diverted traffic onto lengthy regional detours. For HWY 82, the detour to HWY 49 bridge reaches 241 miles.

The distribution of cost components shifts depending on the scenario. For partial closures on interstates, user delay is the overwhelming primary contributor due to massive traffic queuing at the work zone bottleneck. However, for full closures on rural routes like HWY 49 and HWY 82, the primary financial burdens are added delay and added mileage costs accumulated over the extreme detour distances. Safety and crash costs remain a factor across all scenarios, representing the normalized risk associated with increased travel exposure on alternate routes.

Crash history data further informed safety-related impacts. Between 2019 and 2023, I-40 recorded 449 crashes, including 7 fatal incidents, while I-55 had 637 crashes, with 13 fatalities. These figures were used to estimate crash costs under partial closure scenarios using Crash Modification Factors (CMFs).

The Arkansas Statewide Travel Demand Model (ARSTDM) was used to simulate 2,303 closure scenarios and estimate system-wide changes in Vehicle Hours Traveled (VHT) for three vehicle classes: autos, single-unit trucks (SUT), and tractor-trailer trucks (TTT). The PM peak period was identified as the most critical time for disruptions.

Under a full closure of I-40, TTT experienced the most significant impact, with 6,902 miles of roadway showing more than a 4% increase in VHT, representing 7.7% of the modeled network. Autos and SUT were minimally affected, with only 0.55% of links impacted. The I-55 closure resulted in 2,313 miles of 4% or more impacts in VHT for TTT (2.6% of the modelled network), while HWY 49 and HWY 82 had more localized effects. HWY 49 impacted VHT more than 4% for 784 miles (0.9% of the modelled network) for TTT, and HWY 82 had the smallest TTT impact at 301 miles (0.3% of the modeled network), though it showed the highest auto and SUT impacts, 742 miles (0.8% of the modelled network) and 742 miles (1.0% of the modelled network), respectively.

The worst-case scenario, involving simultaneous closures and lane restrictions across multiple bridges, produced the most severe system-wide impacts. During the AM peak period, autos experienced 5,042 miles of roadway with 4% or more VHT increase, SUT had 3,876 miles, and TTT had 18,838 miles, representing increases of 2,111%, 1,325%, and 173% respectively compared to the I-40 closure alone. These results underscore the disproportionate impact of bridge closures on freight mobility and the compounding effects of multi-bridge disruptions.

Bridge closures also disrupt commercial navigation along the Mississippi River. Using Automatic Identification System (AIS) data, the study estimated 24-hour waterway disruption costs for each bridge in 2021 and 2024. In 2021, total disruption costs across all four bridges amounted to \$1.37 million, with HWY 49 incurring the highest cost at \$461,136 per day. By 2024, total costs rose to \$1.47 million, driven by an 8% increase in vessel traffic. HWY 82 saw the most significant growth, with its daily disruption cost nearly tripling from \$70,944 to \$195,096.

Vessel traffic patterns revealed seasonal and directional variations. HWY 49 consistently recorded the highest tug and tow volumes in both years, while HWY 82 experienced the fastest growth. Monthly AIS data showed that vessel crossings peaked in spring and fall, with upstream and downstream flows varying by location and time.

The methodology for estimating waterway impacts involved calculating delay costs per vessel (\$739/hour), closure duration, and tonnage per tug (22,721 short tons). These inputs were scaled using bridge-specific AADT values to produce location-sensitive cost estimates. While the approach does not account for indirect economic effects such as missed shipments or inventory disruptions, it provides a transparent and adaptable framework for estimating direct operational losses.

The development and deployment of the Bridge Closure Impact Analysis Tool are an advancement in how transportation agencies like ARDOT can assess and respond to bridge closure scenarios. By integrating robust backend calculations with an intuitive web-based interface, the tool empowers planners and engineers to quantify both localized and system-wide impacts. Its ability to simulate various closure configurations and automatically compute Road User Costs (RUC) ensures that decision-makers are equipped with actionable insights to prioritize maintenance efforts and optimize traffic management strategies.

The report also highlights a suite of mitigative solutions that cover operational, maintenance-based, and planning-oriented practices that can be employed to reduce the adverse effects of bridge closures. From real-time traffic management using Intelligent Transportation Systems

(ITS) to resilience-based infrastructure assessments and scenario-driven planning models, these strategies offer a multi-layered approach to enhancing the preparedness and responsiveness of transportation networks. The integration of these solutions with tools like the Bridge Closure Impact Analysis Tool can significantly improve the effectiveness of mitigation efforts.

The following summarizes the key insights of the report:

- **Detour Distance as a Primary Cost Driver:** For full closures, the "cost per vehicle" is dictated almost entirely by the distance to the next available crossing. This study restricted detours to AR bridges. In reality, expansion of the analysis to include out of state bridges can lead to further insights.
 - I-40 and I-55 benefit from a short 12-mile detour between them, keeping daily costs relatively low (\$198K–\$251K).
 - HWY 82 traffic must detour 241 miles to the HWY 49 bridge, driving its daily cost to nearly \$1 million, the highest full-closure impact in the study.
- **Bottleneck Dominance on Interstates:** In partial closure scenarios, User Delay is the primary contributor to the total road user cost. For I-40, this delay alone generates a massive financial penalty of over \$67 million over a 30-day period.
- **Regional Dependency of Rural Routes:** While HWY 49 and HWY 82 have lower baseline traffic (AADT), their closures cause the most extreme individual travel disruptions. Because they are the only primary crossings in their respective rural corridors, a closure forces a total redistribution of regional freight and passenger traffic. In the case of HWY 82, the 241-mile detour essentially severs the immediate economic link between the two regions, transforming a routine 10-minute local crossing into a 4-hour interstate trip.
- **Marginalized Safety Costs:** While safety and crash risks increase in every scenario due to higher travel exposure on alternate routes, these costs are dwarfed by the economic penalties associated with traffic queuing and extra mileage.
- **TTTs** are disproportionately affected by closures, with rerouting impacts extending hundreds of miles beyond Arkansas.
- **Waterway disruptions** are substantial and rising, with HWY 82 showing the most rapid growth in vessel traffic and associated costs.
- The **Bridge Closure Impact Analysis Tool** enables planners to simulate scenarios, automate RUC calculations, and visualize system-level impacts, supporting data-driven decision-making.
- **RUC Framework as a Tool:** The RUC framework leads to the insight that partial closures on high-volume facilities (I-40 and I-55) are more expensive than full closures. Following the logic in ARDOTs RUC spreadsheet tool, keeping a single lane open creates a localized work zone bottleneck, whereas a full closure allows traffic to move more freely over short, high-capacity detour routes. The degree to which this holds true is recommended

for future study as it may lead to necessary modifications of the RUC framework adopted by ARDOT.

These findings equip ARDOT with actionable insights to prioritize infrastructure investments, optimize traffic control strategies, and mitigate the economic and mobility consequences of future bridge closures.

CHAPTER 6. REFERENCES

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APPENDIX A. OBSERVED TRAVEL PATTERNS DURING THE I-40 BRIDGE CLOSURE

This appendix provides maps of zonal flows of passenger and commercial vehicle traffic during the 2021 Hernando de Soto bridge closure. Each map is presented as a heat-map showing daily volumes of passenger and commercial vehicle trips at the Traffic Analysis Zone (TAZ) level to and from each of the four Mississippi River bridges. The maps correspond to the pre-closure (April 15 to April 20, 2021), full closure (May 11 to July 31, 2021), and post closure (October 15 to October 30, 2021) periods. The maps corresponding to commercial truck flows using the Geotab probe data are followed by maps corresponding to passenger flows using the StreetLight probe data.

Commercial Vehicle Flows using Geotab Probe Data

The following maps depict the flows to and from each TAZ for each of the four Mississippi River bridges in Arkansas. Each figure presents a heat map with color shading intensity representing traffic volume. Red coloring indicates destination volume (from the bridge to the TAZ). Green coloring indicates originating volume (from the TAZ to the bridge).

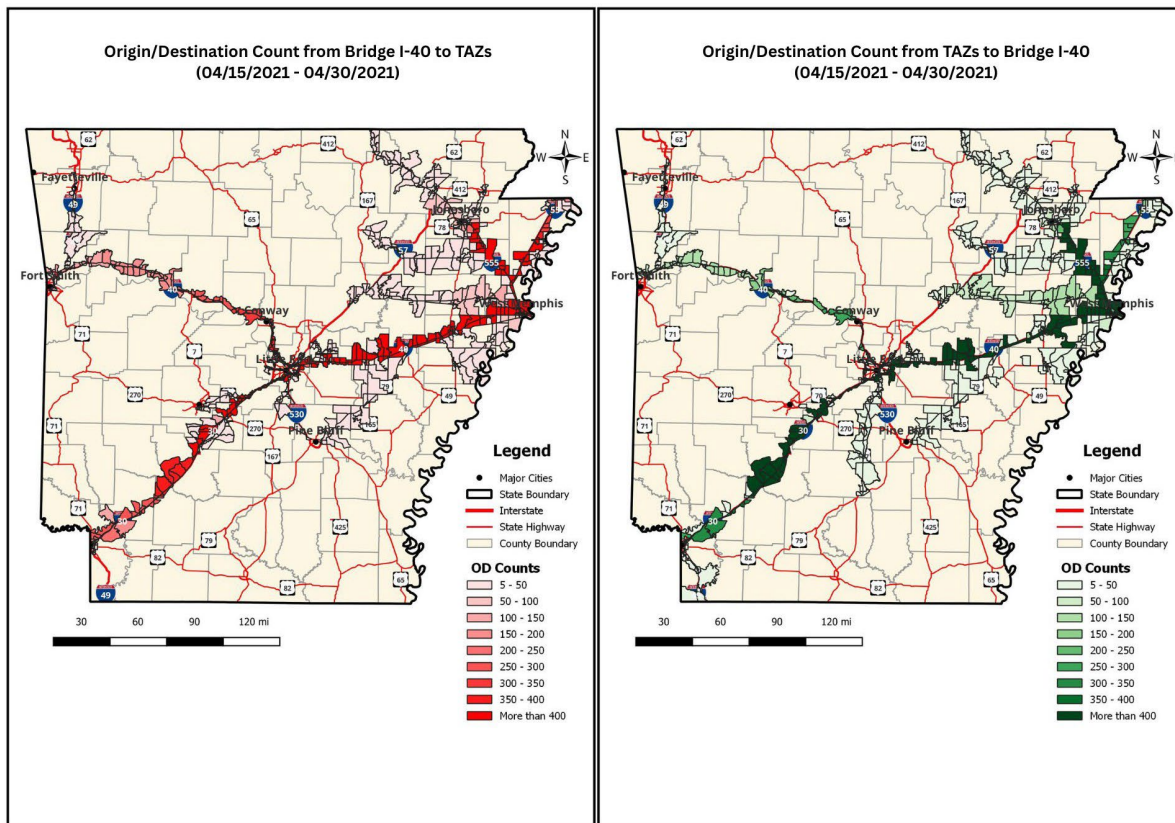


Figure A-1. OD Flows to and from I-40 for April 15 through 30, 2021

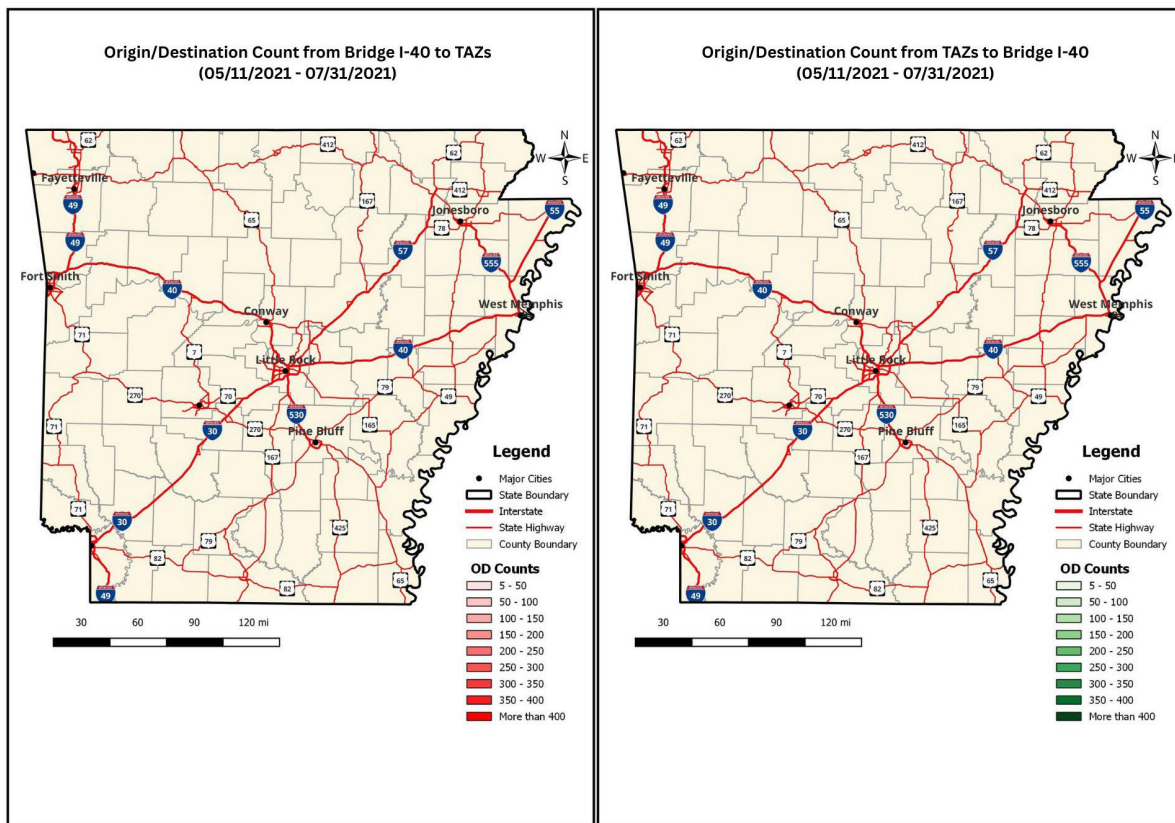


Figure A-2. OD Flows to and from I-40 for May 11 through July 31, 2021

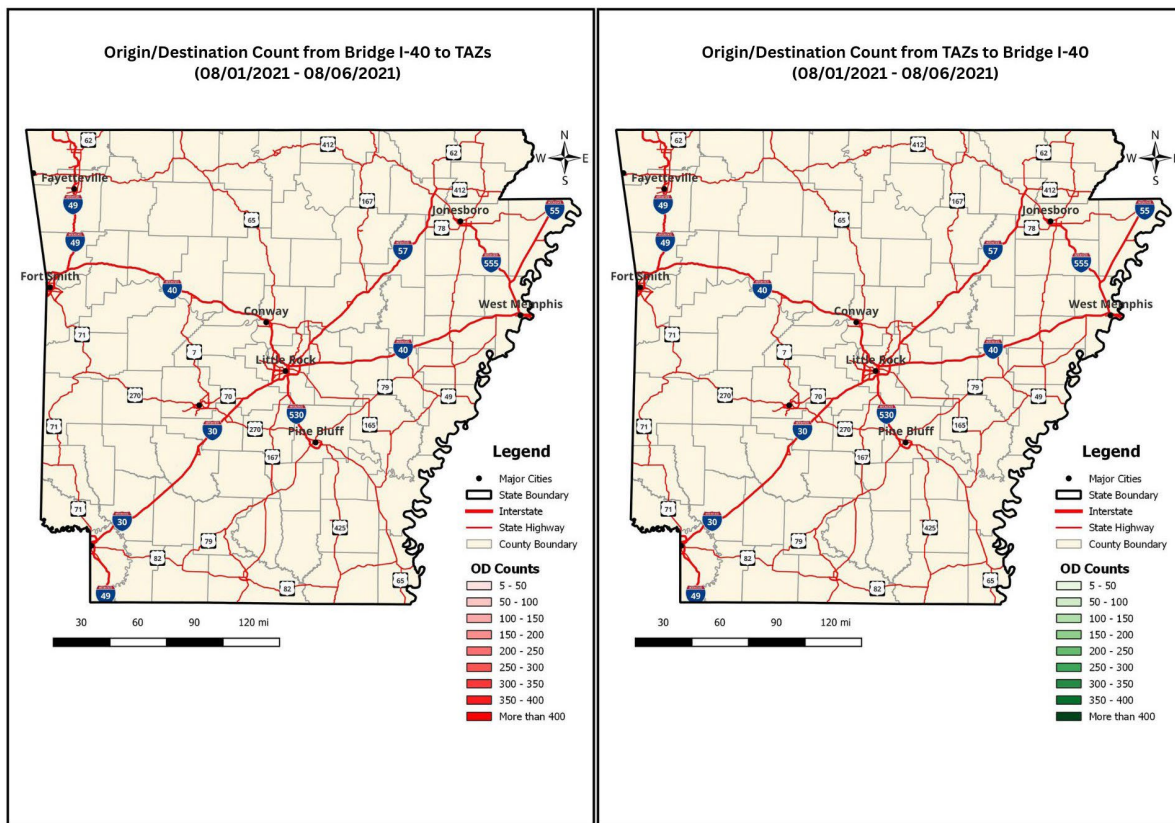


Figure A-3. D Flows to and from I-40 for August 1 through August 6, 2021

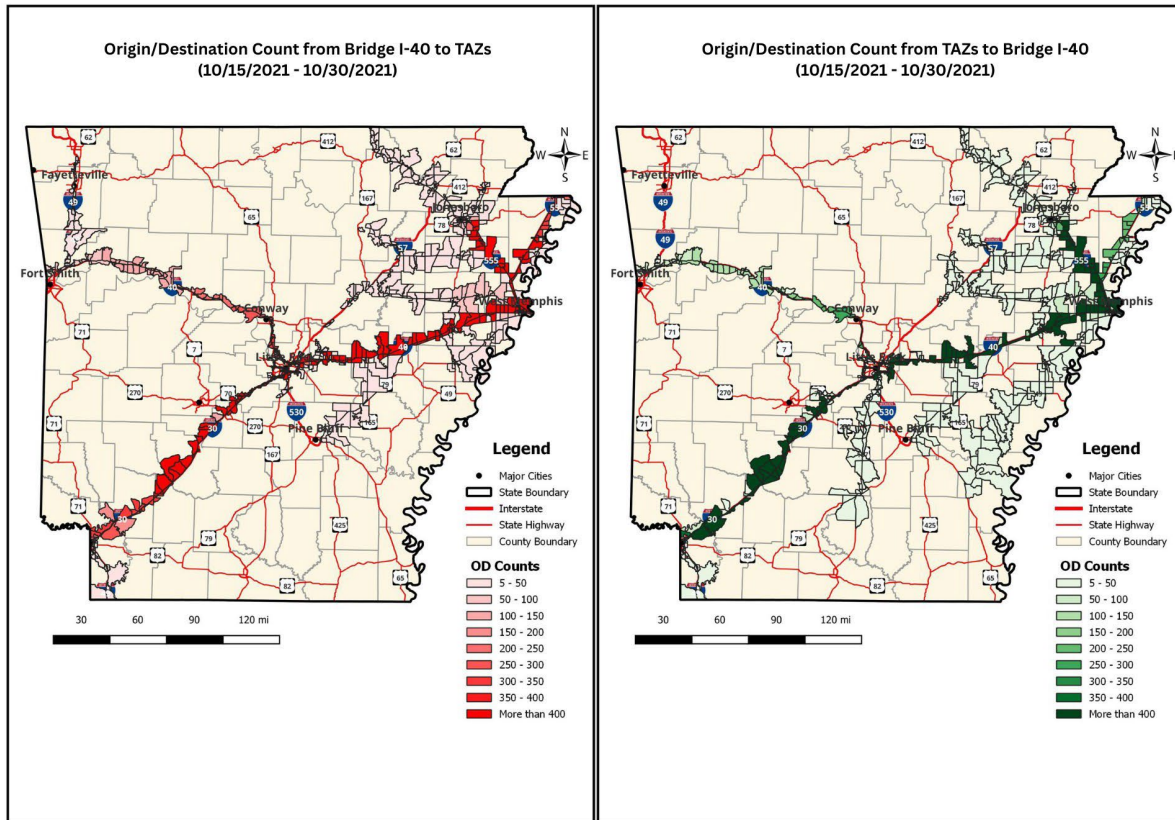


Figure A-4. OD Flows to and from I-40 for October 15 through October 30, 2021

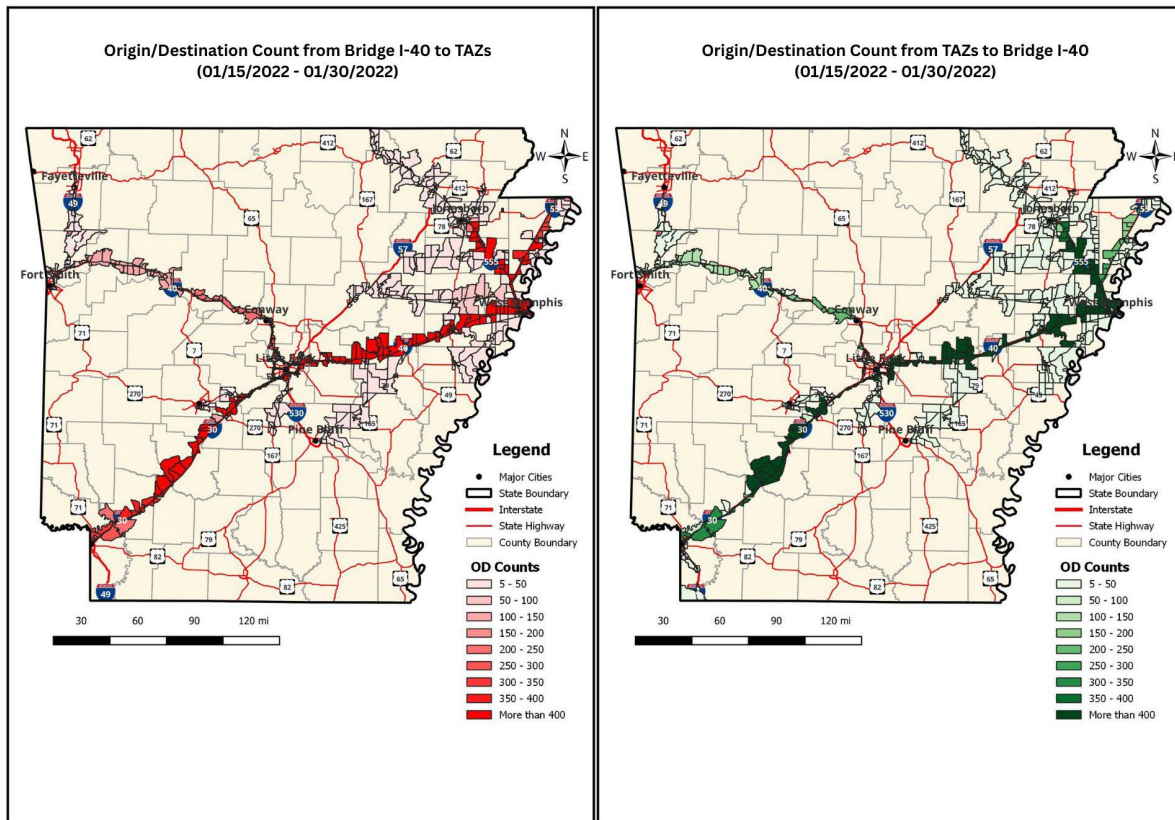


Figure A-5. OD Flows to and from I-40 for January 1 through 30, 2022

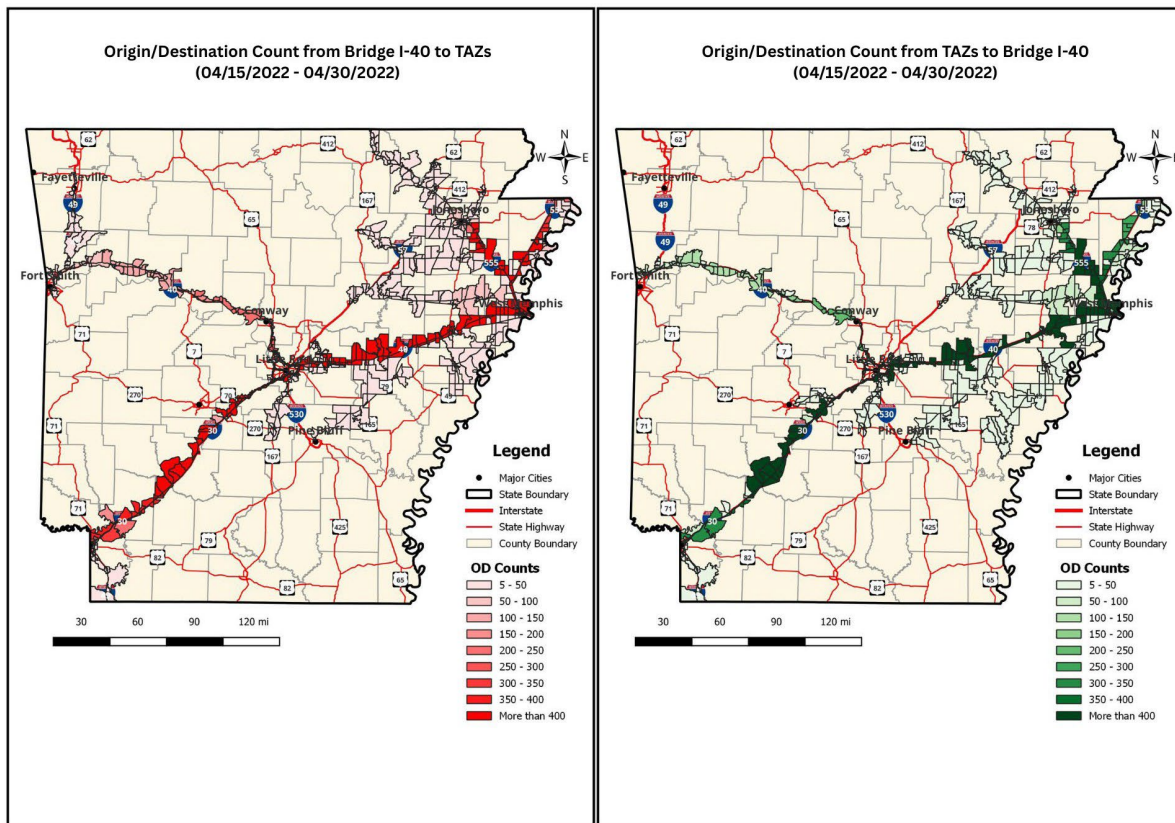


Figure A-6. OD Flows to and from I-40 for April 15 through 30, 2022

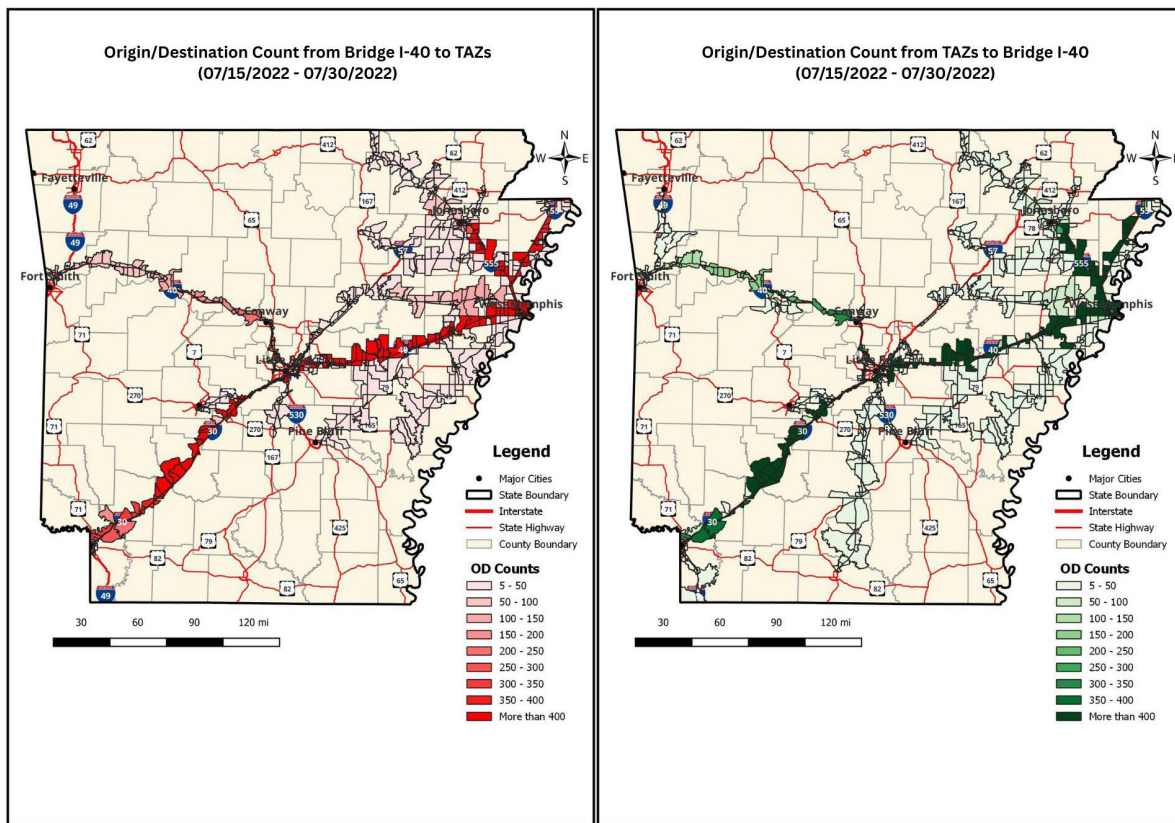


Figure A-7. OD Flows to and from I-40 for July 15 through 30, 2022

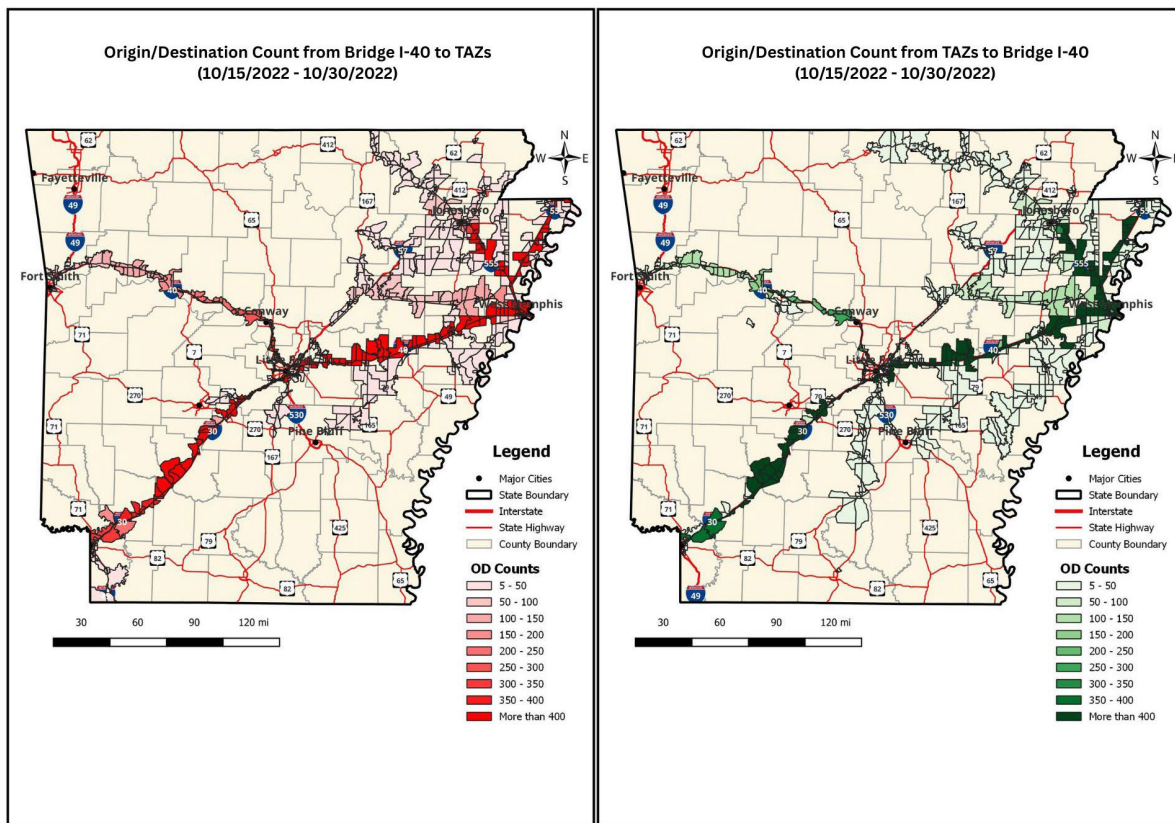


Figure A-8. OD Flows to and from I-40 for October 15 through 30, 2022

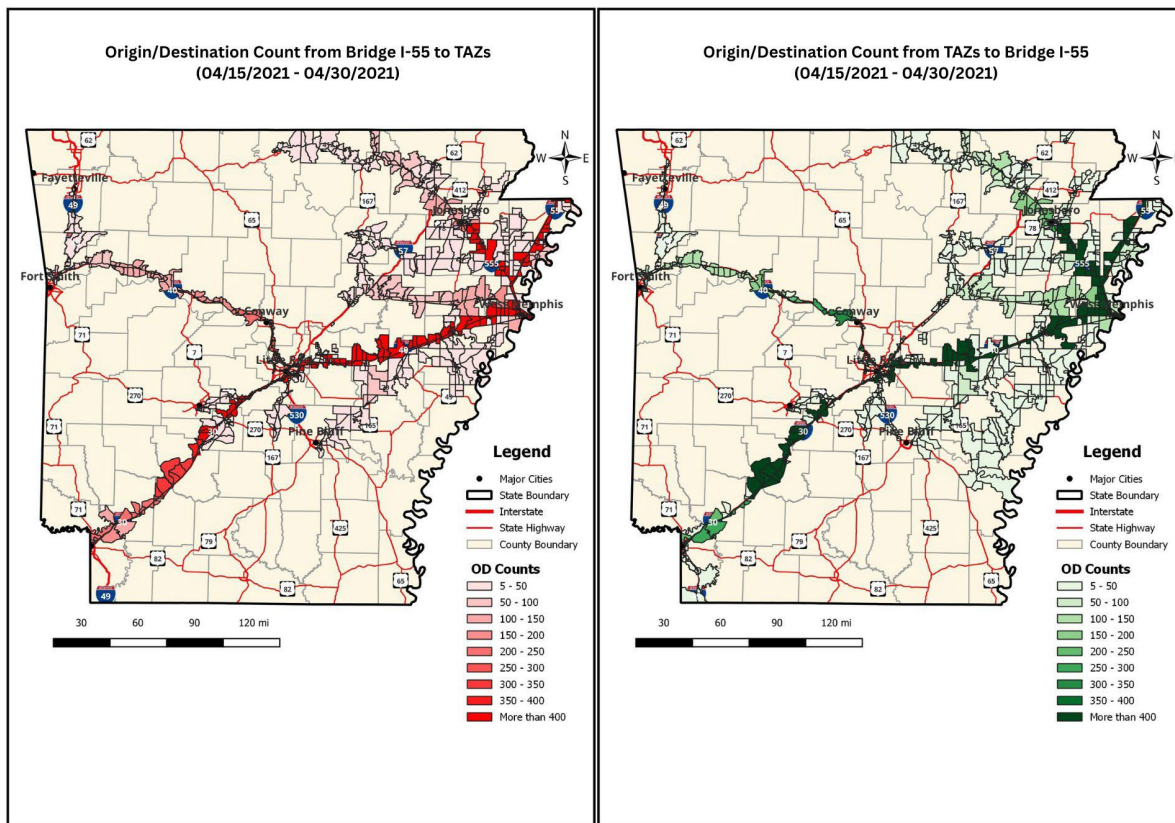


Figure A-9. OD Flows to and from I-55 for April 15 through 30, 2021

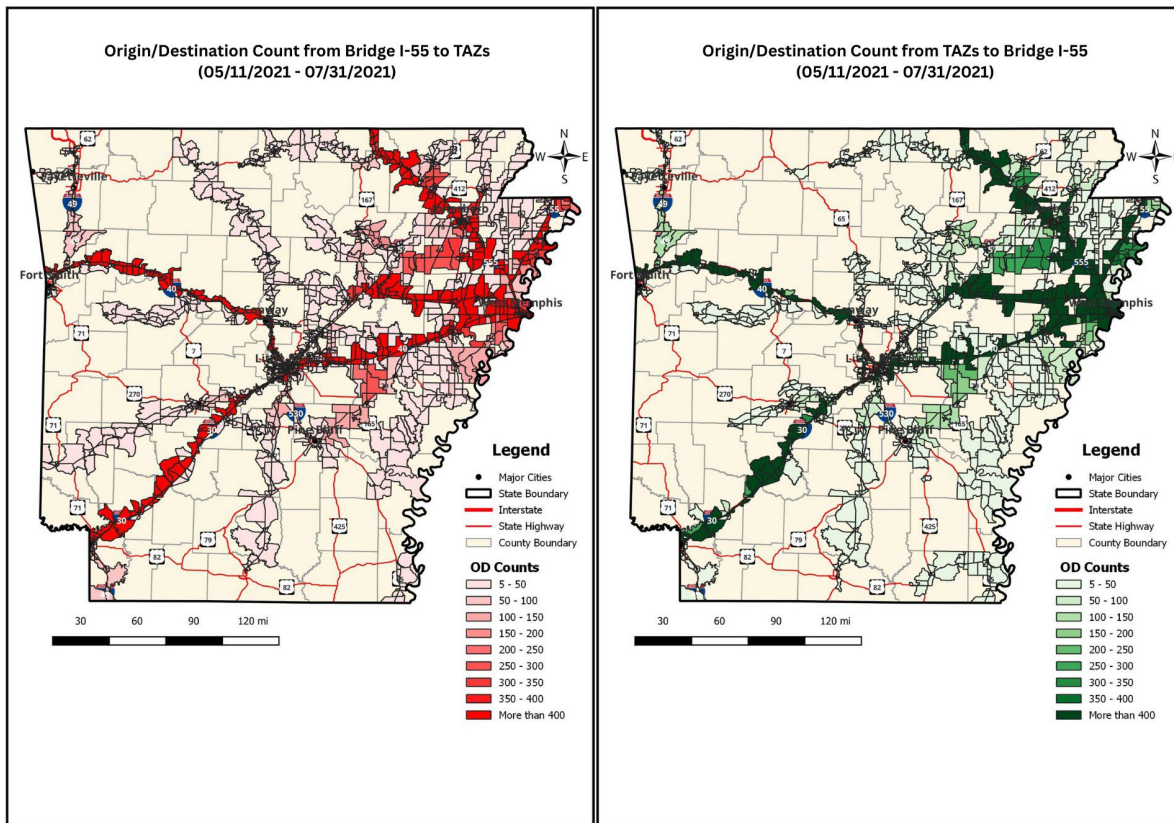


Figure A-10. OD Flows to and from I-55 for May 15 through July 31, 2021

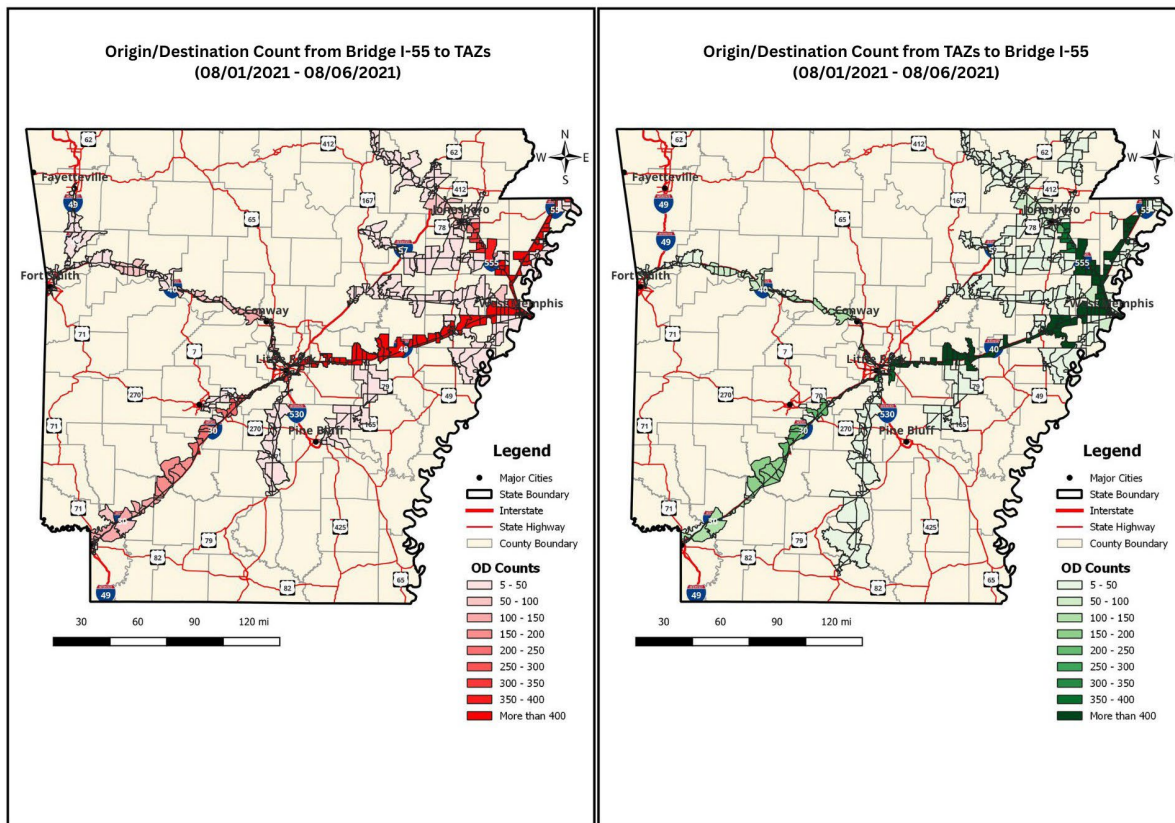


Figure A-11. OD Flows to and from I-55 for August 1 through 6, 2021

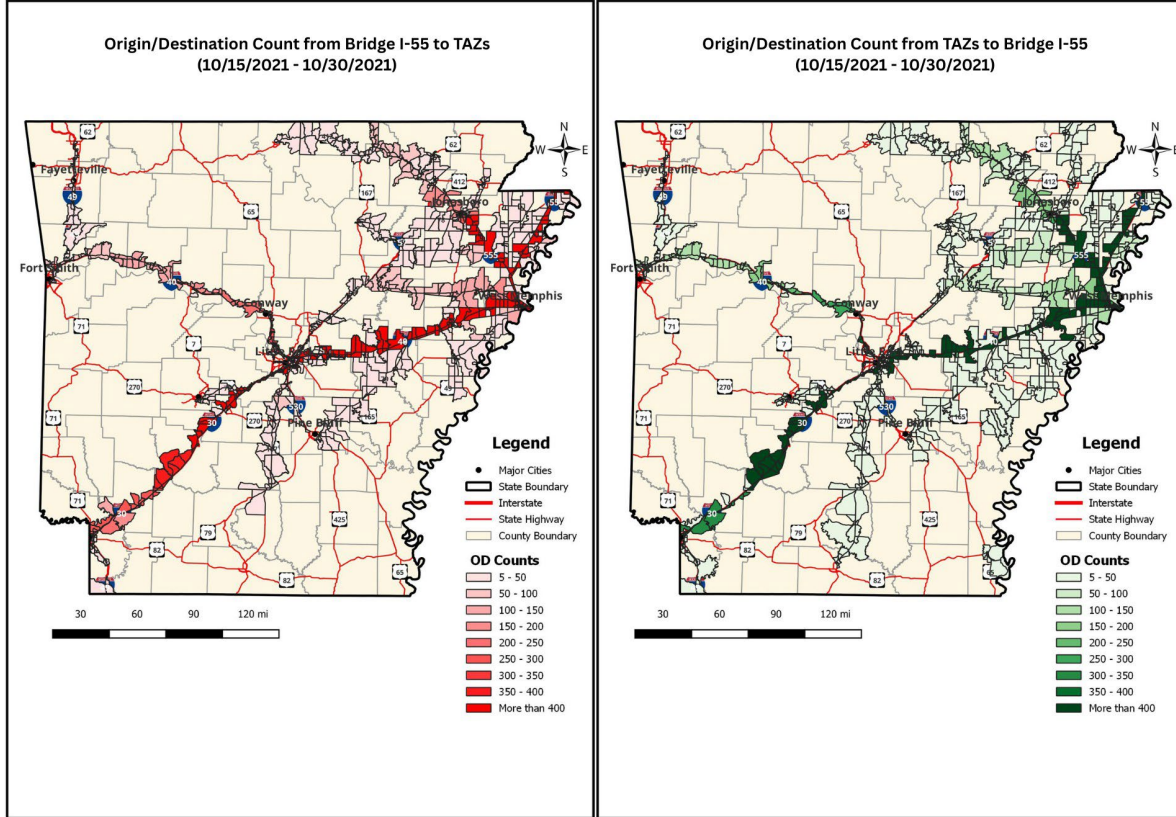


Figure A-12. OD Flows to and from I-55 for October 15 through 30, 2021

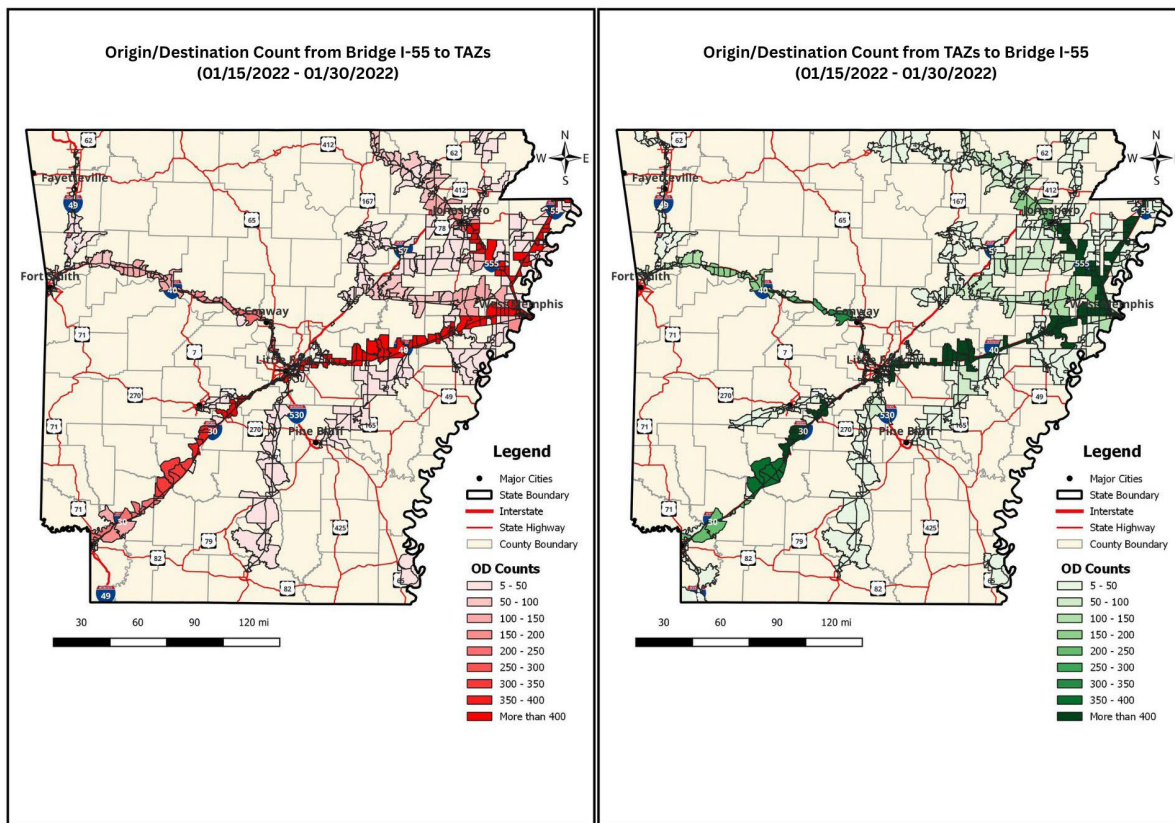


Figure A-13. OD Flows to and from I-55 for January 15 through 30, 2022

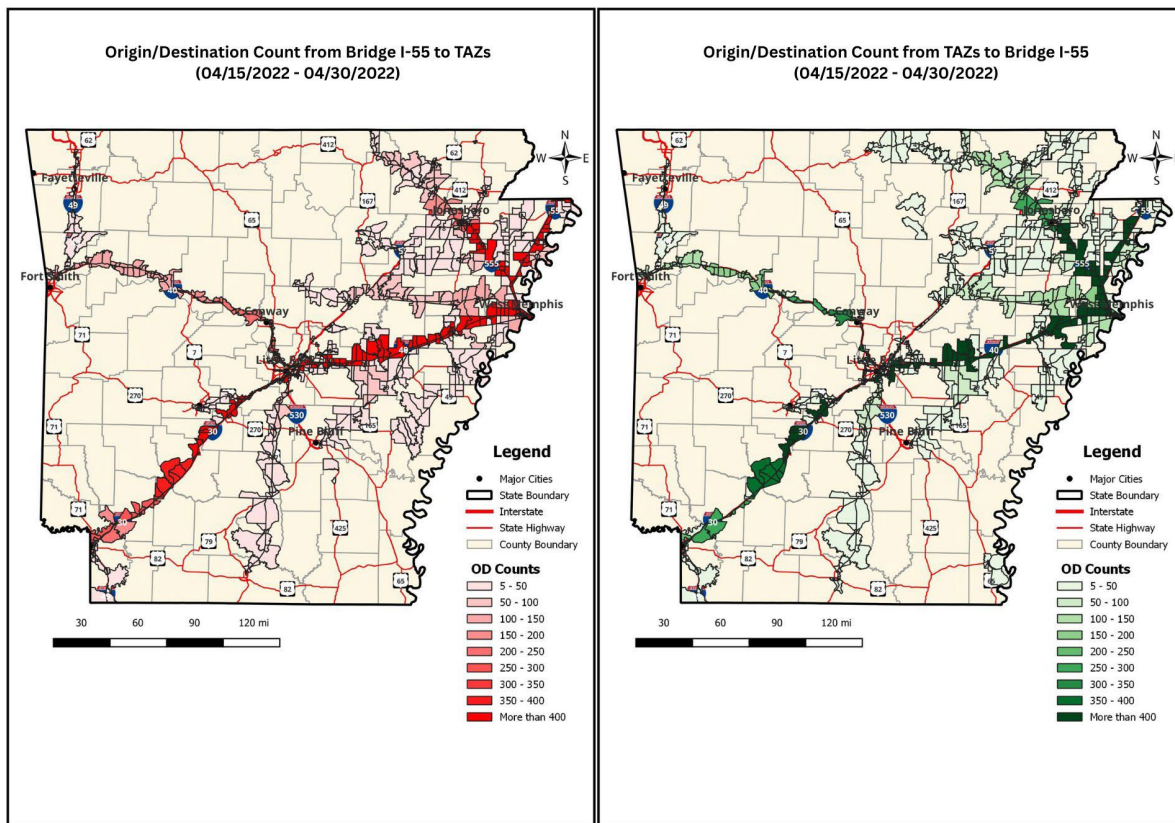


Figure A-14. OD Flows to and from I-55 for April 15 through 30, 2022

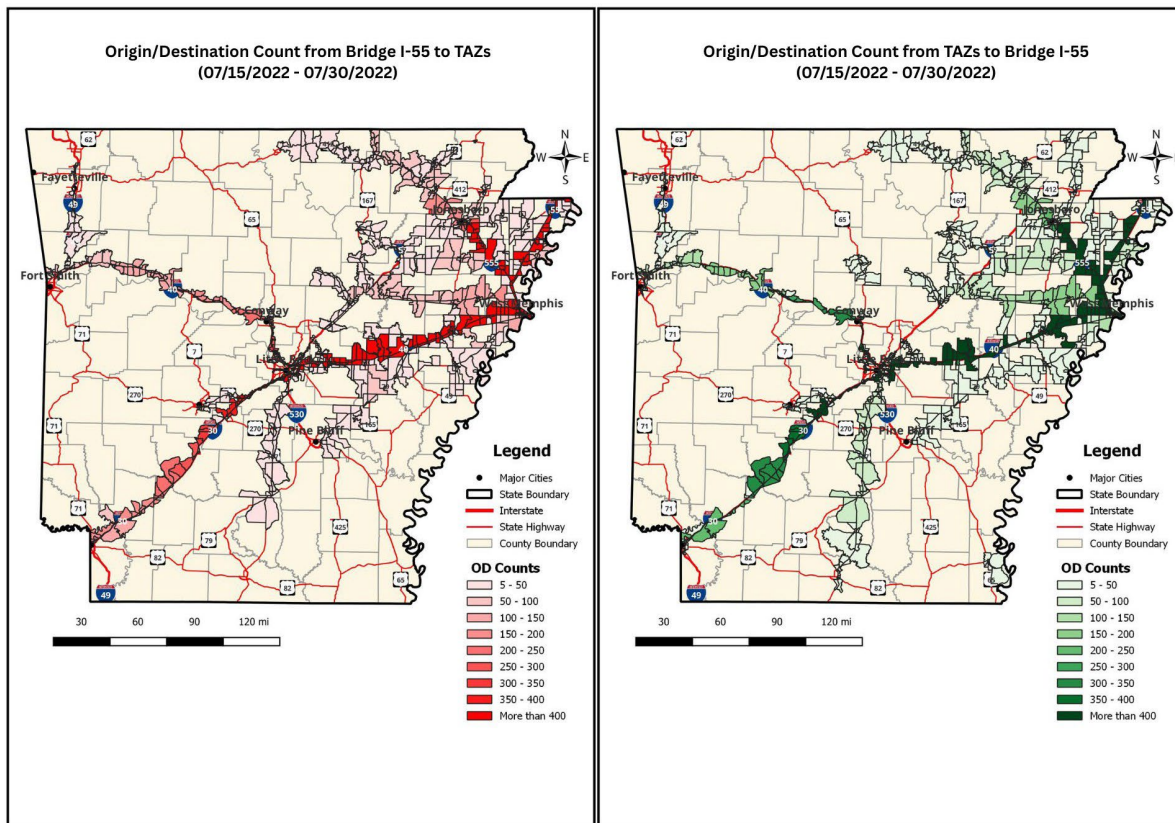


Figure A-15. OD Flows to and from I-55 for July 15 through 30, 2022

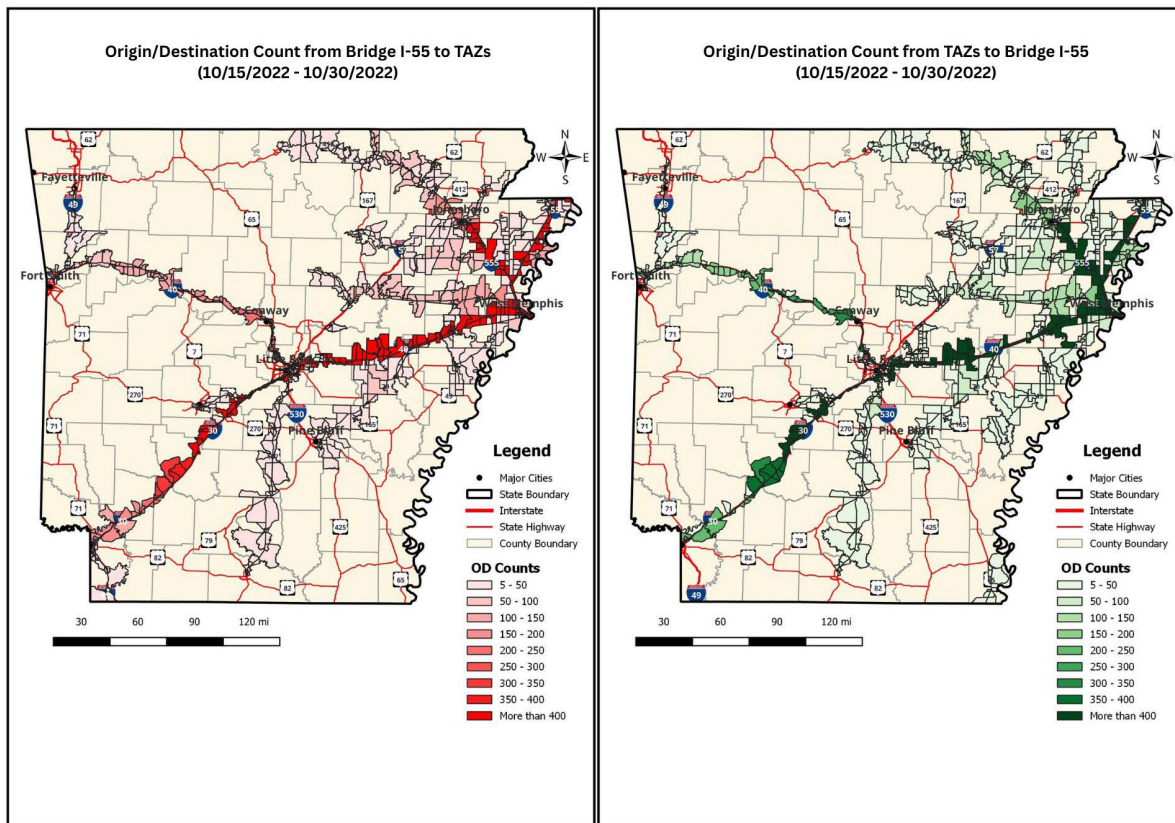


Figure A-16. OD Flows to and from I-55 for October 15 through 30, 2022

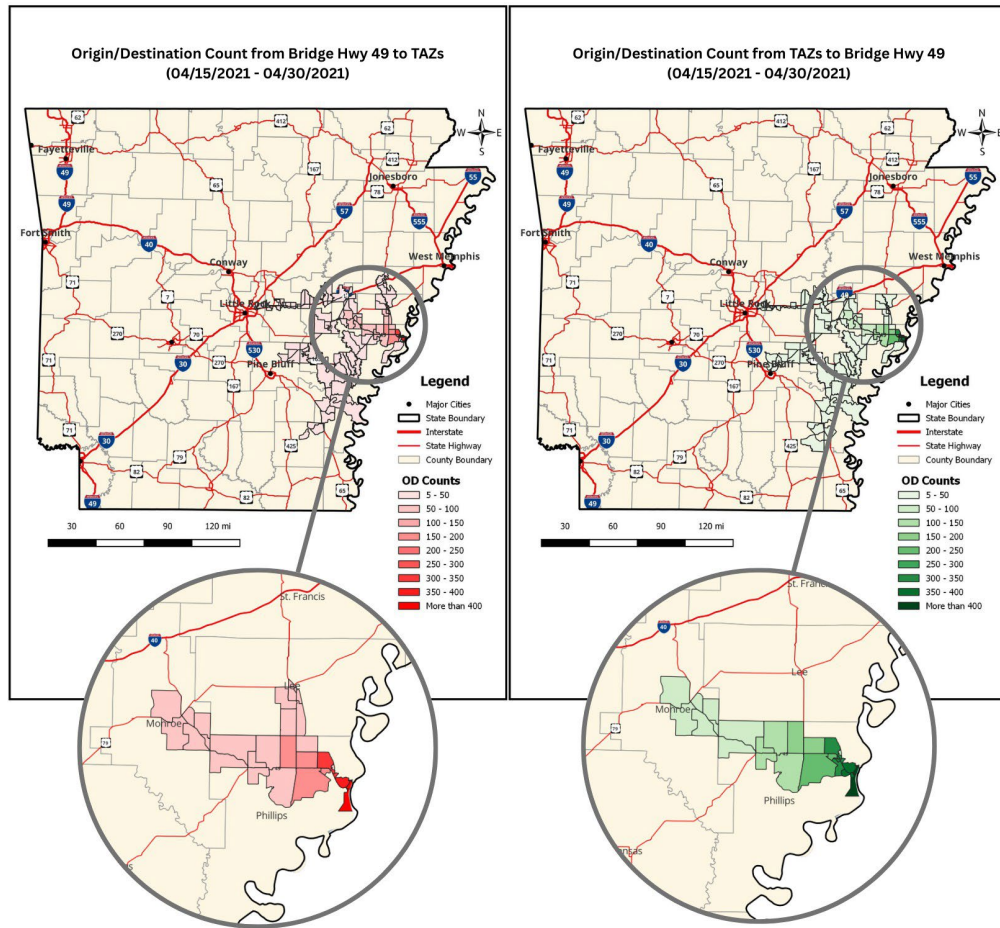


Figure A-17. OD Flows to and from HWY 49 for April 15 through 30, 2021

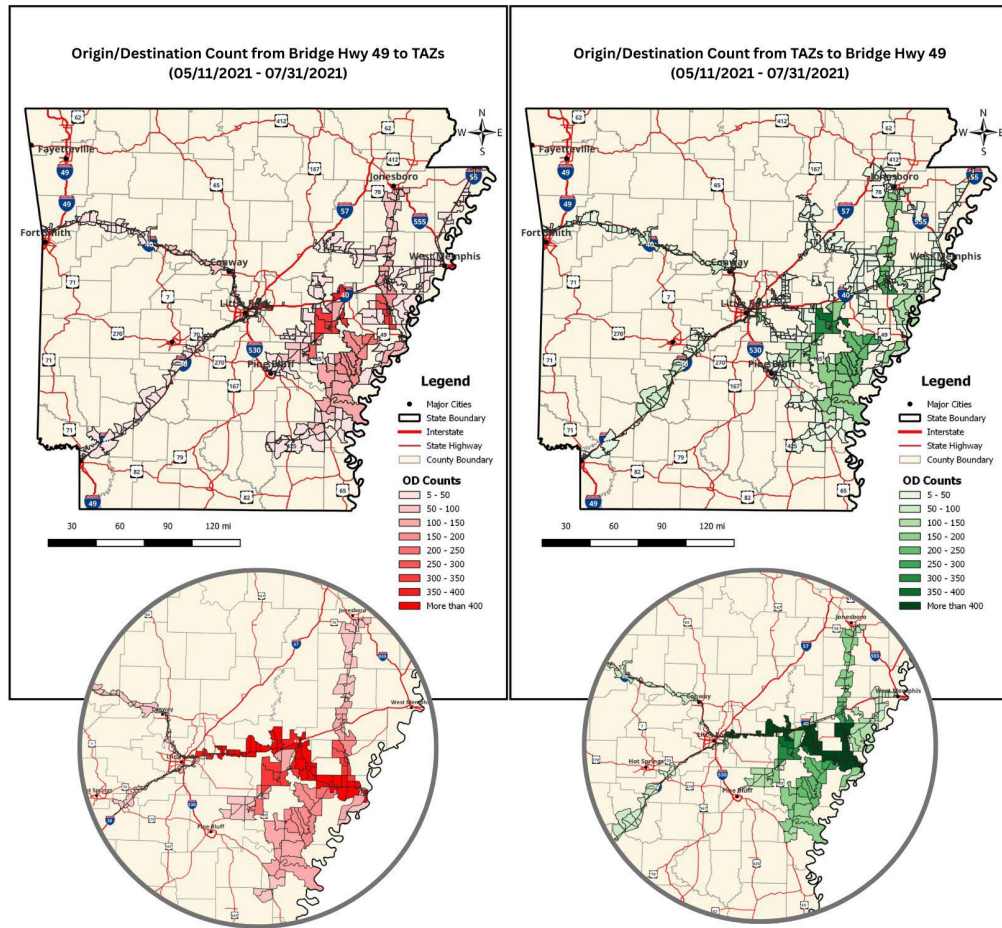


Figure A-18. OD Flows to and from HWY 49 for May 15 through July 31, 2021

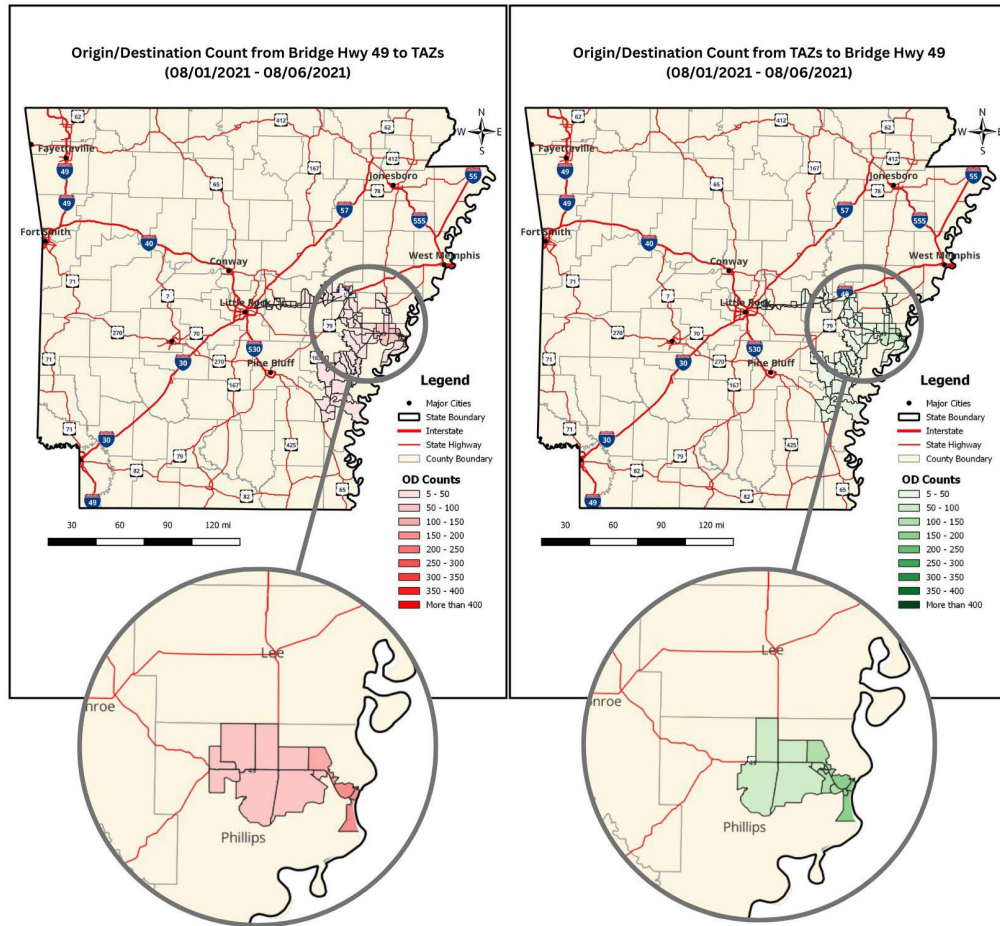


Figure A-19. OD Flows to and from HWY 49 for August 1 through 6, 2021

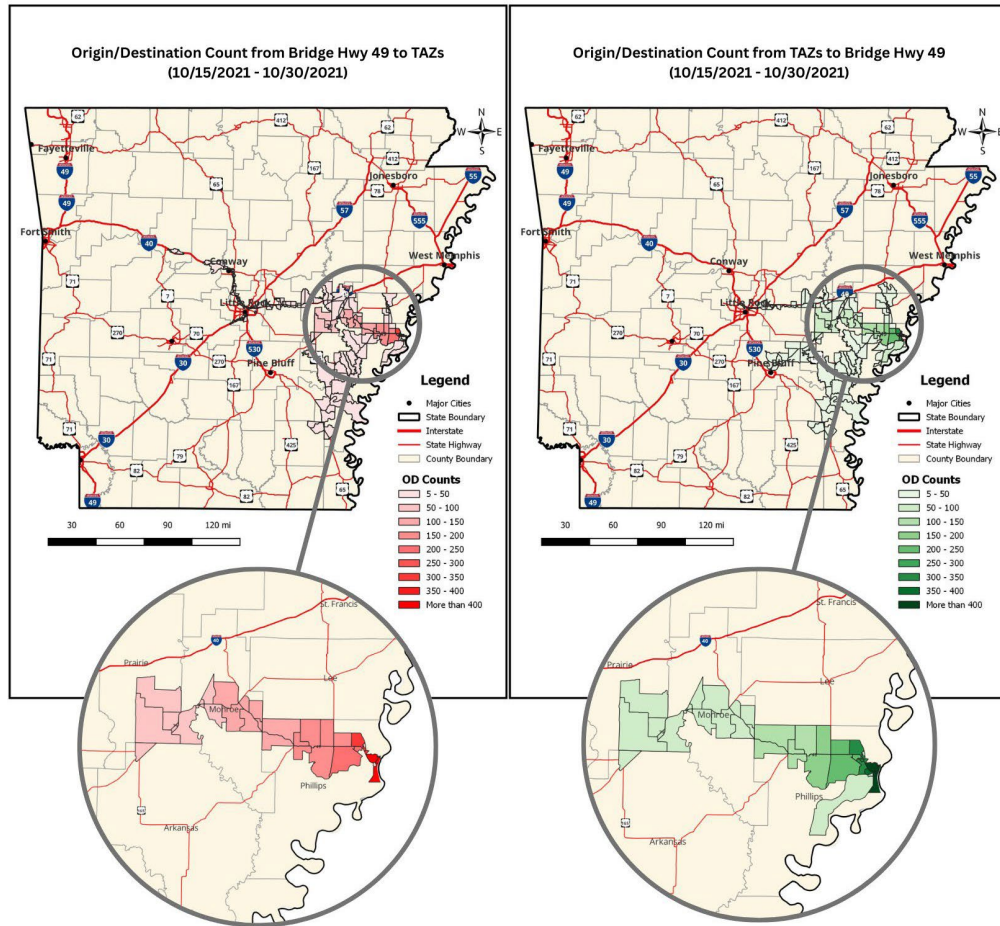


Figure A-20. OD Flows to and from HWY 49 for October 15 through 30, 2021

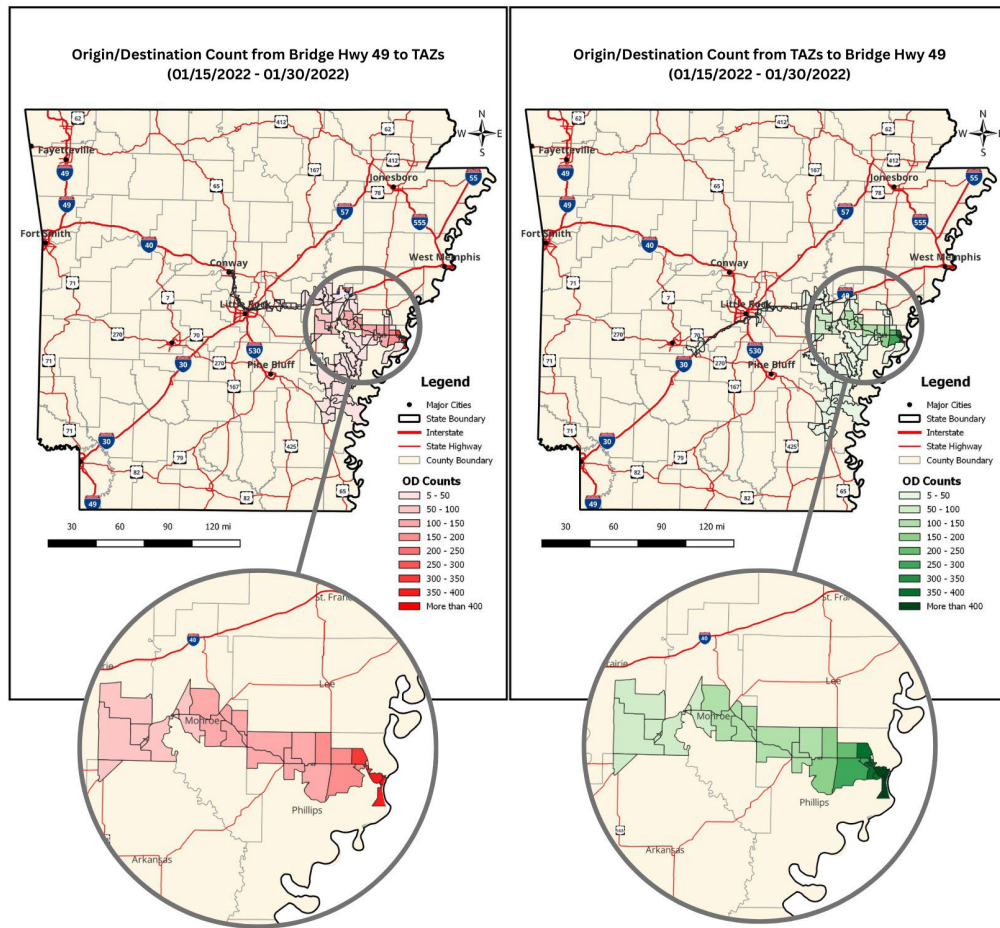


Figure A-21. OD Flows to and from HWY 49 for January 1 through 30, 2022

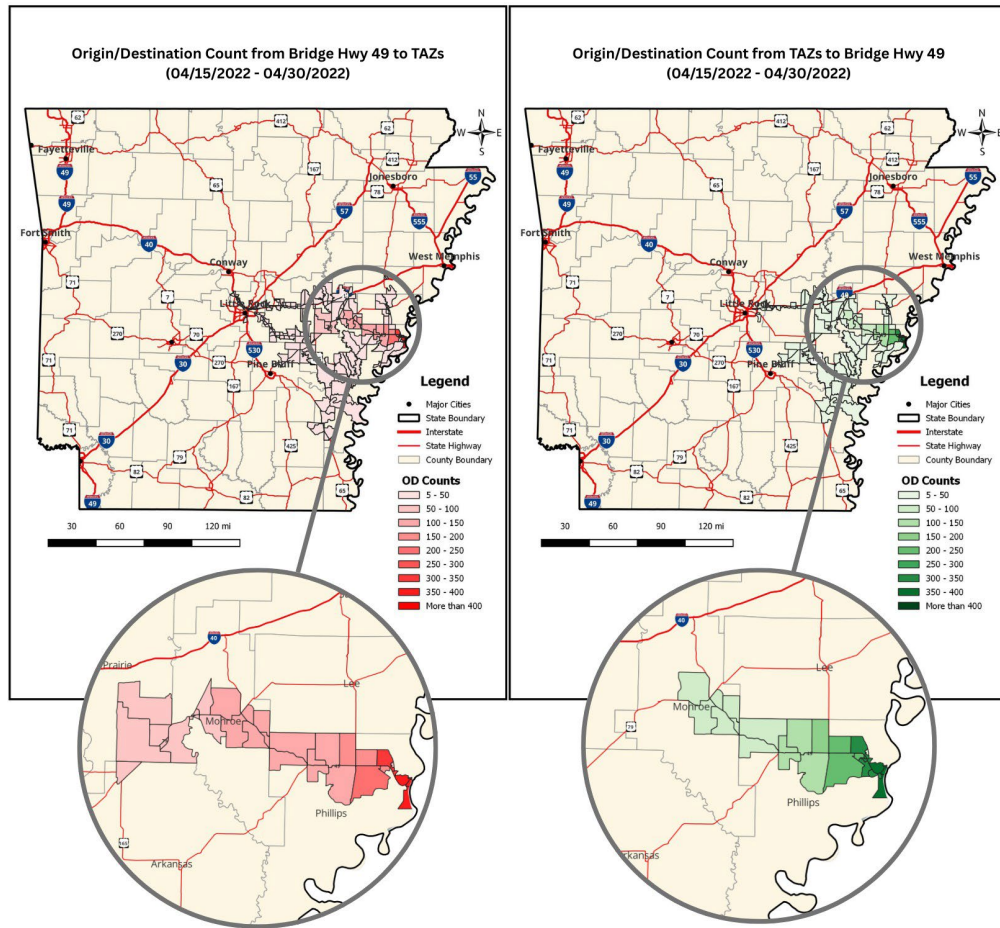


Figure A-22. OD Flows to and from HWY 49 for April 15 through 30, 2022

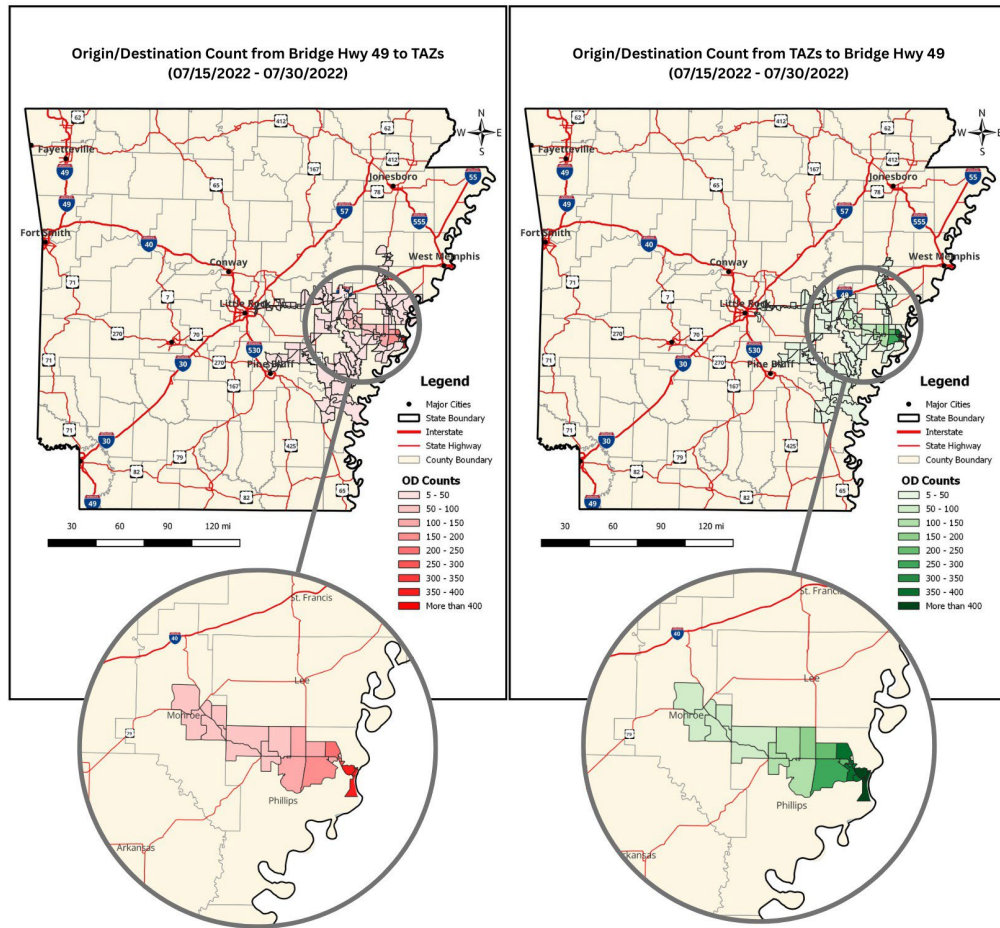


Figure A-23. OD Flows to and from HWY 49 for July 15 through 30, 2022

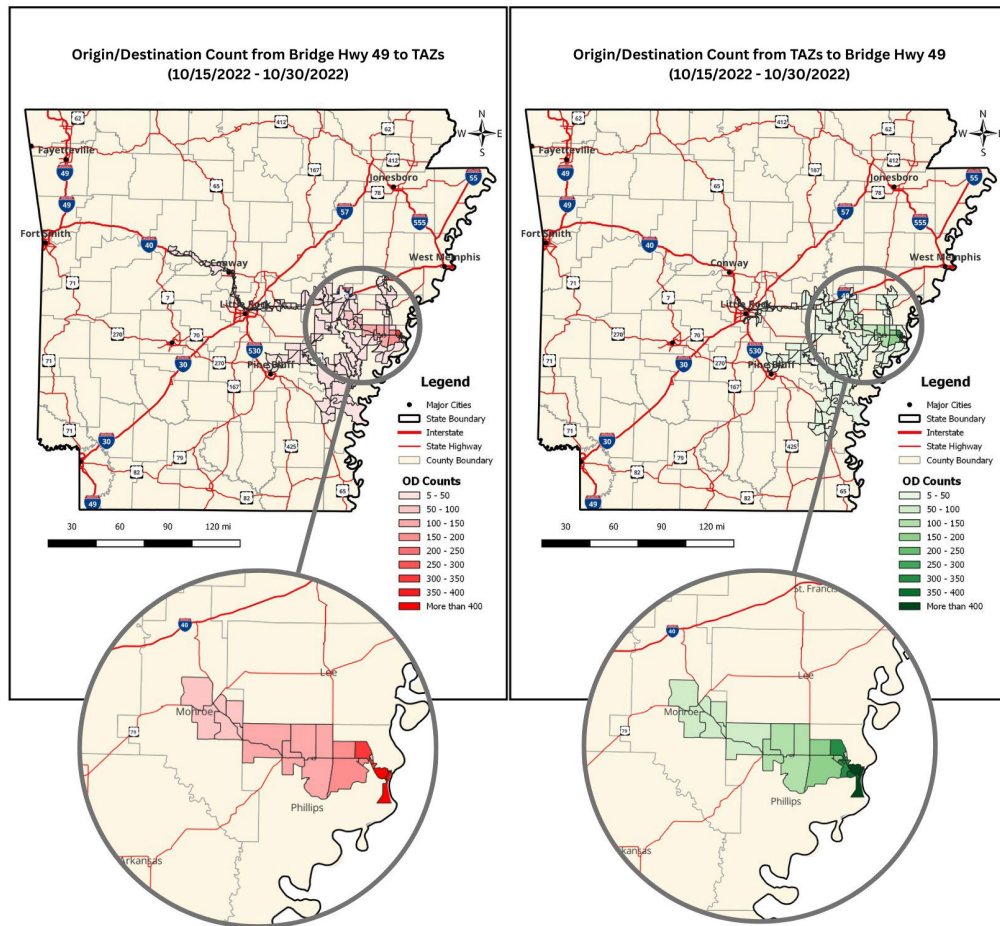


Figure A-24. OD Flows to and from HWY 49 for October 15 through 30, 2022

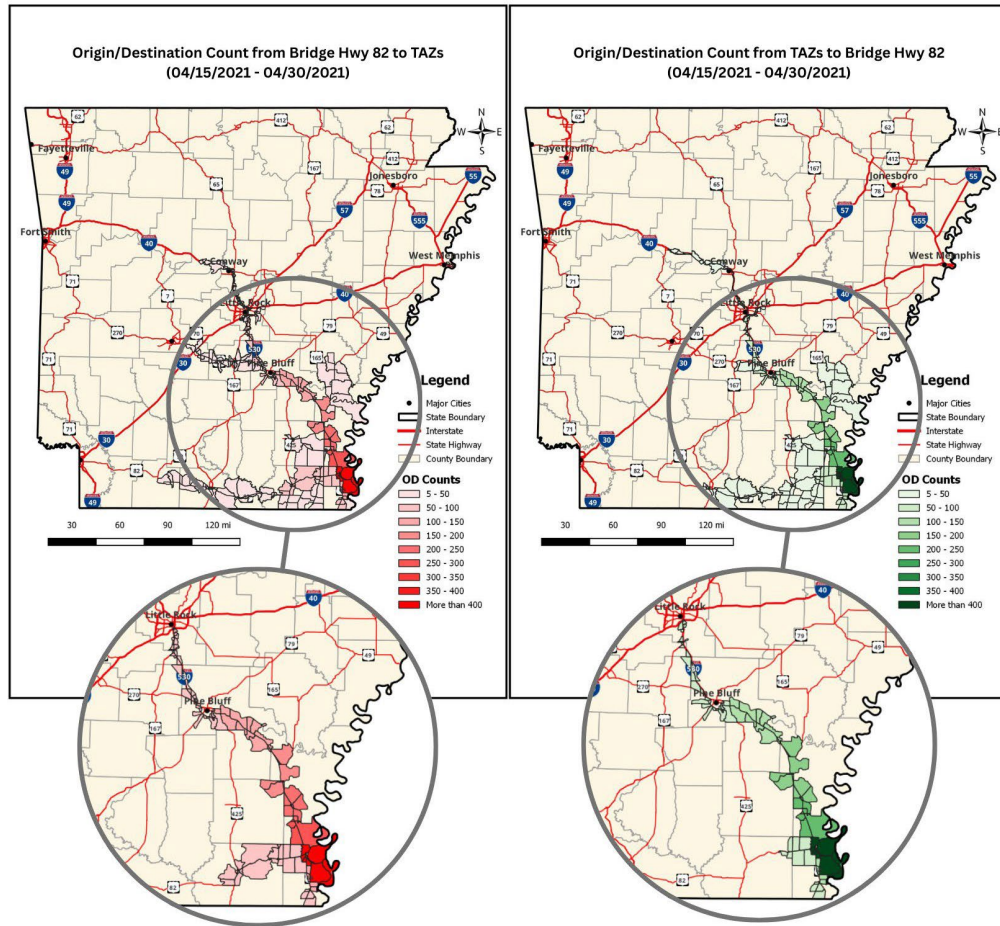


Figure A-25. OD Flows to and from HWY 82 for April 15 through 30, 2021

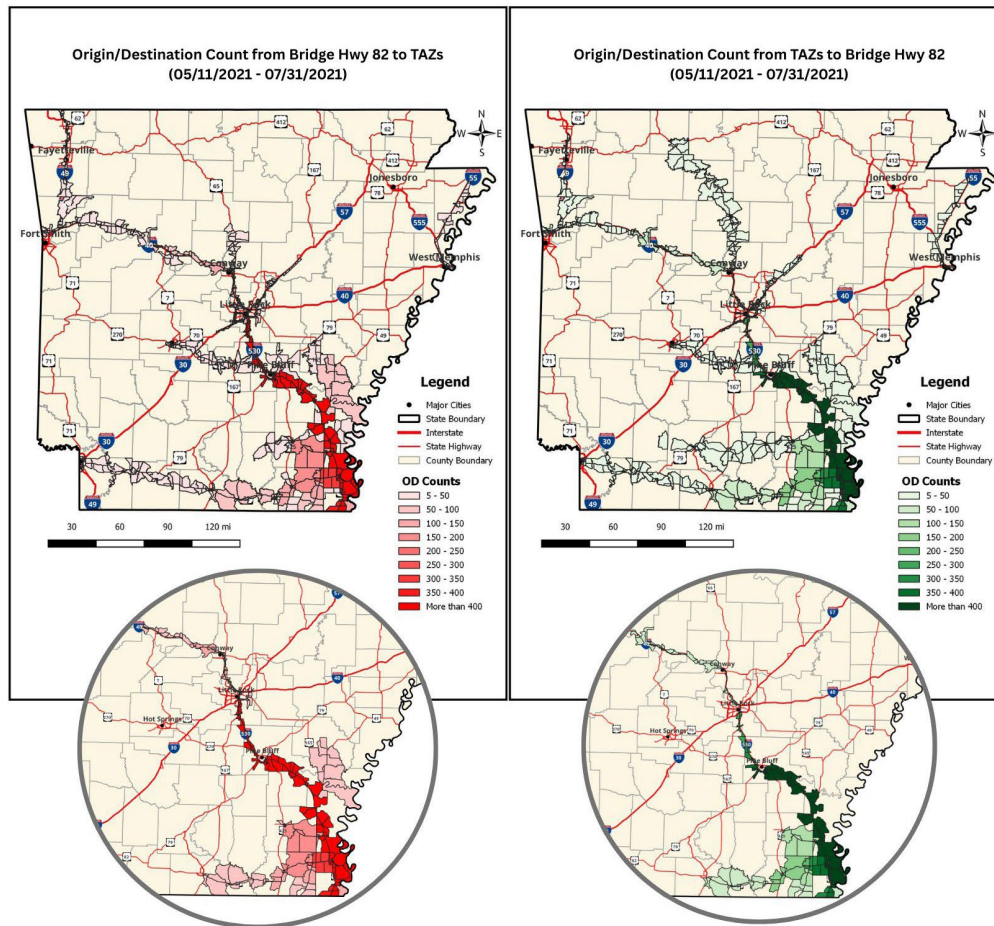


Figure A-26. OD Flows to and from HWY 82 for May 11 through July 31, 2021

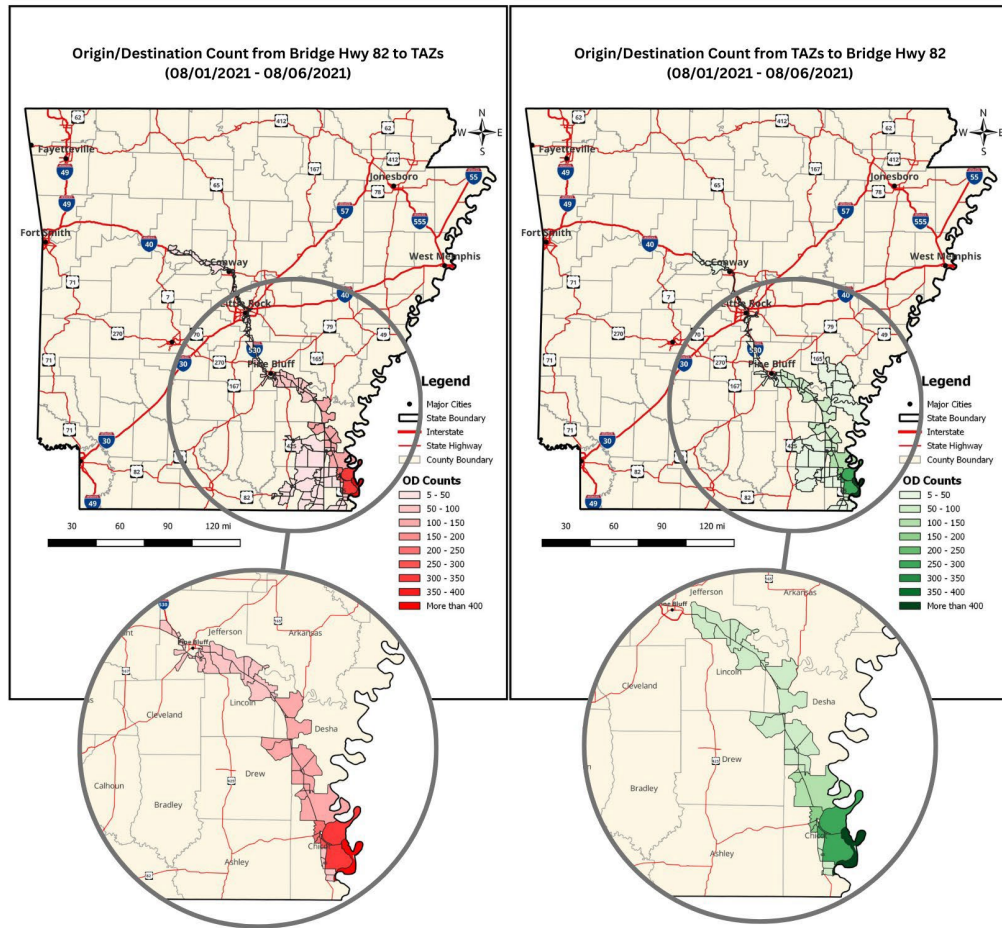


Figure A-27. OD Flows to and from HWY 82 for August 1 through 6, 2021

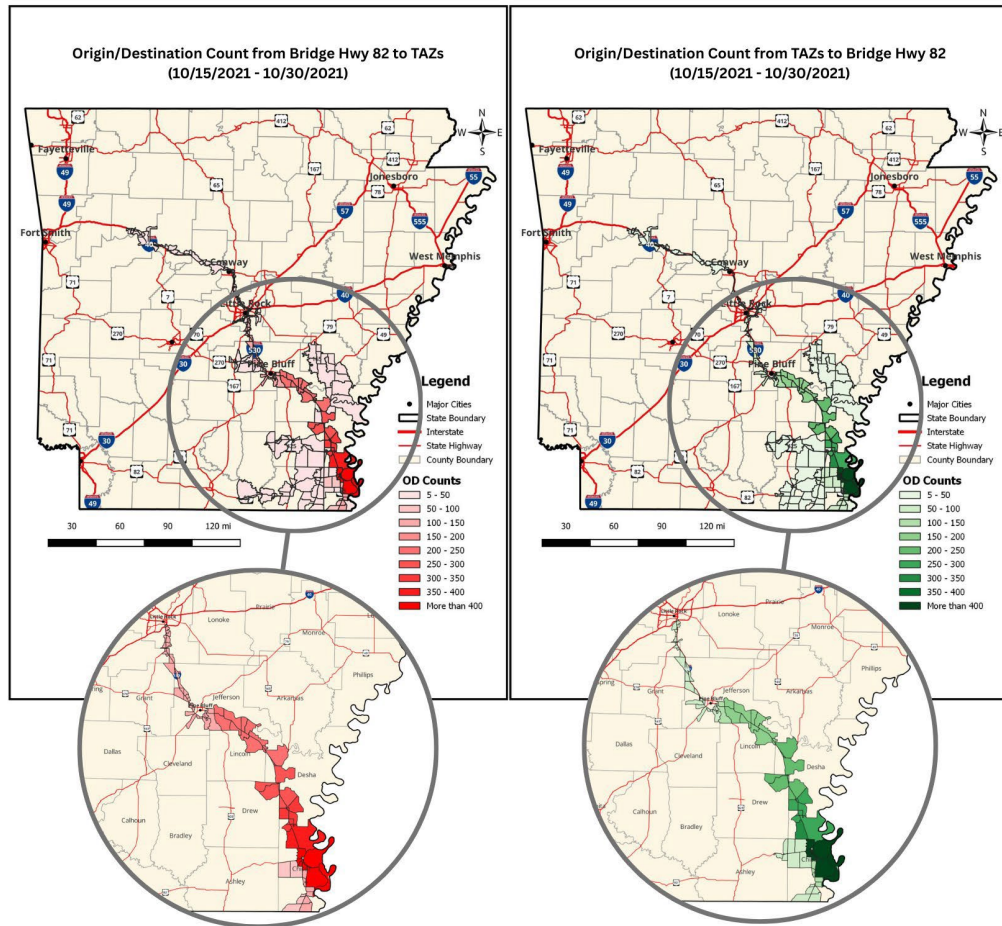


Figure A-28. OD Flows to and from HWY 82 for October 15 through 30, 2021

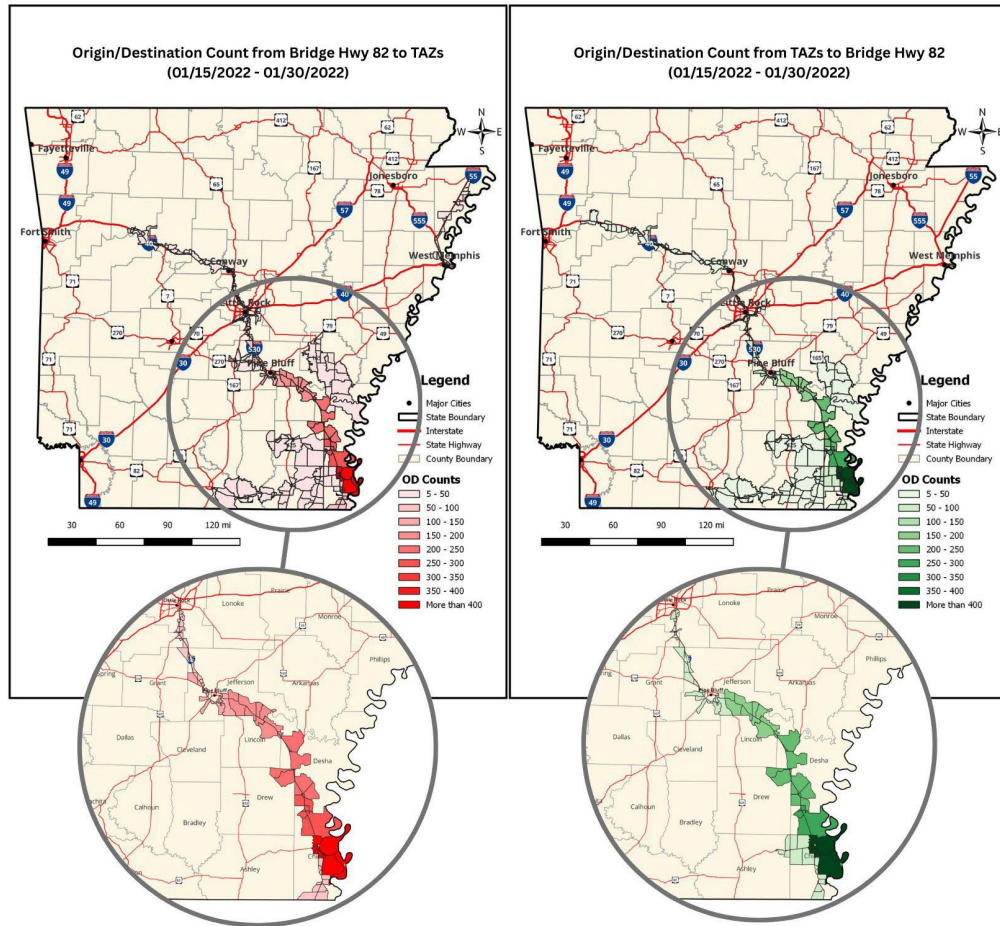


Figure A-29. OD Flows to and from HWY 82 for January 15 through 30, 2022

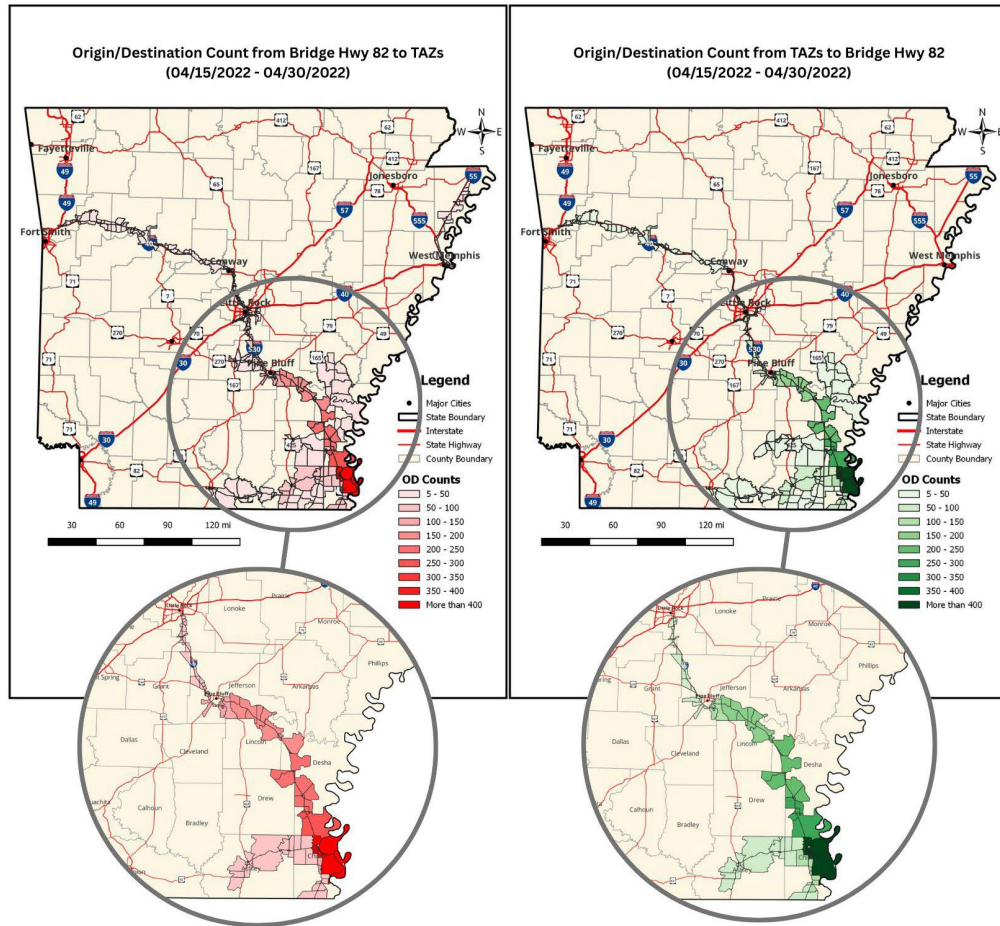


Figure A-30. OD Flows to and from HWY 82 for April 15 through 30, 2022

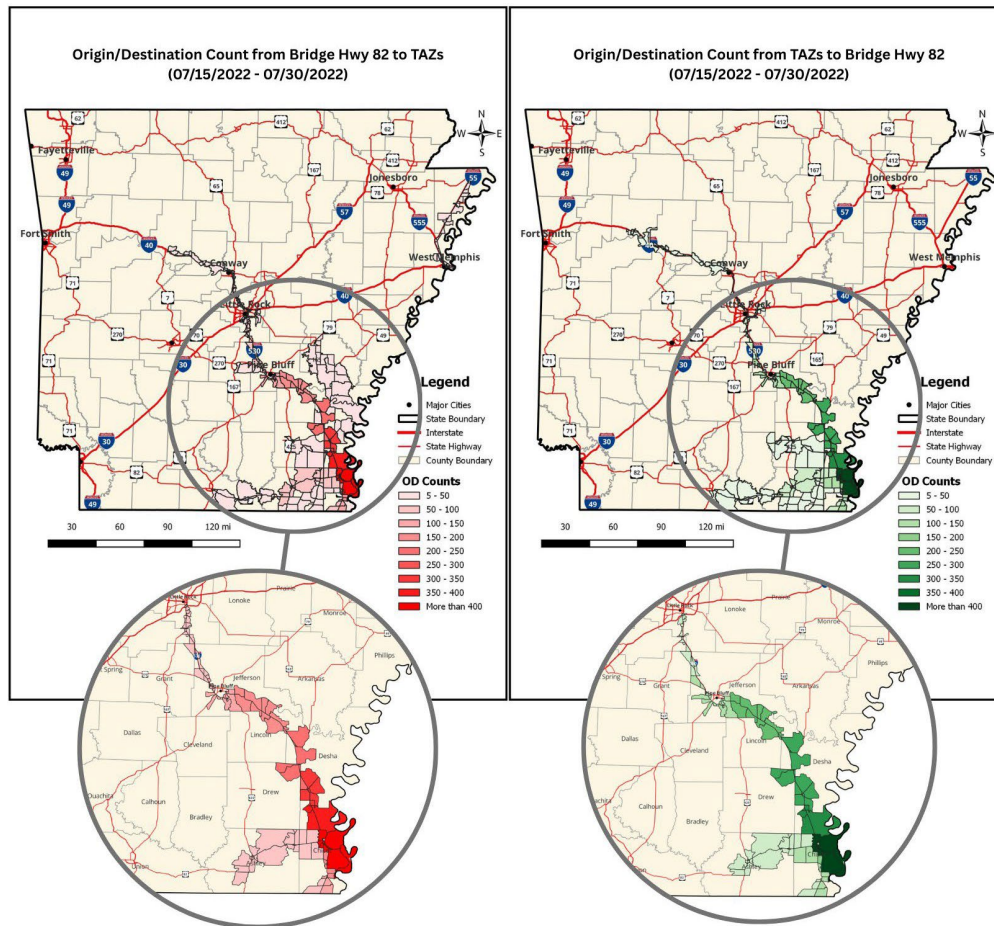


Figure A-31. OD Flows to and from HWY 82 for July 15 through 30, 2022

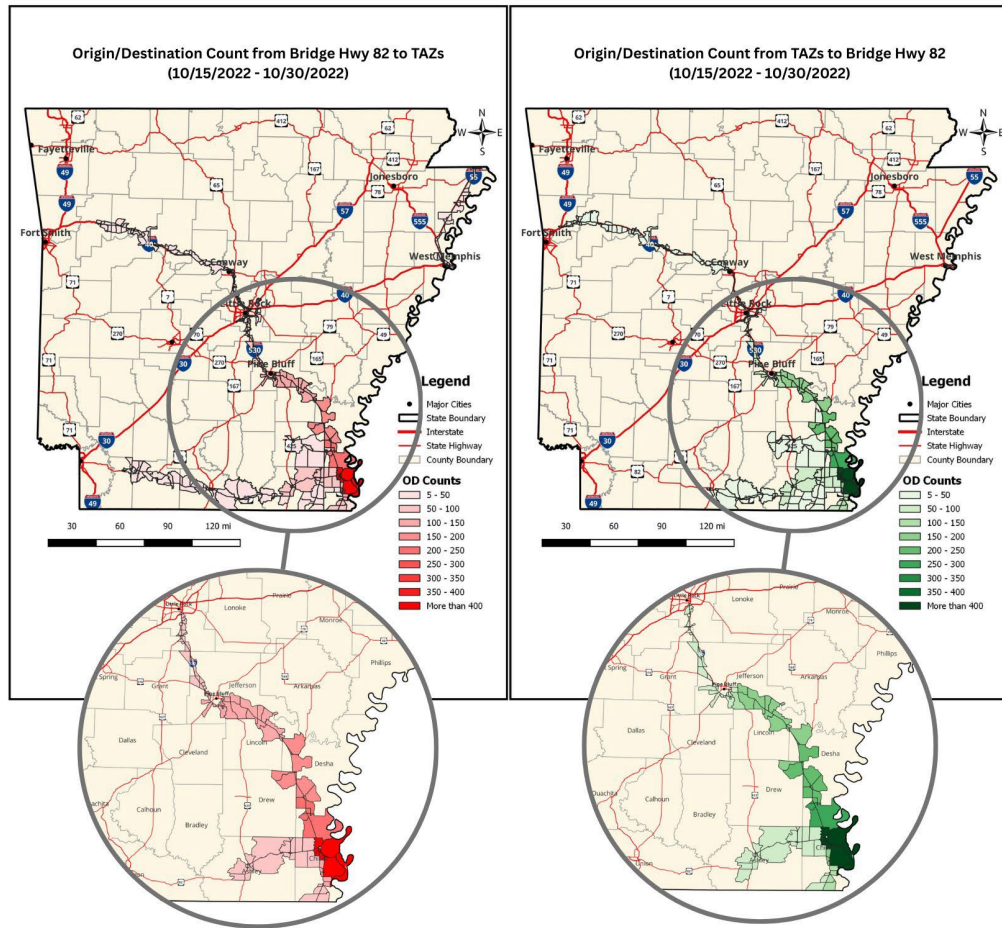


Figure A-32. OD Flows to and from HWY 82 for October 15 through 30, 2022

Passenger Vehicle Flows using StreetLight Probe Data

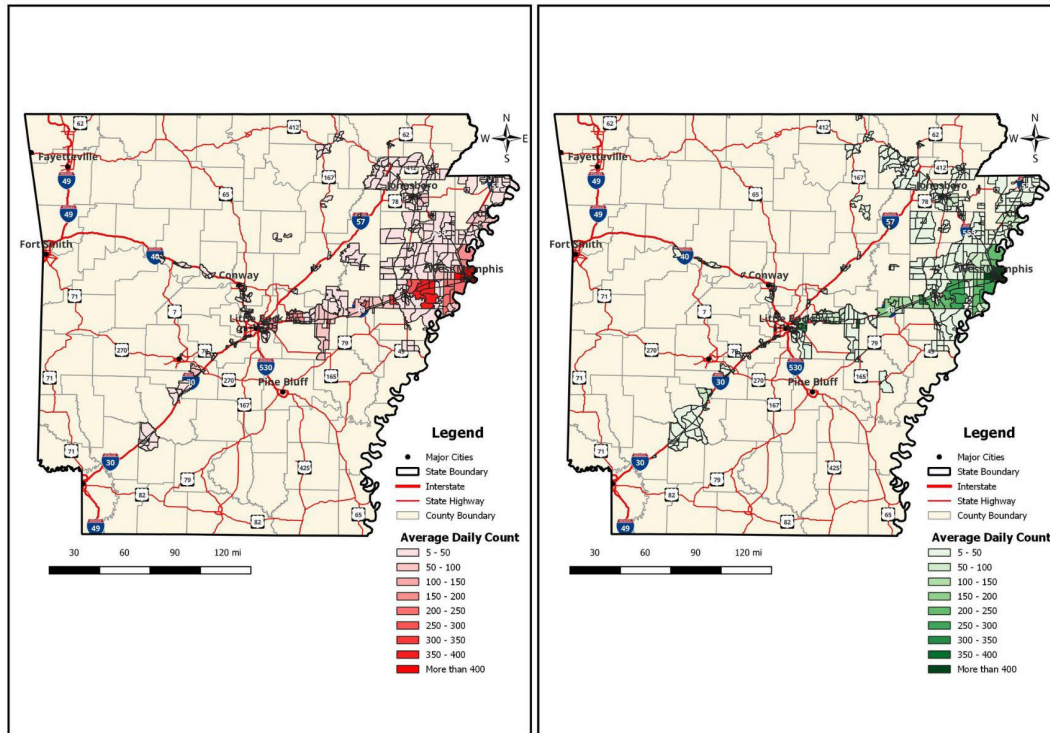


Figure A-33. Comparison of Passenger Vehicle Flows from I-40 bridge to the TAZs (A) and from TAZs to the I-40 bridge (B) (April 15-30, 2021)

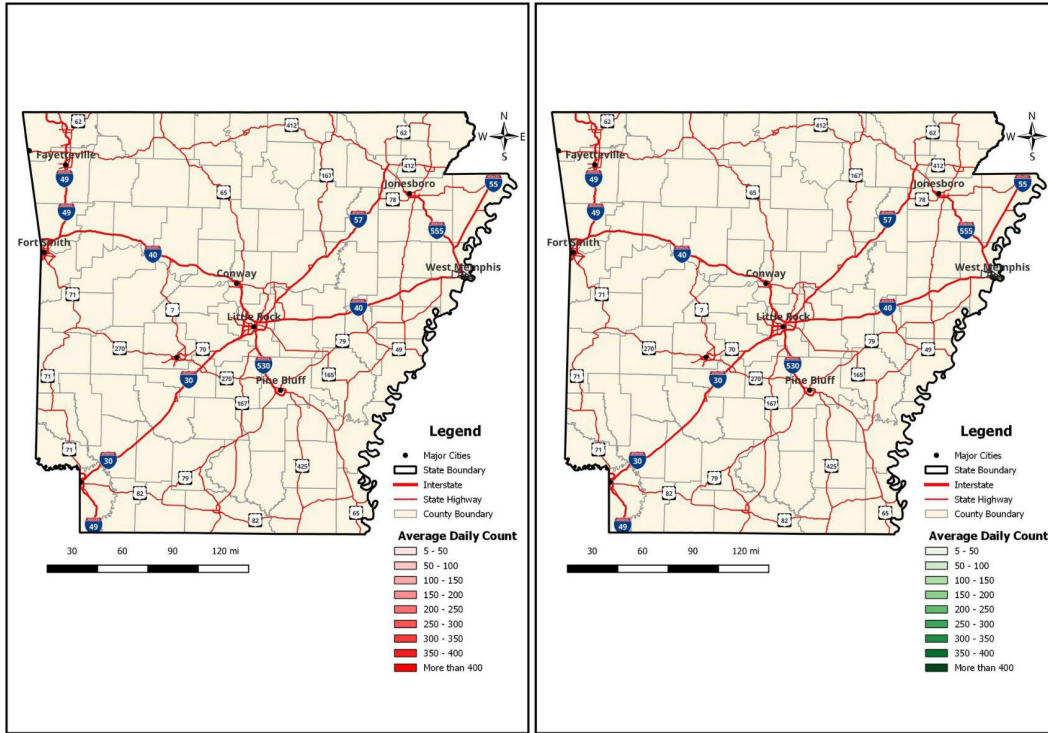


Figure A-34. Comparison of Passenger Vehicle Flows from I-40 bridge to the TAZs (A) and from TAZs to the I-40 bridge (B) (May 11 through July 31, 2021)

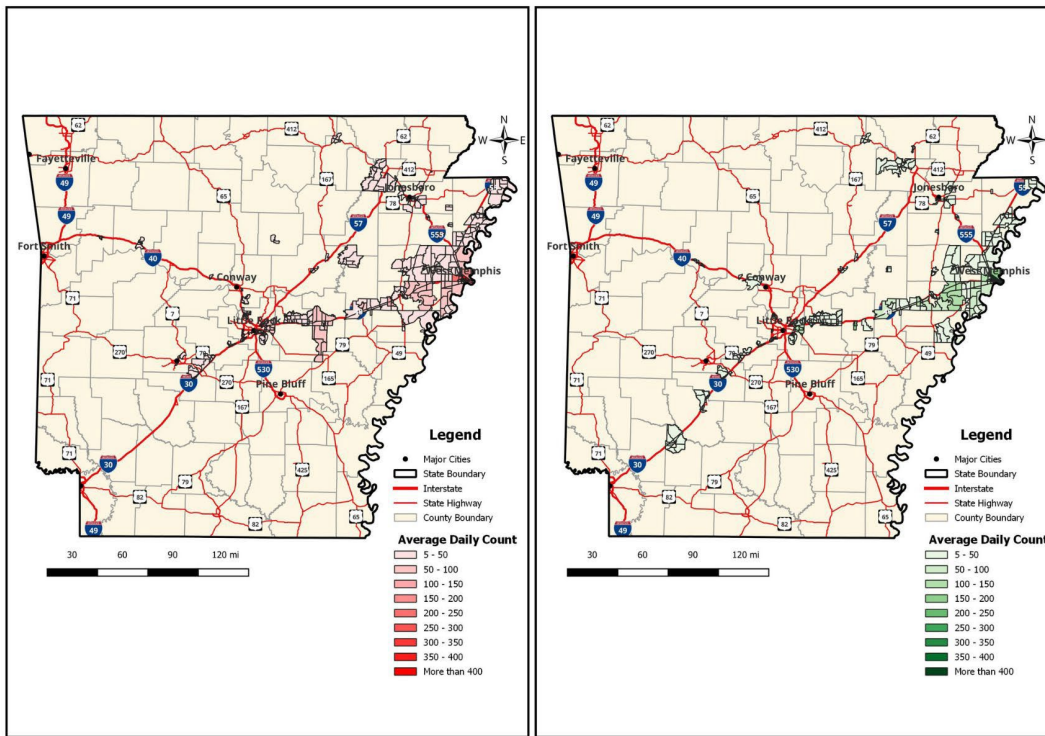


Figure A-35. Comparison of Passenger Vehicle Flows from I-40 bridge to the TAZs (A) and from TAZs to the I-40 bridge (B) (August 01-06, 2021)

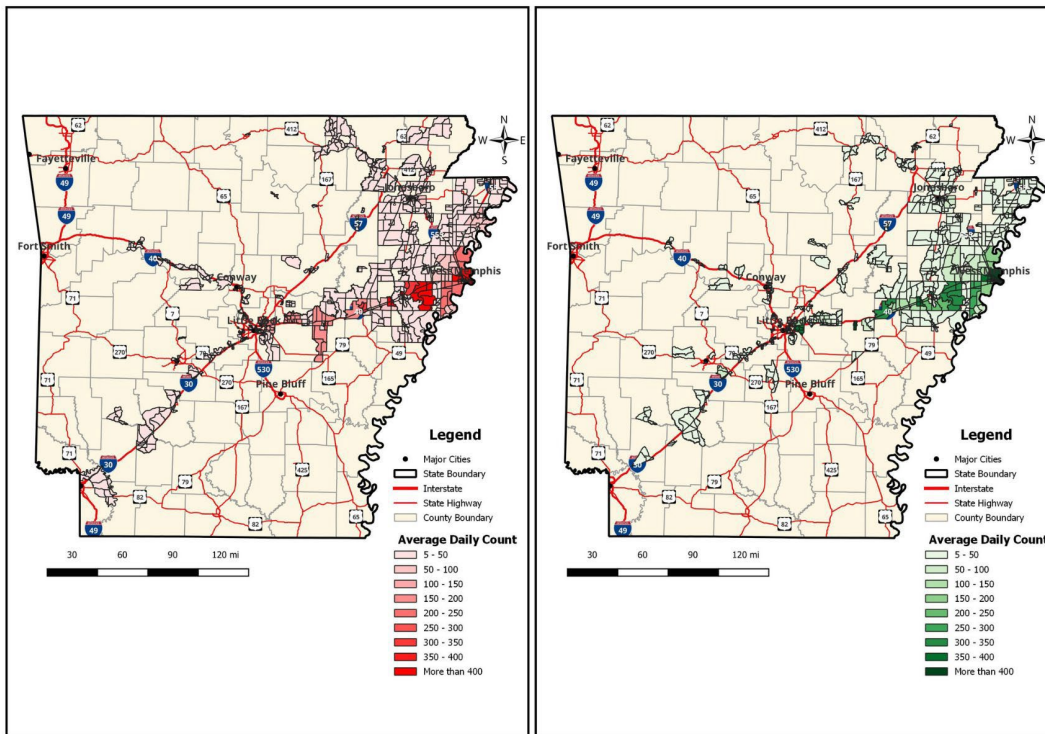


Figure A-36. Comparison of Passenger Vehicle Flows from I-40 bridge to the TAZs (A) and from TAZs to the I-40 bridge (B) (October 15-30, 2021)

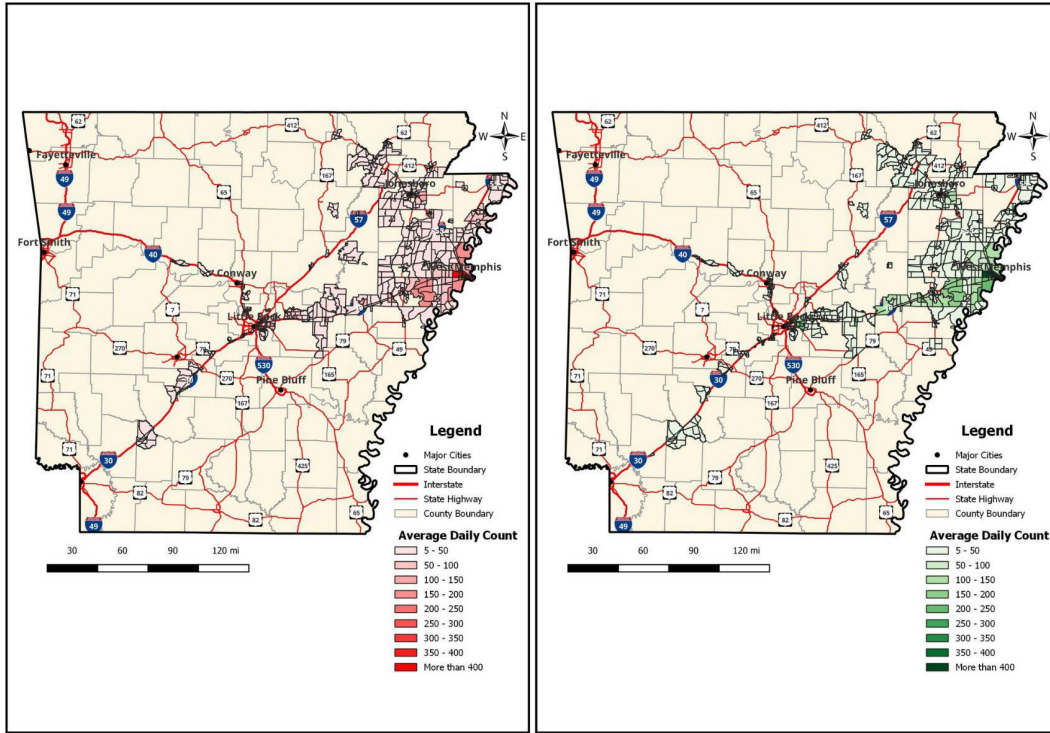


Figure A-37. Comparison of Passenger Vehicle Flows from I-55 bridge to the TAZs (A) and from TAZs to the I-55 bridge (B) (April 15-30,2021)

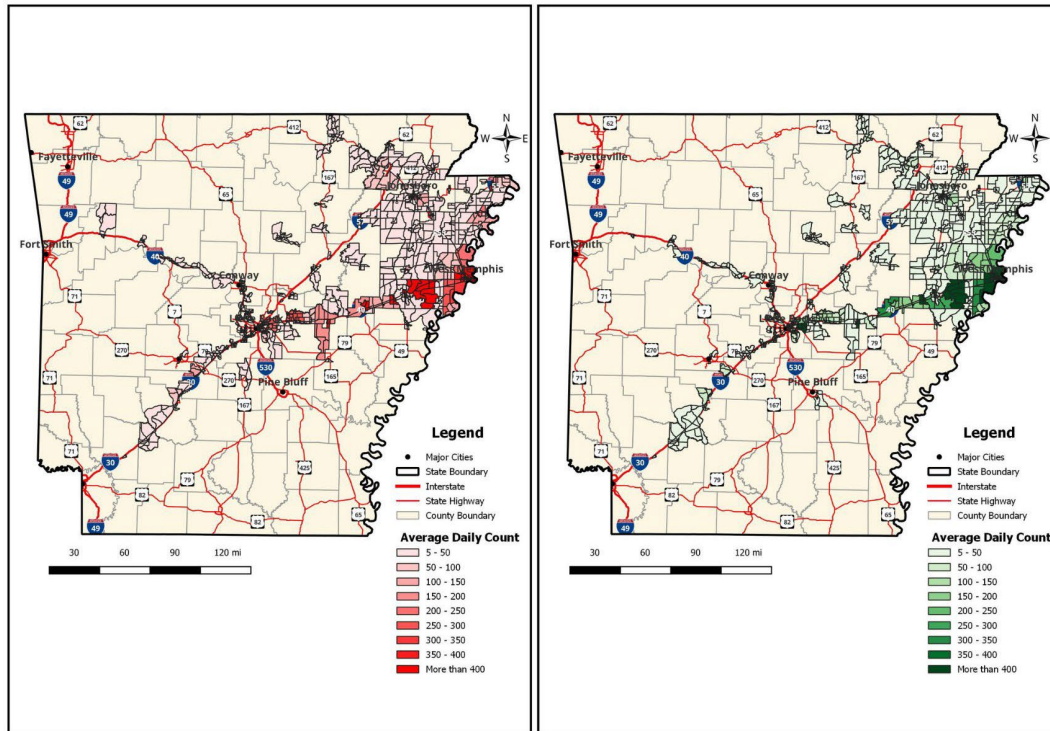


Figure A-38. Comparison of Passenger Vehicle Flows from I-55 bridge to the TAZs (A) and from TAZs to the I-55 bridge (B) (May 11 through July 31, 2021)

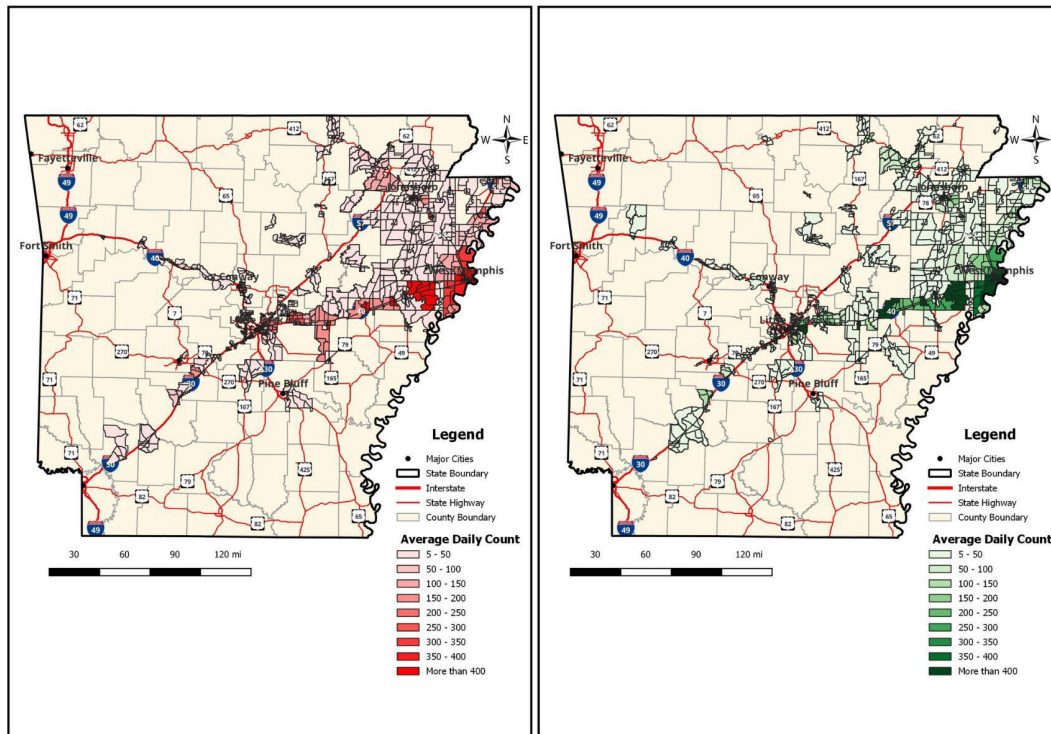


Figure A-39. Comparison of Passenger Vehicle Flows from I-55 bridge to the TAZs (A) and from TAZs to the I-55 bridge (B) (August 01-06, 2021)

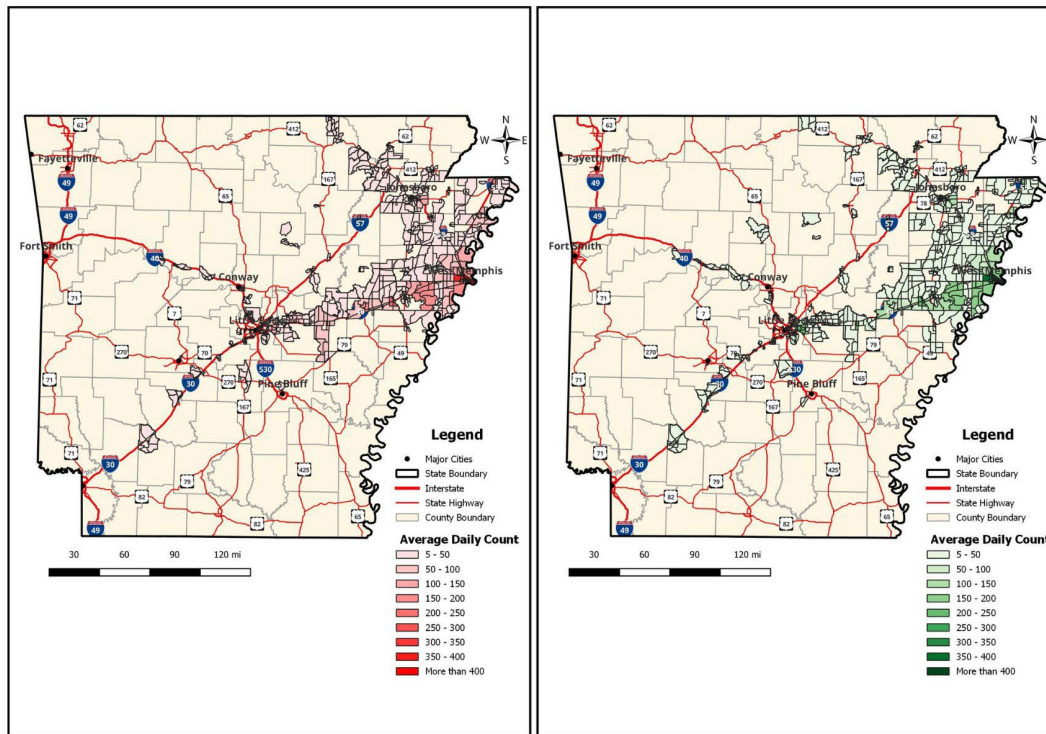


Figure A-40. Comparison of Passenger Vehicle Flows from I-55 bridge to the TAZs (A) and from TAZs to the I-55 bridge (B) (October 15-30, 2021)

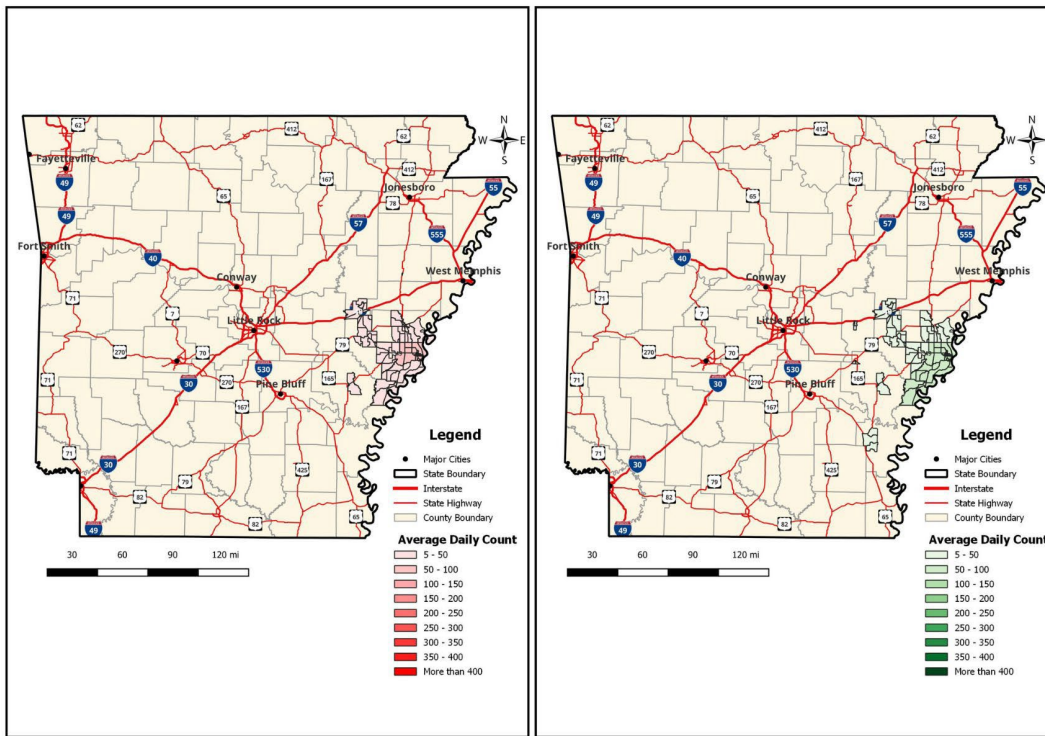


Figure A-41. Comparison of Passenger Vehicle Flows from HWY 49 bridge to the TAZs (A) and from TAZs to the HWY 49 bridge (B) (April 15-30,2021)

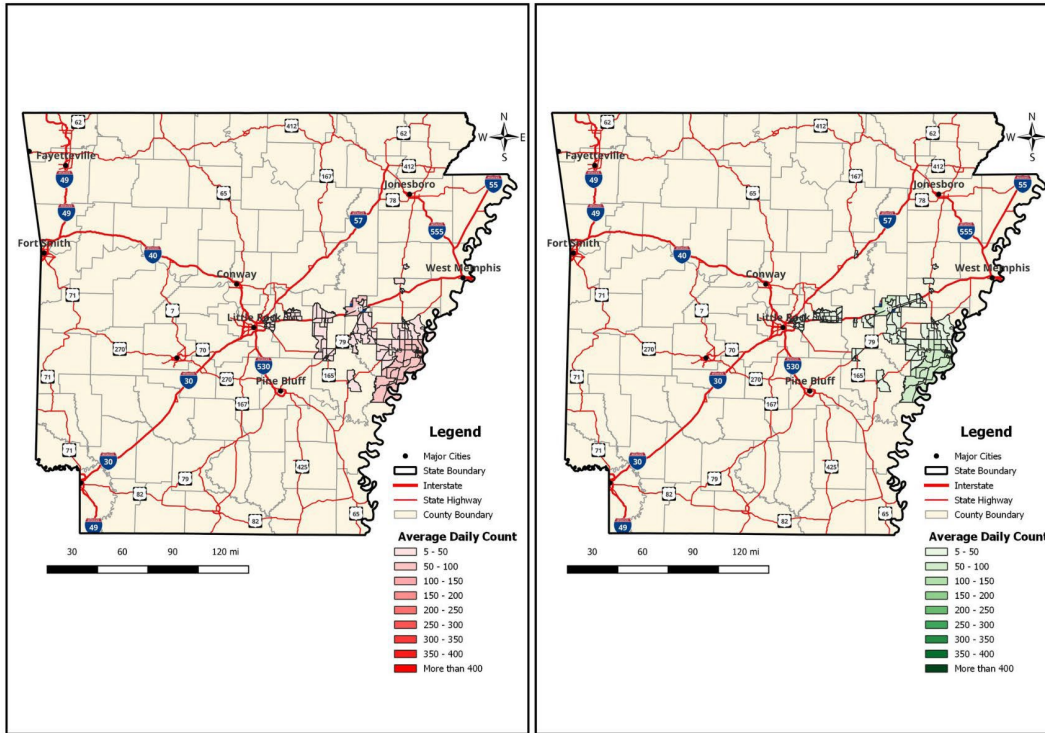


Figure A-42. Comparison of Passenger Vehicle Flows from HWY 49 bridge to the TAZs (A) and from TAZs to the HWY 49 bridge (B) (May 11 through July 31, 2021)

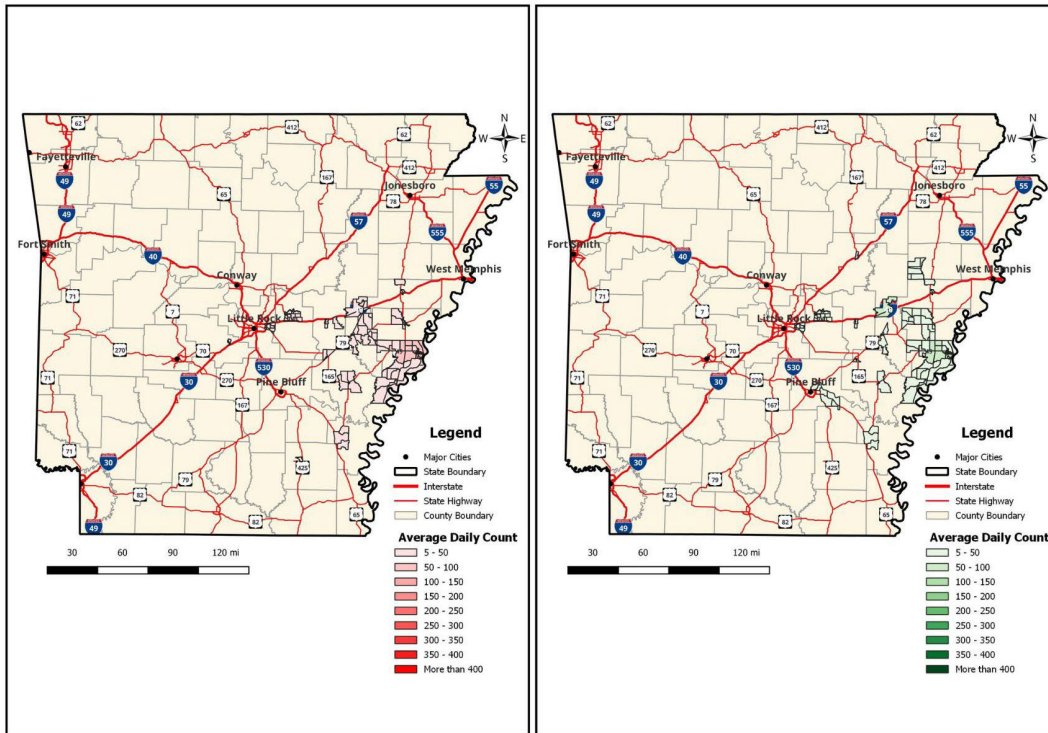


Figure A-43. Comparison of Passenger Vehicle Flows from HWY 49 bridge to the TAZs (A) and from TAZs to the HWY 49 bridge (B) (August 01-06, 2021)

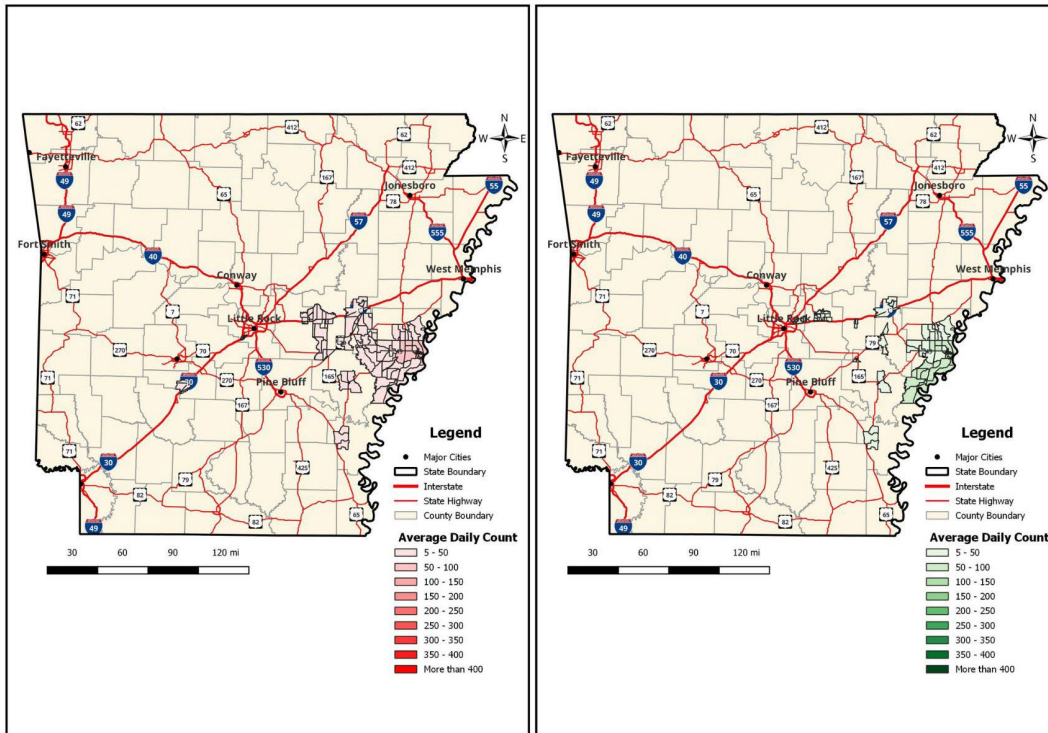


Figure A-44. Comparison of Passenger Vehicle Flows from HWY 49 bridge to the TAZs (A) and from TAZs to the HWY 49 bridge (B) (October 15-30,2021)

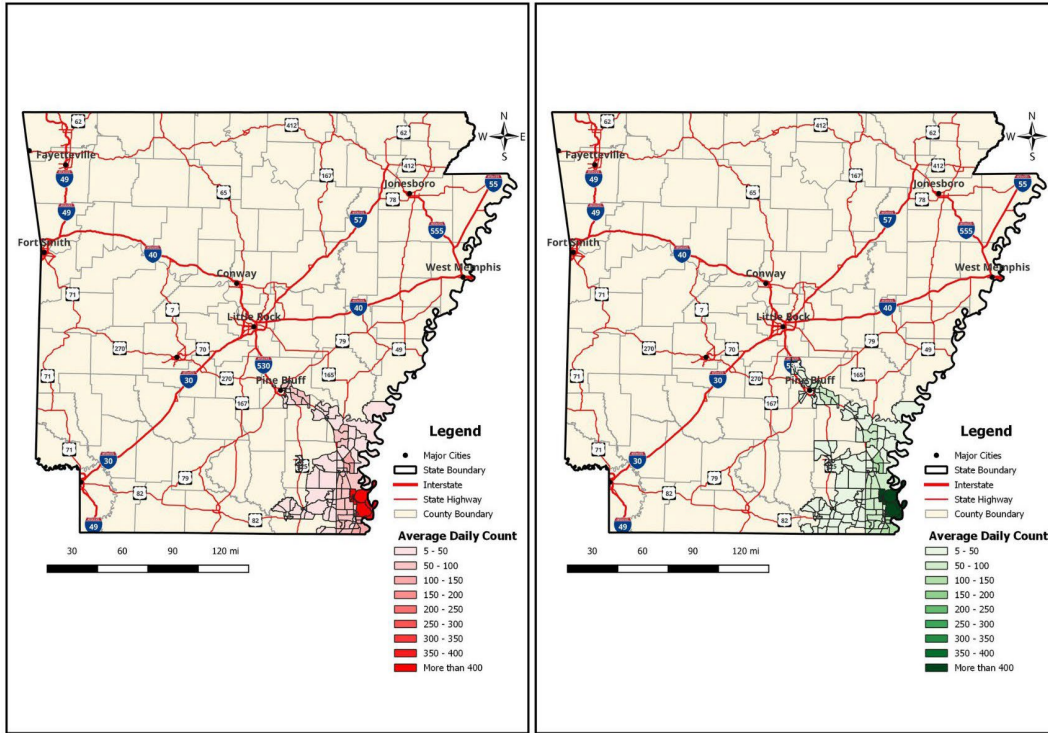


Figure A-45. Comparison of Passenger Vehicle Flows from HWY 82 bridge to the TAZs (A) and from TAZs to the HWY 82 bridge (B) (April 15-30,2021)

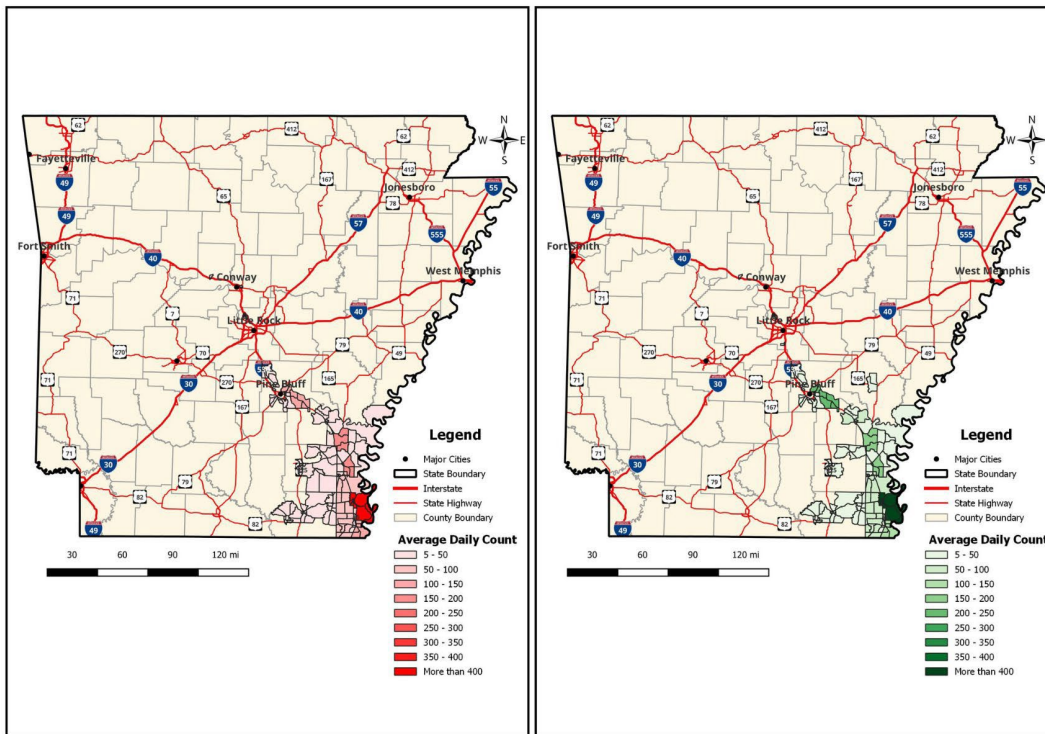


Figure A-46. Comparison of Passenger Vehicle Flows from HWY 82 bridge to the TAZs (A) and from TAZs to the HWY 82 bridge (B) (May 11 through July 31, 2021)

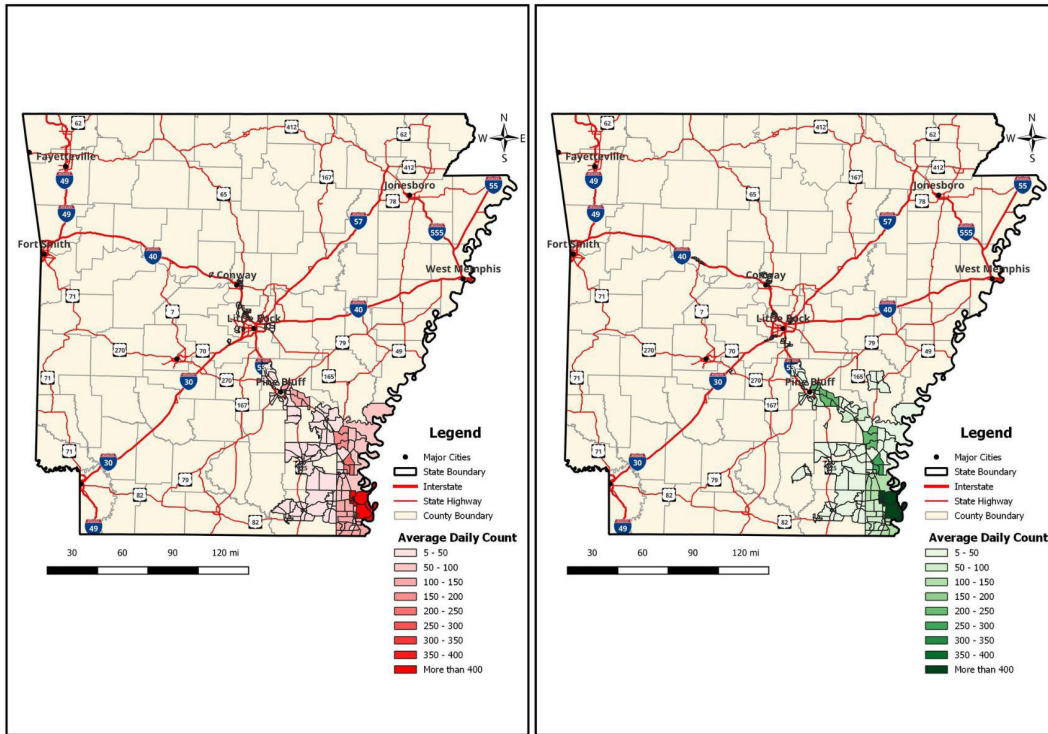


Figure A-47. Comparison of Passenger Vehicle Flows from HWY 82 bridge to the TAZs (A) and from TAZs to the HWY 82 bridge (B) (August 01-06,2021)

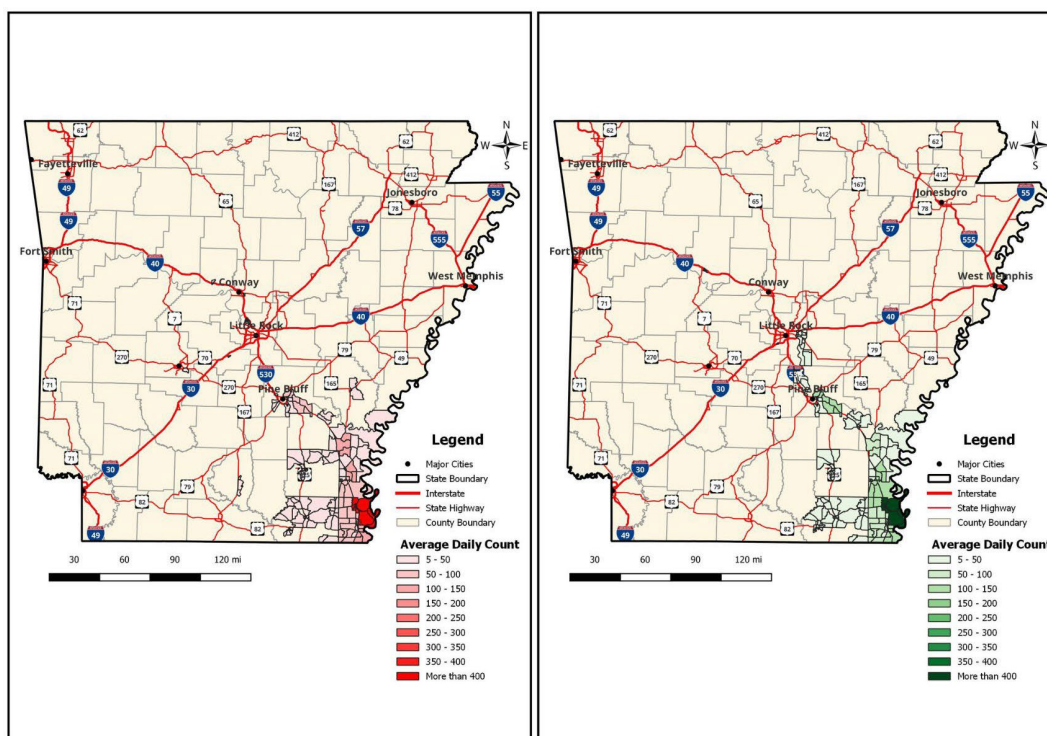


Figure A-48. Comparison of Passenger Vehicle Flows from HWY 82 bridge to the TAZs (A) and from TAZs to the HWY 82 bridge (B) (October 15-30,2021)

APPENDIX B. METHODS FOR MULTIMODAL IMPACT ASSESSMENT FOR BRIDGE CLOSURES

This Appendix describes the state of the art and state of the practice methodologies for multimodal impact assessment of road closures. This Appendix provides context for the methods selected for estimating bridge closure scenarios.

This review is divided into two categories: historical observation and predictive modeling (Figure B-1). The methods and models categorized here as historical observations deal with the study of the impact of bridge closures using observational data. The methods and models categorized as prediction-based studies involved using numerical modeling such as simulation to study the impact of the bridge closures. The studies grounded on the use of historical observation pertain only to roadways and are further categorized into those that rely on surveys or interviews and those that rely on traffic data. The studies based on the use of predictive modeling are divided into travel demand models and simulation techniques. The use of travel demand models pertains only to roadways while the simulation approaches referenced in this review pertain only to waterways. As the overall goal of many studies is to determine the economic impacts of closures, both for roadways and waterways, the review concludes with a discussion on the estimation of economic impacts. Through this review of past studies, the goal is to select appropriate methods and models to assess the impacts of the 2021 Hernando de Soto Bridge closure along I-40 as well as to predict the impact of possible future closures of bridges crossing the Mississippi River along the eastern border of the state of Arkansas.

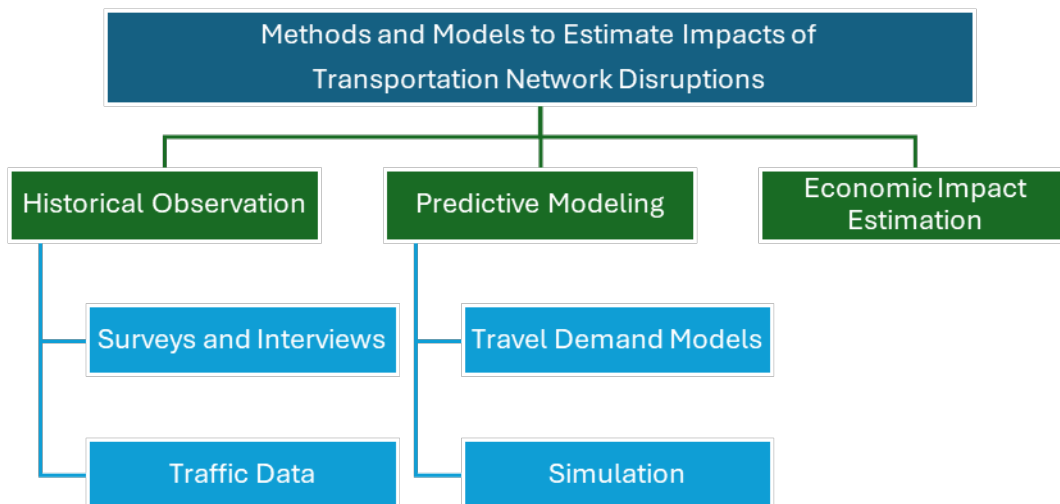


Figure B-1. Organization of Literature Review

Analysis through Historical Observation

Methods used to assess impacts of past events include historical observation through (1) surveys and interviews and (2) analysis of traffic data. The following section describes each of these two approaches.

Surveys and Interviews

Surveys or interviews are often used as the initial method to determine the impact of a disaster on the transportation system. This section reviews studies that used surveys and interviews for impact estimation.

Methods

Approaches can be classified as phone interviews, mail-based surveys, internet-based surveys, and combinations of the three (Table B-1). Phone interviews usually involve a group of people dialing the appropriate respondents to solicit responses from them while the mail-based surveys usually involve physically mailing out the surveys so that the respondents can complete them and return them. On the other hand, internet-based surveys usually deal with dissemination of the survey through the internet and the respondents filling them up anonymously in most cases. While these three methods were popular a few decades ago, the dependencies on them have reduced due to a variety of reasons. Telephone-based and mail-based surveys, though found to be more reliable, have been found to be time-consuming and costly (Biffignandi & Bethlehem, 2021). On the other hand, internet-based surveys help solicit quicker responses, though they tend to have a drawback of sampling ratios and response rates (Nayak & Narayan, 2019).

In an overall conclusion, surveys and interviews are an important method of study for disruption to the road network. However, previous studies suggested that they may produce inaccurate estimates of economic impacts as respondents may be biased (Giuliano & Golob, 1998). Additionally, surveys and interviews, regardless of response rate, are time consuming and costly (Giuliano & Golob, 1998).

Key Findings

During the disruption to the transportation network, non-work related trips were most affected as individuals tend to reduce the non-essential trips (Deakin, 1991; Zhu & Levinson, n.d.) and change their shopping methods (Guiver, 2011). Though vehicular traffic was seen to drop in most cases during the disruption, there were instances where individuals chose alternative routes for work-based trips or offset their working hours (Dahlgren, 2002; Hunt et al., 2002). There was also an instance where a complete change in the modes of transportation from cars to transit was recorded, even after a few years of normal service (Deakin, 1991). Changes to routing and mode experienced during the disruption may become permanent as noted in a 2012 study that found that 20% of the individuals felt scared of driving across bridges after collapse (Zhu et al., 2012).

The way individuals coped with the disruption to the traffic network differed among travelers and businesses. For instance, as a result of the Northridge earthquake 20% of individuals surveyed lost more than a day of work whereas 30% of businesses reported losing more than one day of work per employee (Gordon et al., 1998). The same study also showed that the

individuals reported a loss of 11.2 days on average whereas the local businesses showed that they were closed for 14 days on average. Changes in revenue and cost of the (trucking) companies greatly depended on the type of the company. For example, moving companies showed profits during the earthquake disruptions whereas the intra-state and inter-state trucking companies reported losses (Willson, 1998).

Table B-1. Survey and Interview-Based Studies on Disruption to the Transportation System

Model(s) Used	Focus	Authors	Event	Scale	Sample Size (Response Rate)
Telephone Interview/ Survey	Ridership Road Users	(Deakin, 1991)	Loma Prieta Earthquake, San Francisco, 1989	Local	601 (4%)
	Road Users	(Gordon et al., 1998)	Northridge Earthquake, California, 1994	State wide	357 (N/A)
	Companies and local firms				N/A
	Road Users (drivers only)	(Hunt et al., 2002)	Center Street Bridge, Calgary, Alberta, Canada, 1999	Local	N/A
	Trucking Companies	(Willson, 1998)	Northridge Earthquake, California, 1994	State wide	164 (62%)
	Trucking Companies	(Transportation Statistics, 2021)	I-40, Hernando De Soto Bridge Closure, 2021	Regional	N/A
Mail	Business Firms	(Boarnet, 1998)	Northridge Earthquake, California, 1994	Local	559 (25%)
	Road Users	(Dahlgren, 2002)	I-880 in Oakland, California bridge reconstruction after Earthquake, 1999	State wide	822 (13%)
Internet	Road Users	(Tilahun & Levinson, n.d.)	I-35 W Bridge Collapse, Minnesota, 2007	Local	215 (4%)
Mail and Internet	Road Users	(Zhu et al., 2012)	I-35 W Bridge Collapse, Minnesota After-effects, 2007	Local	141, 137, 215, 349 (14%, 16%, 4%, 7%)
	Transit (Train) and Pedestrian (Bridge)	(Guiver, 2011)	Floods and Bridge Collapse, Workington, UK, 2009	Local	9%
Local press reports, letters to the press	Local businesses and stakeholders				N/A

Traffic Data

The use of traffic data removes sources of bias and reduces the costs experienced with survey and interview approaches. However, traffic data must be collected prior to and during the disruption to be used for impact analysis. Moreover, the type of traffic data necessary for studying disruptions is important. This section reviews the methods and key findings related to the use of traffic data to estimate system disruptions and impacts.

Methods

Probe-based data sources are the most used types of data for assessing the impacts of transportation network disruptions. Methods to collect probe data include Bluetooth tracking, GPS, and cell phone tracking (Table B-2). All these methods are used to track and identify the vehicle's position. Bluetooth data uses the MAC address which is a unique identification for a particular vehicle. Bluetooth tracking requires roadside sensors to capture the unique MAC address. Then, MAC addresses can be matched across locations to calculate the travel time between the two locations (Shahram Tahmasseby, 2015). A key limitation of Bluetooth data is that it needs to have the devices set up in the field and hence, which presents additional costs (Poddar et al., 2023). GPS and cell phone based data track a vehicle's location by passively transmitting the vehicle's (devices') geographical coordinates wirelessly (Quiroga & Bullock, 1999; Shahram Tahmasseby, 2015). The data is considered passive since the owner of the device does not need to actively transmit the data, but rather data is collected by a third-party provider than aggregates the data and disseminates anonymized records and/or travel time/speed and/or origin-destination data. These have the advantage of being completely independent of the infrastructure and hence require no maintenance. Studies using probe data are usually aimed at finding delay and congestion that occurred in the neighboring region of the bridge closure.

There are several limiting assumptions that must be made when using probe data for historical analysis. First, though probe data produces travel time and speed estimates with accuracy, the definition of delay can be subjective. For example, delay might be based on the estimated drop in speed below a pre-determined threshold, as was the case in a study by (McNamara et al., 2015) who defined speeds below 45 mph to be signs of delay. Second, and more importantly, the penetration rate and corresponding representativeness of the probe data must be considered (Ahsani et al., 2019). A "representative" sample of probe data has often been questioned in transportation networks (Narupiti & Mustafa, 2007). As of 2020, the penetration rate of these sources lie in the range of 1.5% - 5%, which makes it difficult to make historical estimates using this data source (Inrix, 2023). For this reason, a combination of both the probe data and infrastructure-dependent sources like loop data and camera-based sensors were used for this study. These sources have been used to calculate the changes to the traffic volume during the various stages of bridge closure and have been used for estimating the travel demand model described in the section below.

Key Findings

Travel time estimates based on probe data can provide proactive real-time updates (McNamara et al., 2015) as well as reactive updates to study how the impacts spread across a region (Brennan et al., 2019; Hamed et al., 2018). Additionally, probe data can be used to observe

route choice to estimate the probability of drivers taking alternative routes (Carrion & Levinson, 2011). By analyzing routing choices among drivers, transportation agencies were able to note common alternative routes and their corresponding travel times. One study shows that through the use of probe data, transportation agencies observed that the designated route was taken by 9% of drivers compared to 57% drivers taking local routes (Hainen et al., 2011).

Volume based estimation was also used to depict the changes in traffic patterns during the road network disruption. Temporary cameras installed along interstates showed that travel rates dropped by about 60% along the closed routes during the planned closure events (Edara et al., 2014).

With regards to the 2021 De Soto bridge closure, historical observation based on traffic data was conducted by the Bureau of Transportation Statistics (BTS) in 2021 (Transportation Statistics, 2021). This analysis showed an estimated increase in travel time of about 400% and delay to about 62 tugs carrying 1,058 barges.

Table B-2. Data Sources to Evaluate Traffic Operations During Bridge Closures

Datatype	Author	Event	Measures of Effectiveness	Traffic Scenarios
GPS and Survey	(Carrion & Levinson, 2011)	I-35 W Bridge Collapse, Minnesota, 2007	Probability of taking alternate I-35 W	Alternate Route during bridge closure
Camera Based	(Edara et al., 2014)	I-57 Bridge Closure, Missouri, 2011	Traffic Volume	Before and During Closure
Loop Detector	(He & Liu, 2012)	I-35 W Bridge Closure, Minnesota, 2007		During Closure
Bluetooth	(Hainen et al., 2011)	Bridge Closure due to Structural Faults on Cline Avenue bridge in Indiana, 2009	Travel Time	During Closure with Google Time
	(Day et al., 2017)	Wildcat Creek Bridge on I-65 N closed in Indiana, 2015	Travel Time	During bridge closure
Probe	(McNamara et al., 2015)	Wildcat Creek Bridge on I-65 N closed in Indiana, 2015	Speed drop below 45mph	Real time
	(Brennan et al., 2019)	I-276 bridge closure in New Jersey Turnpike, 2017	Travel Time	Mean Percentage Increase in Travel Time compared to Free Flow Travel Time
	(Hamed et al., 2018)	I-85 Bridge Collapse, Atlanta, 2017	Bottleneck Analysis, Travel Time Index, Planning Time Index	Before, During, and After Closure
Loop Detector and Probe Data	(Kuncheria et al., 2023)	Richmond-San Bridge Closure, CA, 2019	Traffic Volume and Speed	Before and During Closure

Analysis through Predictive Modeling

Predictive modeling of transportation network disruptions allows for scenario-based investigation of possible impacts due to full and partial closures of transportation assets such as bridges. The main forms of predictive modeling found in the literature include the use of Travel Demand Modeling (TDM) for roadways and simulation approaches for waterways. This section reviews the literature related to each of these approaches.

Travel Demand Models (Roadways)

The most common type of predictive modeling applied to study the impacts of transportation system disruptions on roadways is TDMs. TDMs can take various forms but the most common found in the literature include the four-step approach of trip generation, trip distribution, mode choice, and trip assignment. In brief, TDMs are calibrated and validated using traffic data collected from continuous or short-term traffic count stations (e.g., Annual Average Daily Traffic (AADT)). The calibrated models are then used to evaluate road closure scenarios such as bridge closures. The outputs of the analysis include estimated traffic volume changes, travel time and speed estimates, and route decisions that result from the closure scenario.

Methods

While evaluating the impact of road network disruptions, previous research (Table B-3) focused on variations to the traffic assignment step of the traditional four-step TDM. In other words, changes to trip generation, distribution, and mode choice are assumed to be unaltered when evaluating network disruptive events (Xie & Levinson, 2011). Examples of traffic assignment models include Static Traffic Assignment (STA) and Dynamic Traffic Assignment (DTA). STA assumes fixed travel demand and conditions. STA is further classified into All-or-Nothing (AON) and User Equilibrium (UE) assignment models. AON employs shortest-path algorithms to allocate traffic flow, whereas UE assumes drivers possess perfect knowledge and choose their optimal routes accordingly (Aydin et al., 2012). The current AR-TDM uses STA. It should be noted that to enhance the accuracy of simulations for short-term disruptions, Dynamic Traffic Assignment (DTA) models are superseding STA in many traditional applications. DTA provides a more precise estimation of traffic diversion to alternate routes, accounting for temporal and spatial flow shifts resulting from changes in network supply or traffic demand (Xin et al., 2014). However, to maintain the scope and schedule for the present study, we will not alter the AR-TDM to run DTA.

To calibrate and validate STA and DTA assignment procedures, historical traffic count, usually Annual Average Daily Traffic (AADT) and Annual Average Daily Truck Traffic (AADTT) are used. Simulated traffic counts are compared to observed (historical) counts. Traffic count data can be real-world fixed sensor data like loop detectors or cameras (Jiang & Jin, 2023; Kuncheria et al., 2023; Xie & Levinson, 2011; Zhu & Levinson, 2010a). Data from probe based technologies like GPS and cell phone data (Hainen et al., 2011; Kuncheria et al., 2023) is more often used for calibration and validation of origin and destination inputs to the trip distribution step of a traditional TDM. As shown in the literature, when evaluating network disruptions due to bridge closures, data from pre-, during, and post-closure periods can be used for calibration and

validation. As an implementation example of traffic assignment calibration for bridge closures, when modeling the Stony Plain Road Bridge closures, traffic data from the bridge's operational (pre-construction) phase was used for calibration while data from the bridge closure (during-construction) phase was used for validation (Xin et al., 2014).

Table B-3. Travel Demand Model Applications for Bridge Closure Events

Model(s)	Author	Event	Scale	Measure of Effectiveness	Traffic Scenarios
STA (TransCAD)	(Aydin et al., 2012)	I-40 Bridge Collapse (OK, 2002)	Statewide (OK), Nationwide	VMT, VHT, VCR ¹ , WAFD ²	Pre-closure Under- closure (Full)
DTA (SONG 2.0)	(Xie & Levinson, 2011)	I-35W Bridge Collapse (MN, 2007)	Local (Twin Cities, MN)	VHT, VMT	Pre-closure Under- closure (Full)
DTA (Dynameq)	(Xin et al., 2014)	Stony Plain Road Bridge Closure (Canada, 2013)	Local (Canada)	TTT ³	Pre-closure, Under-closure (Full)
DTA (Mobiliti)	(Kuncheria et al., 2023)	Richmond-San Bridge Closure (CA, 2019)	Local (San Francisco, CA)	VMT, VHD	Pre-closure, Under-closure (Full)
DTA, STA (EMME/2)	(Kiremidjian et al., 2007)	Earthquake Related Bridge Closure	Local (San Francisco, CA)	TTT ³	Pre-closure, Under-closure (Full)
DTA (SONG 2.0)	(Zhu & Levinson, 2010a)	Lafayette Bridge Closure Simulation	Local (Saint Paul, MN)	VHT, VMT	Pre-closure Under- closure (Partial vs full)
DTA (SONG 2.0)	(Zhu & Levinson, 2010b)	St Croix Bridge Closure Simulation	Local (Stillwater, MN)	VHT, VMT	Pre-closure Under- closure (Partial vs full)
DTA	(Chang et al., 2010)	Flood-Induced Disruptions Simulation	Local (Portland, OR)	VMT, VHD	Pre-closure, Under-closure (Full)
STA (Cube Voyager)	(Twumasi-Boakye & Sobanjo, 2017)	Five Bridges Closure Simulation	Local (Tampa Bay, FL)	VHT, VMT	Pre-closure, Under-closure (Full)
DTA (SUMO)	(Jiang & Jin, 2023)	Runyang Bridge Simulation	Local (China)	Velocity, Occupancy, Delay	Flow change Capacity change

1. VCR = Volume-to-Capacity Ratio 2. WAFD = Weighted Absolute Flow Difference 3. TTT = Total Travel Time 4. LOS = Level of Service

Key Findings

Recent research into the impact of the 2002 I-40 Bridge collapse in Oklahoma revealed a 0.0047% increase in both Vehicle Miles Traveled (VMT) and Vehicle Hours Traveled (VHT) nationwide with the AON model. Conversely, under the UE model, VMT experienced a rise of 0.0047%, while VHT saw a minimal increase of 0.000003%. This underscores the recommendation for incorporating regional planning models that utilize a UE assignment (Twumasi-Boakye & Sobanjo, 2017). A simplified study of the collapse of the I-35W bridge in 2007 in the Twin Cities Metropolitan region showed an increase in daily VHT ranging from 0.31% to 1.09%, while daily Vehicle Kilometers Traveled (VKT) decreased by 0.3%.

The key benefit of TDMs as compared to historical observations is the ability to carry out scenario analysis. The main limitation is the accuracy of the model, which is dependent, in part, on the calibration/validation data used for the model. Additionally, TDMs used for bridge closure analysis have been implemented in a variety of model software platforms including TransCAD, EMME/2 (Equilibre Multimodal/Multimodal Equilibrium/) and Cube Voyager.

While both STA and DTA serve essential roles in understanding traffic behavior during disruptions, it's important to note that the most recent AR-TDM model is designed as a Static Traffic Assignment. The AR-TDM utilized the TransCAD Multi-Modal Assignment (MMA) architecture with standard User Equilibrium for highway assignment (Alliance Transportation Group, 2015a). Within this model, passenger and freight model results are combined to enable joint assignment for distinct passenger vehicles and truck trip tables. The validation of the AR-TDM incorporated 2010 traffic count data from ARDOT into the roadway networks. Validation involved comparing model results for 2010 with actual traffic counts using three key indices: Percent of Count, Correlation Coefficient, and Percent Root Mean Squared Error (%RMSE) (Alliance Transportation Group, 2015b).

This study aims to understand the impact of closures of Mississippi River bridges in Eastern Arkansas such as the Hernando De Soto bridge. It aims to achieve this by calibrating and validating the AR-TDM with real-world data during the closure and re-opening periods of the Hernando De Soto bridge.

Simulation (Waterways)

Modeling waterway traffic is more challenging as compared to roadway traffic due to various factors, including limited data availability, dynamic infrastructure types, and environmental considerations (Chang et al., 2010). Transportation experts have adopted similar methodologies from TDMs to address the complexities in waterborne traffic analysis. In this section, literature related to bridge and other waterway closures is discussed.

Methods

In the framework of waterway modeling, the concept involves treating waterway channels as if they were roadway links, with ports transforming into nodes, bridges, locks, and other relevant components becoming integral elements within the system. Traffic data for waterway modeling is often sourced from Automatic Identification System (AIS) data, which provides comprehensive information about vessel movements, positions, and characteristics on the waterway. The AIS data has been widely used in generating inland waterway trip information such as traffic volumes and traffic patterns (Dobbins & Langsdon, 2013; Silveira et al., 2013; X. Wu et al., 2016).

Discrete simulation models including one-dimensional microscopic models, cellular automata models, and proprietary modeling tools (e.g., Arena) have been used to evaluate waterway closures (Table B-4). A discrete event simulation model is a computational framework employed to simulate the generation of vehicles/vessels/etc. that enter the road/waterway (Rahimikelarijani et al., 2017). Incorporating AIS data into a discrete-event model simulates the traffic and queue in the ship channel under different closure scenarios in a dynamic modeling context (Rahimikelarijani et al., 2017).

As an example, the one-dimensional model for inland waterway traffic flow is a dynamic microscopic approach that integrates physics-based equations of motion and models for dynamic bottlenecks (Fischer et al., 2014). In this simulation, emphasis is placed on the vessels' longitudinal motion exclusively, with each vessel treated as an individual entity. The model considers the dynamic behavior of vessels, incorporating fundamental principles of physics to describe their motion along the waterway. Additionally, it accounts for dynamic bottlenecks, reflecting factors like water channel depths and widths, waterway conditions and fleet compositions that can affect traffic flow. Other discrete simulation approaches use Arena, a proprietary discrete simulation tool, that is commonly used in practice across a wide variety of disciplines.

Table B-4. Simulation Models for Waterway Closure Events

Model(s)	Author	Event	Scale	Measure of Effectiveness	Traffic Scenarios
One-dimensional Microscopic Model	(Fischer et al., 2014)	Ship Movement Simulation	Local (Rhine River)	Maximum flows, Desired speeds	Varying traffic demand and fleet composition
Cellular Automata / Discrete Model	(Qu & Meng, 2012)	Ship Movement Simulation	Local (Singapore Straits)	Travel time	Different traffic volume
Arena (proprietary discrete simulation software)	(Rahimikelarijani et al., 2017)	Ship Channel Closure Simulation	Local	Average wait time Total wait time	Pre-closure Under- closure (Full)
	(Rahimikelarijani et al., 2018)	Ship Channel Closure Simulation	Local (Houston, TX)	Average wait time Total wait time	Pre-closure Under- closure (Full)
	(Kania et al., 2019)	Ship Channel Closure Simulation	Local (Houston, TX)	Average wait time Total wait time	Pre-closure Under- closure (Full)

Key Findings

Compared with the studies conducted for roadway closures, there has been relatively limited attention given to the study of waterway closures. Both one-dimensional model and discrete-event simulation model have the capacity to offer a microscopic simulation of inland waterway system, it predominantly focuses on individual waterway segments on a daily basis, which may not be applicable for larger geographic areas and long-term closure simulations. For example, utilizing the discrete simulation model, Arena, Rahimikelarijani et al. (2018) investigated the impact of Houston Ship Channel closures. Their findings revealed that under a 3-hour closure, 2-hour open, 3-hour closure (3-2-3) scenario, the cumulative waiting times for vessels could extend to 35 hours. Similar research conducted by Kania et al. (2019) on Houston Ship Channel closures concluded that a 3-5-3 daytime closure scenario resulted in a waiting time of up to 2.3 hours per vessel. While Arena produces valuable insights in these case examples, it was limited to a single shipping channel and required specialized and/or proprietary software for implementation. This is the limitation for potential adoption by ARDOT and thus in this study we explore modeling tools that do not require additional purchase or subscription costs.

Thus, rather than implementing an extensive modeling process such as simulation, this research will use waterway traffic data (e.g., AIS) to analyze river traffic flows before, during, and after the closure of the Hernando DeSoto Bridge. The historical AIS data will then be used to determine typical waterway traffic volume and patterns, which will assist us to quantify the total delay tonnages of each commodity type.

Economic Impact Analysis of Closures and Disruptions

The end goal of most modeling efforts related to transportation system disruptions is to translate traffic impacts (road or waterway) into economic impacts typically in terms of user costs. Estimates of user costs are needed to compare closure scenarios to select the closure scenario that produces the least impact on users. In this section, the research related to estimating user costs is presented for roadways and waterways.

Roadway User Cost Estimation

Roadway user cost estimation is carried out in the literature in two main forms (Table B-5): (1) use of TDM performance measures (outputs of TDMs) in combination with user cost factors, and (2) economic impact models that consider interactions between industry sectors. Each is discussed in this section.

Methods

The TDM produces travel time, speed, delay, etc. performance estimates that can then be translated into economic terms via the estimation of user costs. Estimating user costs of a roadway closure involves various cost inputs, such as vehicle operating costs (VOC), travel delay costs (TDC), accident costs (AC), vehicle emission costs, and others (FHWA, 2011). According to Federal Highway Administration (FHWA), VOC is the sum of energy, fluids, repair, maintenance, and vehicle depreciation, while delay costs were computed as the monetary value of travel time (MVT). Environmental costs, on the other hand, are often considered externalities in economic analysis. An externality is a cost or benefit that affects a party who did not choose to incur that cost or benefit. In the case of transportation, emissions and noise pollution are considered negative externalities, as they impose costs on society that are not directly paid for by road users.

Not all economic impact analysis models rely on outputs from TDM. Instead, models like Input-Output (IO) model generate estimates of economic impacts independently to assess sector-specific and state-level economic consequences resulting from the collapse of highway bridges (Cho et al., 2015). The IO model approach generated freight assignments based on commodity flows between origin and destination points, employing the shortest path principle, and facilitated the estimation of economic losses at the state and sector levels by aggregating the impacts. An IO model often relies on static assumptions about economic behavior, and necessitates a substantial volume of input data, such as industry or sector data, production data and demand data.

Table B-5. Roadway User Cost Models Applied to Bridge Closure Events

Model(s)	Author	Event	Scale
User Cost Factors Approach	(Aydin et al., 2012)	I-40 Bridge Collapse (OK, 2002)	Statewide (OK), Nationwide

Model(s)	Author	Event	Scale
(TDM)	(Xie & Levinson, 2011)	I-35W Bridge Collapse (MN, 2007)	Local (Twin Cities, MN)
	(Zhu & Levinson, 2010a)	Lafayette Bridge Closure Simulation	Local (Saint Paul, MN)
	(Zhu & Levinson, 2010b)	St Croix Bridge Closure Simulation	Local (Stillwater, MN)
	(Twumasi-Boakye & Sobanjo, 2017)	Five Bridges Closure Simulation	Local (Tampa Bay, FL)
Input-Output Model (TranNIMO)	(Cho et al., 2015)	Multi-bridge Closure Simulation	National

Key Findings

Use of performance measure outputs from TDMs in combination with user cost factors is more widely used compared to IO models. Compared to applying outputs directly from TDM, IO models require a large amount of input data such as industry or sector data, production data and demand data. It requires access to proprietary software which may not be accessible to ARDOT for implementation, which limits the use of IO models for the current project. It is important to note that IO models may oversimplify complex economic interactions and fail to capture dynamic feedback loops that can arise in real-world scenarios.

Considering the approach of using performance measures from TDMs in combination with user cost factors, a limitation is the variety of cost factors that can be used. As shown in Table 4, a range of cost factors are referenced. Value of Time and other cost factors can vary by location, setting, vehicle type (car or truck), among other factors. For this present study, ARDOT provided Road User Cost (RUC) factors that will be referenced for estimating the impacts of bridge closures. In short, the AR-TDM model, built in TransCAD, provides a means to generate performance measurements such as VHT, VMT etc. and will be used along with the ARDOT provided RUC factors to estimate the user costs of bridge closures for this study.

Waterway User Cost Estimation

Unlike roadways, where closures can sometimes lead to rerouting options, vessels and barges navigating on waterways have fixed routes and cannot easily change course to another river when the waterway is closed. In such cases, a company will choose the alternate mode if the cost of using the alternate mode is lower than the cost of keeping their product at the port (MacKenzie et al., 2012). The total user cost for waterway closures is the sum of holding cost, penalty cost and transportation cost (Oztanriseven & Nachtmann, 2017). Waterway user cost models include Input-Output (IO), Monte Carlo Simulation, and Agent Based approaches (Table B-6). Each is discussed in this section.

Methods

The Leontief Input-Output (IO) Model has been widely adopted for its ability to analyze interdependencies between different sectors of an economy by considering the flow of goods and services (Leontief, 1986). An upgraded IO model, dynamic inoperability input-output model (DIIM), introduces a novel approach for assessing the impacts resulting from the

incapacity of a state or industries to either import or export specific commodities (MacKenzie et al., 2012; Pant et al., 2015; K. Welch et al., 2022).

IO model typically offers a macro-level perspective, focusing on aggregated data for sectors or groups. In contrast, Agent-Based Models (ABM) enable a more detailed examination, as they model the behaviors of individual agents (MacKenzie et al., 2012). A framework that combines agent-based modeling, economic interdependence analysis, and Bayesian modeling, employing the Approximate Bayesian Computation Sequential Monte Carlo (ABC-SMC) algorithm, is capable of efficiently parameterizing a complex model using data from just a single disruption event (Johnson et al., 2023). A Monte Carlo simulation model is a computational technique utilizing random sampling to simulate the behavior of intricate systems or processes, employed specifically to stochastically assess potential waterway disruptions (MacKenzie et al., 2012; Oztanriseven & Nachtmann, 2017). Oztanriseven and Nachtmann (2017) developed a Monte Carlo simulation model to assess economic impacts for MKARNS under various disruption scenarios, including different durations, accuracy levels of estimations, and types of affected commodities.

In addition to utilizing the IO model, an end-to-end systems analysis can be more comprehensive for estimating the consequences due to inland waterways disruptions. The methodology applies available waterway commodity movement data, facility characteristics data, restoration time and cost data, and consequence factors (Folga et al., 2009). It then calculates direct and indirect costs, fatalities and injuries, and societal impacts such as population evacuated/displaced due to flooding and inundation (Folga et al., 2009).

Table B-6. Waterway User Cost Models Applied to Various Disruptive Scenarios

Model(s)	Author	Event	Scale	User Cost
System-level Simulation Model (ESRI ArcView, IMPLAN)	(Folga et al., 2009)	Waterway Disruptions Simulation	-	Costs, health and safety, societal impacts
Input-Output Model	(MacKenzie et al., 2012)	Port Closure (Port of Catoosa, OK)	Multi-regional (10 states)	\$5.1 B in lost production for 10 states (1-2 months)
Input-Output Model (MRIIM)	(Pant et al., 2015)	Port Closure (Port of Catoosa, OK)	Multi-regional (10 states)	\$111.8 M direct and \$72.9 M indirect losses for industry sector across 10 states (2 weeks)
Monte Carlo Simulation Model (@RISK 6)	(Oztanriseven & Nachtmann, 2017)	Waterway Disruption (MKARNS)	Multi-regional (OK, AR)	Industry sector cost (accurate) Ex. petrol \$0.35 M (10 days) \$12.0 M (60 days) \$14.9 M (180 days)
Input-Output Model (IMPLAN)	(K. Welch et al., 2022)	Flood Disruptions Simulation	Statewide (OK)	Industry sector cost Ex. petrol \$10.31 / ton (2 months) \$23.21 / ton (4 months)

Model(s)	Author	Event	Scale	User Cost
				\$36.11 / ton (6 months)
Input-Output Model (IMPLAN)	(K. L. Welch et al., 2023)	Flood Disruptions Simulation	Multi-regional (4 states)	Industry sector cost Ex. petrol \$5.23 M (2 months) \$16.67 M (4 months) \$28.10 M (6 months)
Agent-Based Model	(Johnson et al., 2023)	Flood Disruptions Simulation	Multi-regional (UMR)	Posterior production losses and savings by State

Key Findings

According to Mackenzie's (2012) study, a closure of the Port of Catoosa in Oklahoma on the McClellan-Kerr Arkansas River Navigation System (MKARNS) for one to two months could result in a staggering \$5.1 billion in lost production, assuming companies allow \$110 million worth of product to sit at the port. Similarly, a study by Pant (2014) demonstrated that an exploration of a two-week disruption scenario for the inland Port of Catoosa in Oklahoma led to \$45 million in export-import losses in port industries, which subsequently translated to \$111.8 million in direct and \$72.9 million in indirect losses across industry sectors spanning 10 states. A recent study from Welch (2022) indicates that a disruption in the OK-MKARNS could result in significant economic losses: 63 to 750 jobs, \$14.5 million to \$165 million in output, and \$5.7 million to \$68.7 million in value-added to the economy.

Conducting an economic impact study for waterway disruptions, whether at a micro or macro level, presents considerable challenges in data collection and cost. These studies demand a multidisciplinary approach, enlisting expertise in economics, transportation, and environmental science. IO models require access to proprietary software, such as MRIIM and IMPLAN, which may not be accessible to ARDOT for implementation.

Instead, we adapted aggregated industry sector costs from established IO models (including those by Oztanriseven & Nachtmann, 2017; K. Welch et al., 2022; K. L. Welch et al., 2023) and applied those costs to the estimated delayed volume (in terms of number of vessels, etc.) derived from AIS data. This approach leveraged the outputs of region-specific IO models (Mississippi and Arkansas River systems) while staying within the scope and schedule of the current study by not developing a new IO model. Further we used AIS data to estimate closure impacts realized during the Hernando de Soto Bridge closure rather than producing a new simulation model. This approach is an adaptation and combination of approaches in literature, and in this way is considered to have evidence-based support.

APPENDIX C. INPUTS, ASSUMPTIONS, AND APPLICATION OF THE ROAD USER COST (RUC) ANALYSIS TOOL

Background

The purpose of estimating RUC is to quantify the economic and safety impacts experienced by motorists and the broader community due to disruptions from work zone activities. These impacts are typically expressed as a daily dollar value. The RUC values obtained on this report were calculated using a spreadsheet-based tool developed by ARDOT. This tool was created based on the methodology outlined in the Federal Highway Administration (FHWA) manual titled *Work Zone Road User Costs – Concepts and Applications* ¹⁵, published in December 2011. It incorporates both economic costs (such as travel delay and vehicle operating costs) and safety costs (based on crash modification factors and crash rate changes in work zones).

The economic component of the RUC is calculated based on the traffic delays and vehicle operating costs. Delays are calculated based on queuing and queue dissipation, which are determined by analyzing lane capacity in relation to traffic demand. Vehicle operating costs consider various factors such as driver value of time (personal and commercial drivers) and vehicle depreciation. These variables are informed by economic indicators published by the U.S. Department of Labor, such as the Consumer Price Index (CPI), Employment Cost Index (ECI), and Producer Price Index (PPI). Using these indices, hourly dollar values are calculated to represent the economic cost per hour for different vehicle classes, including passenger cars, single-unit trucks, and tractor-trailers.

The safety component of RUC is estimated using crash modification factors (CMFs), CMFs are multiplicative values that estimate the proportion of crashes expected after implementing specific roadway changes or countermeasures ¹⁶. To calculate the increased crash risk, the crash rate expected under work zone conditions is compared to historical crash data. This difference serves as a multiplier representing the heightened risk associated with the work zone. The safety cost is then calculated as the product of this increased crash risk and the typical crash cost. These crash costs vary by severity level and are sourced from the FHWA: *Crash Cost Estimates by Maximum Police-Reported Injury Severity Within Selected Crash Geometries* ¹⁷.

The RUC spreadsheet is organized into the following tabs: Traffic, Economic Cost, Delay and Operational Cost, Detour Cost, Summary. The content of each tab is summarized below:

- Traffic Tab: Contains traffic volume data, vehicle classification, Passenger Car Equivalency (PCE) factors, and ADT inputs.

¹⁵ <https://ops.fhwa.dot.gov/wz/resources/publications/fhwahop12005/>

¹⁶ <https://cmfclearinghouse.fhwa.dot.gov/>

¹⁷ <https://www.fhwa.dot.gov/publications/research/safety/05051/>

- Economic Cost Tab: Contains pre-set economic unit costs and indices used for delay and vehicle operating cost calculations.
- Delay and Operational Cost Tab: Conducts the main RUC calculations by integrating traffic, economic, and construction variables.
- Detour Cost Tab: Estimates additional costs due to detour length and travel time changes under full closure scenarios.
- Summary Tab: Consolidates output values for total economic and safety-related user costs.

These tabs collectively process the input data to estimate the total user costs (RUC) under each bridge closure scenario. This report focuses on two specific case types:

- Full closure scenarios, in which all lanes are closed, and detours are required.
- Partial closure scenarios, in which one lane in each direction remains open and traffic continues to flow through the work zone.

To estimate Road User Costs (RUC) for the four bridges, Miovision video-based traffic counts were collected for each of the four bridges, except HWY 82. For HWY 82, no direct traffic data was available; however, due to its geometric and functional similarities with HWY 49 (both being two-lane rural highways), HWY 49's traffic counts were used as a proxy. Table C-2 shows the location of each bridge across the state of Arkansas. Table 3 summarizes the facility type and the count date for each bridge.

Table C - 1. Traffic Data Collection Summary

Bridge	Facility Type	Count Dates
I-40	Urban Interstate	Nov 15–16, 2022
I-55	Urban Interstate	Nov 15–16, 2022
HWY 49	Two-lane Rural Highway	May 27–28, 2021
HWY 82	Two-lane Rural Highway	May 27–28, 2021

In summary, this report applies the ARDOT spreadsheet-based RUC tool to evaluate the economic and safety-related impacts of full and partial bridge closures across four critical Mississippi River crossings. The following sections provide a step-by-step example of tool implementation, describe assumptions used for each bridge and closure type, and present comparative results to support decision-making for future construction planning.

Example of RUC Completion

To quantify the system-wide impacts of an I-40 full closure, the analysis evaluates how traffic demand is redistributed across the regional network using the RUC tool. This tool is organized into six primary tabs: Traffic, Economic Cost, Delay and Operational Cost, Crash Cost, Detour Cost, and Summary. When the Hernando de Soto Bridge is completely restricted, the ARSTDM

model simulates a shift in travel patterns, resulting in significant additional traffic on the I-55 and HWY 49 bridges. While HWY 82 is included in the network model, the TDM predicts that for an I-40 closure the primary impacts are on the closer facilities (I-55 and HWY 49). Because these alternate routes must absorb the diverted volume, the true cost of the I-40 closure is the sum of the extra friction experienced on these specific routes.

For example, during this scenario, the I-55 bridge absorbs most of the redistributed traffic due to its proximity. To isolate the specific impact of this added volume, parameters across the RUC spreadsheet are updated as follows:

- **Traffic Tab:** The diverted traffic volume is entered into cell BO39 (Other ADT). It is also essential to verify the Passenger Car Equivalent (PCE) in cell BR1, as the vehicle mix directly influences the operating and delay costs on the detour route.
- **Crash Cost Tab:** Historical crash data is entered into cells L9 through L13 to establish the baseline safety risk for the detour facility. Crucially, the baseline AADT of the detour route itself is used to calculate crash probabilities, ensuring the denominator remains realistic and the risk assessment is grounded in the actual capacity of the facility.
- **Detour Cost Tab:** The specific detour geometry is defined by inputting the base route time and distance into cells O3 and O4, while the new detour time and distance are entered into cells N8 and N9 for Eastbound or R8 and R9 for Westbound.

For a full closure, the final impacts are derived from the Detour Cost tab. This section isolates the added delay, mileage, and safety risks incurred by the vehicles forced onto the alternate route. By summing these localized increases across all impacted detour bridges, we arrive at the final scenario cost. For the I-40 full closure, these combined network impacts result in a total daily road user cost of \$198,625.

1. Traffic Tab

The manual input process for the Traffic tab is simplified for a full bridge closure. While this tab includes various fields for localized work zone settings, the Other Average Daily Traffic (ADT) in cell BO39 is the primary driver for generating scenario costs.

The Detour Cost tab pulls the hourly traffic distribution directly from the Traffic tab and scales it based on the value in the Other ADT cell. In this I-40 example, we entered 32,644 into cell BO39. This figure represents the modeled marginal increase in traffic demand on the I-55 detour route specifically caused by the I-40 closure. By inputting only the diverted vehicles rather than the combined total of all bridge traffic, the tool isolates the exact added delay, mileage, and safety penalties created by the closure.

Since the Detour Cost tab calculates regional redistribution rather than localized capacity restrictions, fields like Capacity and Number of Lanes Opened (which apply to the active work zone itself) are not utilized for this calculation. However, maintaining accurate Passenger Car Equivalent (PCE) values remains critical. This ensures that the added operating costs, such as fuel and maintenance, accurately reflect the high heavy vehicle percentage found in diverted interstate freight traffic.

BO39	BE	BF	BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BC	BR	BS	BT	BU	BV	BW	BX	BY	BZ	CA	CB	CC	CD	CE	CF
39	525	359	29	141	528						22:00-23:00	553	26	366	945	58%	3%	39%	42%	1337	0.46	639	30	448	1117	57%	3%	40%
39	559	436	23	126	584						23:00-0:00	405	23	315	743	55%	3%	42%	45%	1080	0.46	471	27	386	884	53%	3%	44%
39	555	414	25	135	574							27222	1564	12589	41375	62%	4%	35%	38%			31305	1722	14427	47454	62%	4%	34%
39	576	459	26	142	627																							
39	668	460	26	147	633																							
39	694	494	23	161	677																							
39	650	474	24	136	634																							
39	634	412	25	147	584																							
39	640	425	21	172	617																							
39	591	415	31	181	627																							
39	638	381	34	202	616																							
39	594	340	29	207	575																							
39	577	394	27	218	638																							
39	567	392	32	193	616																							
39	578	424	27	212	662																							
39	557	382	23	201	605																							
39	559	368	27	215	609																							
39	578	407	27	225	658																							
39	561	385	33	228	646																							
39	575	386	37	227	649																							
39	585	410	30	177	616																							
39	583	446	25	212	682																							
39	590	428	23	209	680																							
39	570	435	34	224	693																							
39	582	465	26	234	724																							
39	588	482	31	243	756																							
39	571	455	33	208	695																							
39	570	465	30	223	717																							
39	556	450	35	212	697																							
39	619	461	28	212	701																							

Figure C - 1. Example Inputs to the Traffic Tab

2. Economic Cost Tab

The Economic Cost tab incorporates various factors that influence the total cost of travel delay. These factors are published by government agencies and include the Consumer Price Index (CPI), Employment Cost Index (ECI), and Producer Price Index (PPI). They also include Median Household Income, Freight Inventory Cost, and FHWA average cash costs. The RUC tool manager typically updates this tab periodically to reflect current economic conditions. For this study, the values are pre-configured to establish a consistent baseline for all bridge scenarios.

G33	=((G29+G31)*G27))												
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Red numbers should be regularly updated												
2	Green numbers should be monitored but not updated unless new data becomes available												
3	General Inputs												
4										UPDATED ON	4/20/2022		
5													
6	287,504	Current CPI (All Items)	March 2022			http://www.bls.gov/news.release/pdf/cpi.pdf	pg. 9 All Items; Unadjusted				CPI Archives		
7	264,525	Cur. Trans. CPI	March 2022			http://www.bls.gov/news.release/pdf/cpi.pdf	pg. 16: Transportation; Unadjusted						
8	147,896	Current ECI (Private Industry Workers)	December 2021			http://www.bls.gov/news.release/pdf/eci.pdf	pg. 10: Private Industry Workers; All Workers; Unadjusted				ECI Archives		
9													
10													
11	Cost per vehicle hour (personal delay):												
12	Car:	\$27.21					*Although most factors come from base values in the FHWA report, all values (not just highlighted) are encouraged to be updated when new studies become available						
13	SU	\$32.49											
14	TT:	\$39.65											
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Figure C - 2. Screenshot of the Economic Cost Tab

3. Crash Cost Tab

This tab calculates the cost of shifts in safety outcomes caused by bridge closures. The analysis provides a comprehensive view of safety risk by evaluating three distinct severity levels: Property Damage Only (PDO), Injury, and Fatality. The tool calculates these costs by multiplying the modified crash rates by the current FHWA average crash costs for each category.

The required inputs for this calculation include historical crash data, the length of the analyzed roadway segment, and the baseline Average Annual Daily Traffic (AADT). For full bridge closure

To calculate crash probabilities accurately, the analysis utilizes the baseline AADT of the detour route (41,200 vehicles per day for the I-55 bridge). Using the baseline volume as the denominator ensures the risk assessment remains realistic and grounded in the facility's actual capacity. Simultaneously, the Other ADT field in the Traffic tab is set to the diverted volume of 32,644 to isolate the specific economic impact of the added traffic. For this scenario, a segment length of 4 miles is defined to capture the primary conflict points along the detour bridge and its immediate approaches.

Figure C - 3. Screenshot showing inputs of the crash tab

The table below shows a summary of all the crash cost inputs used for the I-40 full bridge closure scenario.

Category	Parameter	Unit	I-55
Crash History (2019-2023)	Fatal	crashes	7
	Disabling injury	crashes	3
	Evident injury	crashes	33
	Possible injury	crashes	63
	Property damage only (PDO)	crashes	343
Roadway Characteristics	Hard-coded total length	miles	4
	Weighted average ADT	veh/day	41,200
CMFs	Active work with temporary lane closure	-	0
	Active work with no lane closure	-	0
	No active work with no lane closure	-	24

4. Detour Cost Tab

The RUC tool separates safety calculations based on traffic flow. The Crash Cost tab is designed exclusively to calculate the cost of reduced safety within the primary work zone environment. Conversely, the Detour Cost tab functions as a supplemental, stand-alone calculator. It is utilized only when a project requires a full or partial detour, or for "new location" jobs where traffic is being rerouted entirely.

When a closure forces traffic onto alternate routes, the tool uses this tab to compute detour impacts across three specific components:

- *User Delay*: The cost of added travel time.
- *Safety*: The marginal increase in crash risk due to extra travel.
- *Vehicle Operating Cost (VOC)*: Often referred to as mileage depreciation or wear and tear, this covers the added fuel and maintenance costs.

The geographic boundaries for these two tabs differ fundamentally. The localized Crash Cost relies on a static, defined roadway segment (typically a maximum work zone length of 4 miles). In contrast, the Detour Safety cost is not bound by a segment length; it is driven entirely by the additional distance traveled, calculated by comparing the baseline route mileage against the new detour route mileage.

The underlying math for determining risk also differs. For the localized work zone, the Crash Cost tab utilizes the weighted average daily traffic (ADT) to calculate a "Work Zone Exposure" metric. This ensures the safety penalty is scaled by the total volume passing through the restricted area. The Detour Cost tab does not use this baseline exposure calculation, focusing instead on the marginal increase in mileage for the diverted vehicles.

The detour safety calculation relies on a narrower set of severity factors. While these costs are derived from the same FHWA economic factors used elsewhere in the tool, the Detour Cost interface calculates the Safety Costs Per Mile using only the financial rates for Injury and Property Damage Only (PDO) crashes. Fatalities are excluded from this specific per-mile detour penalty to prevent rural, long-distance detours from generating mathematically improbable safety costs.

In the spreadsheet, traffic data is automatically pulled into columns A through E and G through J. To evaluate the I-40 full closure, the baseline ("Without Detour") trip is established as 11 minutes and 10.7 miles. The detour route via the I-55 Memphis-Arkansas Bridge is defined as 13 minutes and 12.0 miles for both directions. This 1.3-mile difference, multiplied by the diverted volume, forms the basis for the added mileage and safety costs.

Figure C - 4. Screenshot showing Detour Cost Tab with inputs

- *Without Detour:* These cells contain the travel time and distance for the existing, unrestricted route. The starting point for this baseline is the major split in West Memphis where motorists choose between the I-40 and I-55 bridges. The endpoint is defined as the I-40/I-240 interchange in Memphis.
- *With Detour:* These cells capture the travel time and distance for the diverted path. This route begins at the same decision point in West Memphis, continues over the I-55 Memphis-Arkansas Bridge, and concludes at the I-40/I-240 interchange.

Table C - 3. Summary of Inputs for the Detour Cost Tab

The final section of the Detour Cost tab serves as the summary dashboard for the scenario outputs. This area consolidates the geometric inputs and applies specific economic rates to determine the total daily costs. On the right side of the sheet, the tool displays established monetary rates for each vehicle classification.

These include the hourly value of time, the safety cost per mile, and the Vehicle Operating Cost (VOC) per mile. For example, the tool applies a higher hourly delay cost for tractor-trailers (\$57.01) compared to passenger cars (\$28.64) to reflect the greater economic impact of delaying commercial freight and logistics operations.

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END OF REPORT