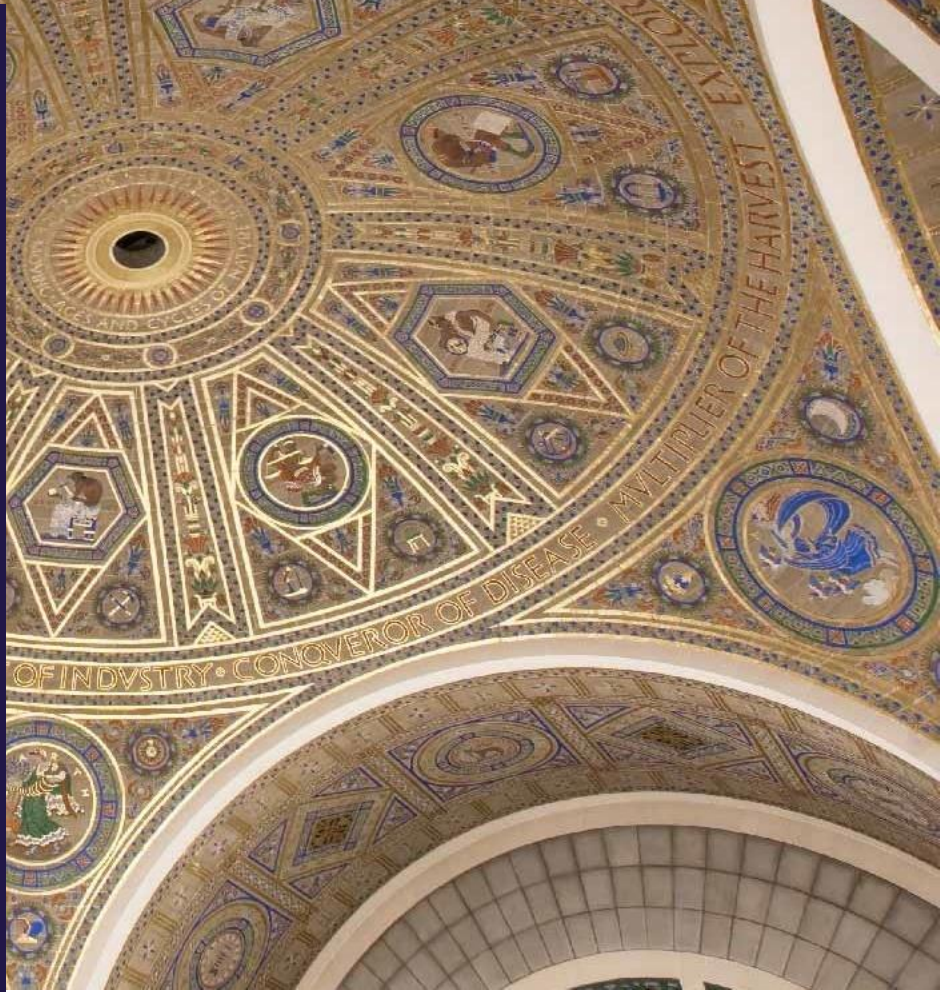
NATIONAL ACADEMIES *Sciences Engineering Medicine*

TRB TRANSPORTATION RESEARCH BOARD

TRB Webinar: Impacts, Lessons, and Insights from Recent Roadway Structure Failures

July 16, 2024

10:30 – 12:00 PM



PDH Certification Information

1.5 Professional Development Hours (PDH) – see follow-up email

You must attend the entire webinar.

Questions? Contact Andie Pitchford at TRBwebinar@nas.edu

The Transportation Research Board has met the standards and requirements of the Registered Continuing Education Program. Credit earned on completion of this program will be reported to RCEP at RCEP.net. A certificate of completion will be issued to each participant. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the RCEP.

ENGINEERING RCEP REGISTERED CONTINUING EDUCATION PROGRAM

AICP Credit Information

1.5 American Institute of Certified Planners Certification Maintenance Credits

You must attend the entire webinar

Log into the American Planning Association website to claim your credits

Contact AICP, not TRB, with questions

Purpose Statement

This webinar will deepen the understanding of critical road infrastructure failures' transportation and social implications, including human casualties, infrastructure damage costs, traffic operations, business disruptions, and community impacts. Presenters will share a methodology and process for evaluating statewide crash data, analysis of resulting truck travel pattern shifts, and flood impacts on vital roadway infrastructure.

Learning Objectives

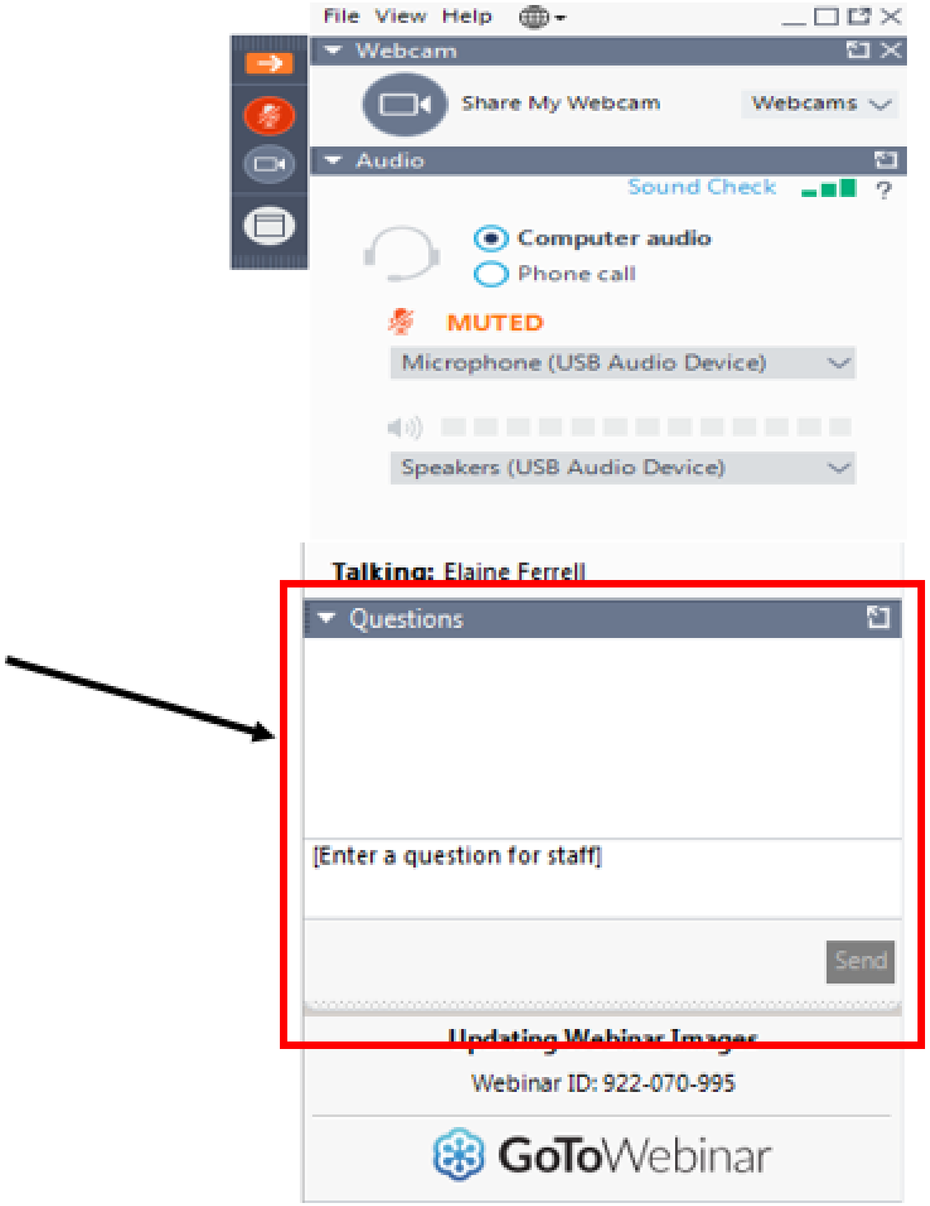
At the end of this webinar, you will be able to:

(1) Analyze challenges associated with handing critical infrastructure failure from different stakeholders' perspectives

(2) Reduce the risk or mitigate the negative impacts of hazards on critical infrastructure using the latest technology or organizational procedures

Questions and Answers

- Please type your questions into your webinar control panel
- We will read your questions out loud, and answer as many as time allows



Today's presenters

Rahil Saeedi
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cpcs Better infrastructure solutions. Better lives.

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NATIONAL ACADEMIES TRB

GRID ENGINEERS

Webinar

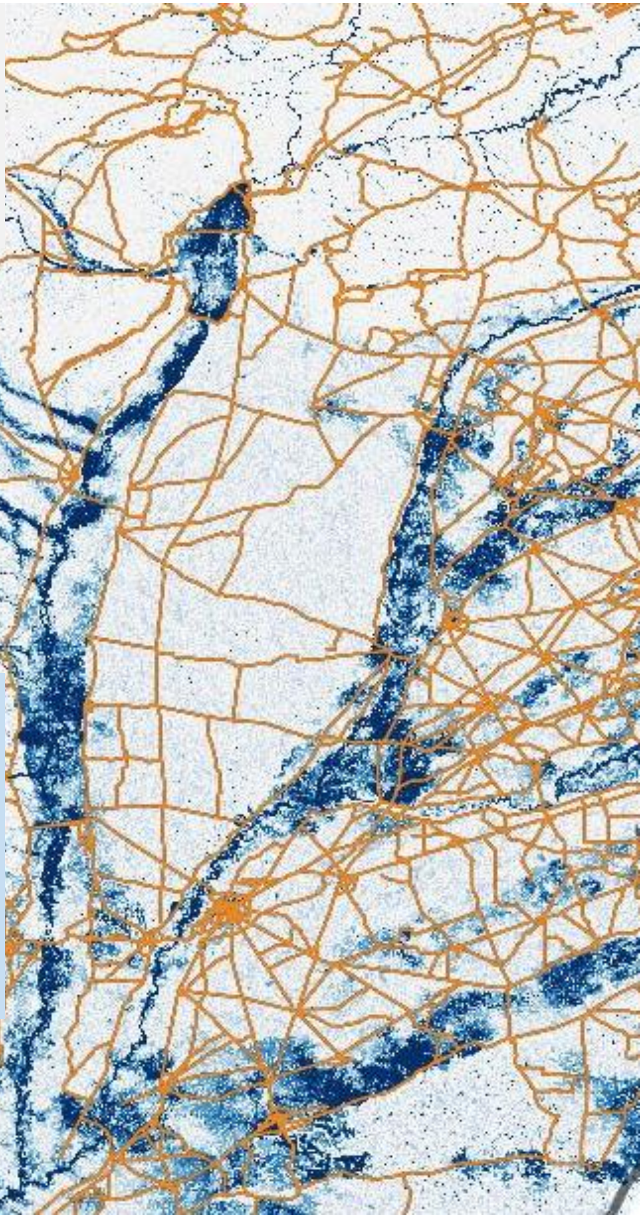
IMPACTS, LESSONS, AND INSIGHTS FROM RECENT ROADWAY STRUCTURE FAILURES

Assessing flood impacts on critical infrastructure

Field-evidence-informed guidelines and tools for road networks

Presenter:
MARIANNA LOLI, PHD

July 16, 2024

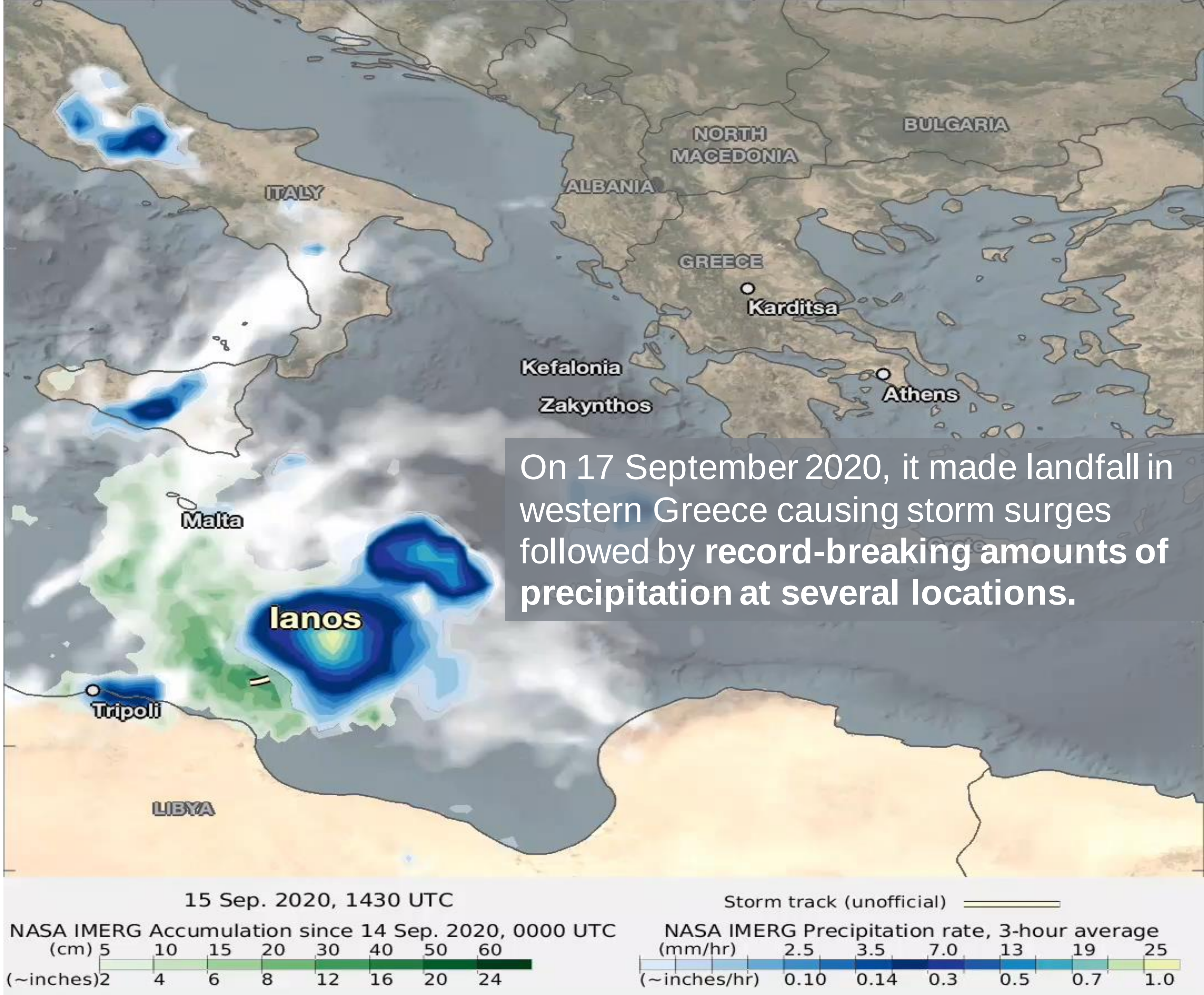


Contents

1
Case Study

18 September 2020

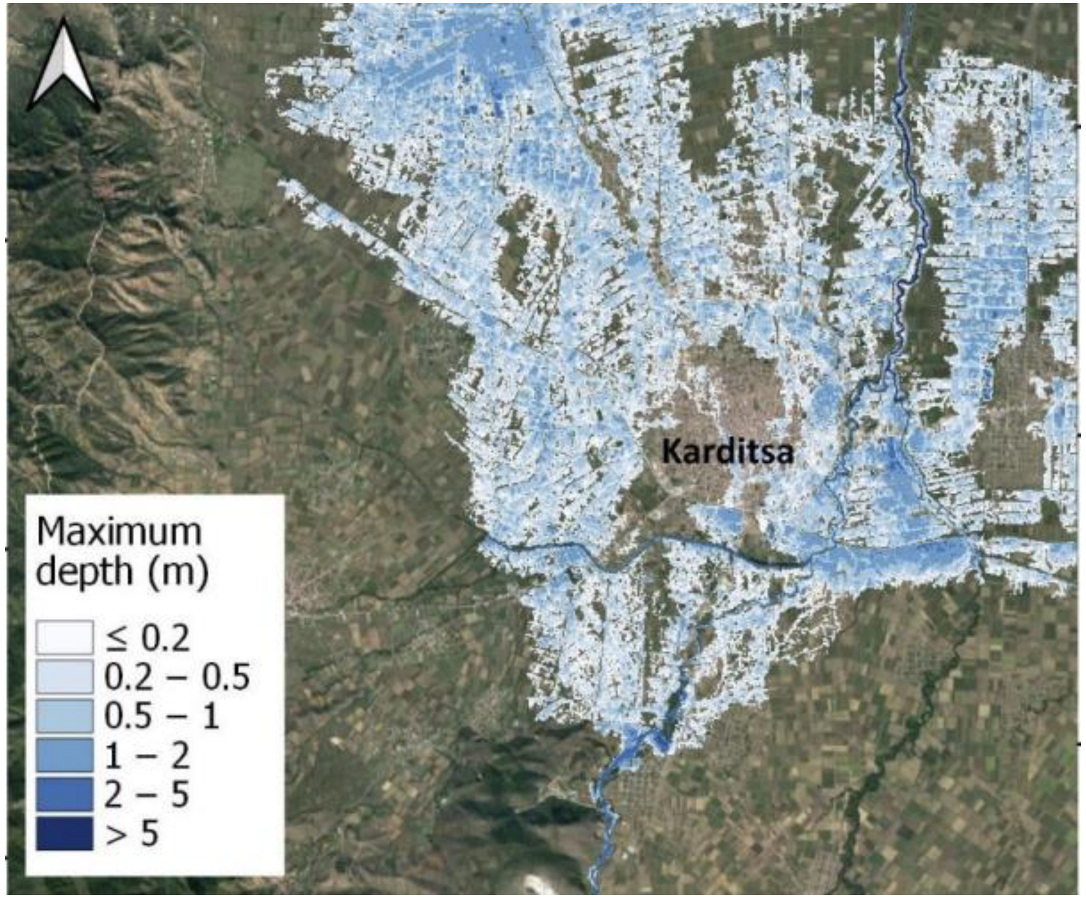
An **unprecedented** event, at the time



On 17 September 2020, it made landfall in western Greece causing storm surges followed by **record-breaking amounts of precipitation at several locations.**

Causing…

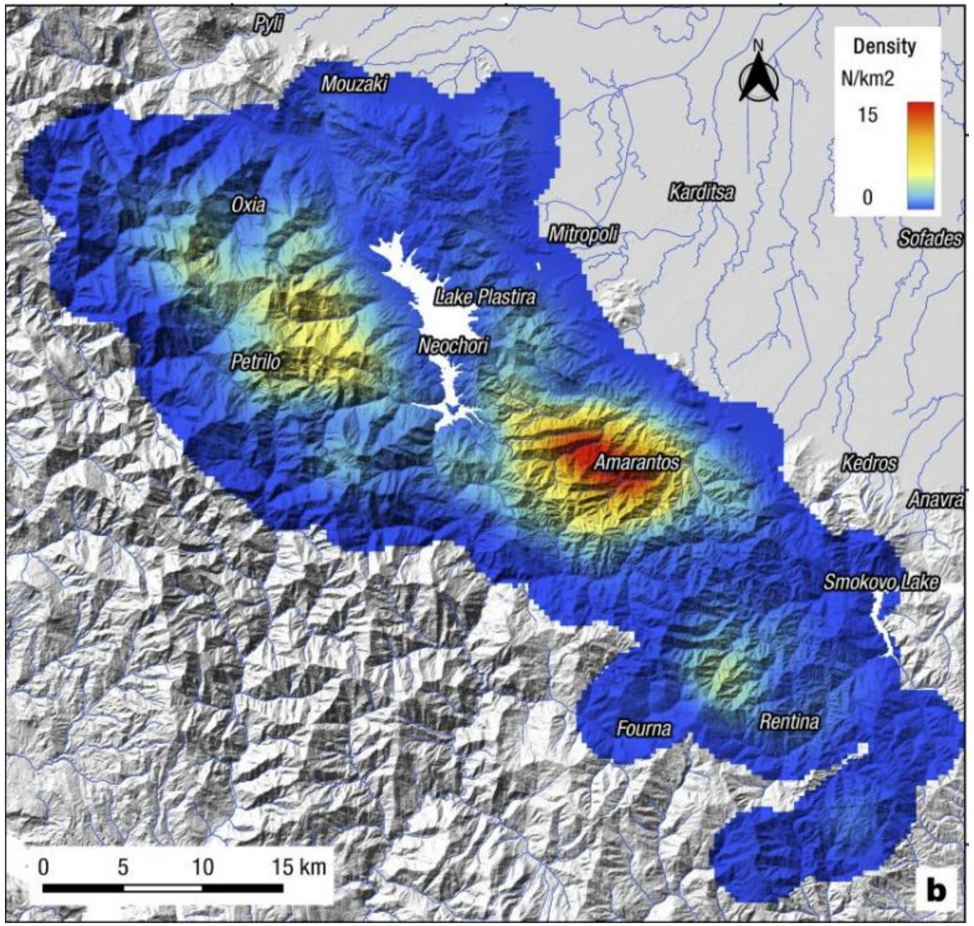
Extensive flooding: Inundation of over 400 km^2 of agricultural & urban land.



Tegos et al., 2022. Forensic Hydrology: A Complete Reconstruction of an Extreme Flood Event in Data-Scarce Area. https://doi.org/10.3390/hydrology9050093

Causing…

Numerous landslides and debris flows



Valkaniotis et al. (2020). Landslides Triggered by Medicane Ianos in Greece, September 2020: Rapid Satellite Mapping and Field Survey. https://doi.org/10.3390/app122312443

Causing…

Excessive riverbank erosion, impacting buildings & powerlines.

Aerial image captured the day after the event

[Mouzaki](#)

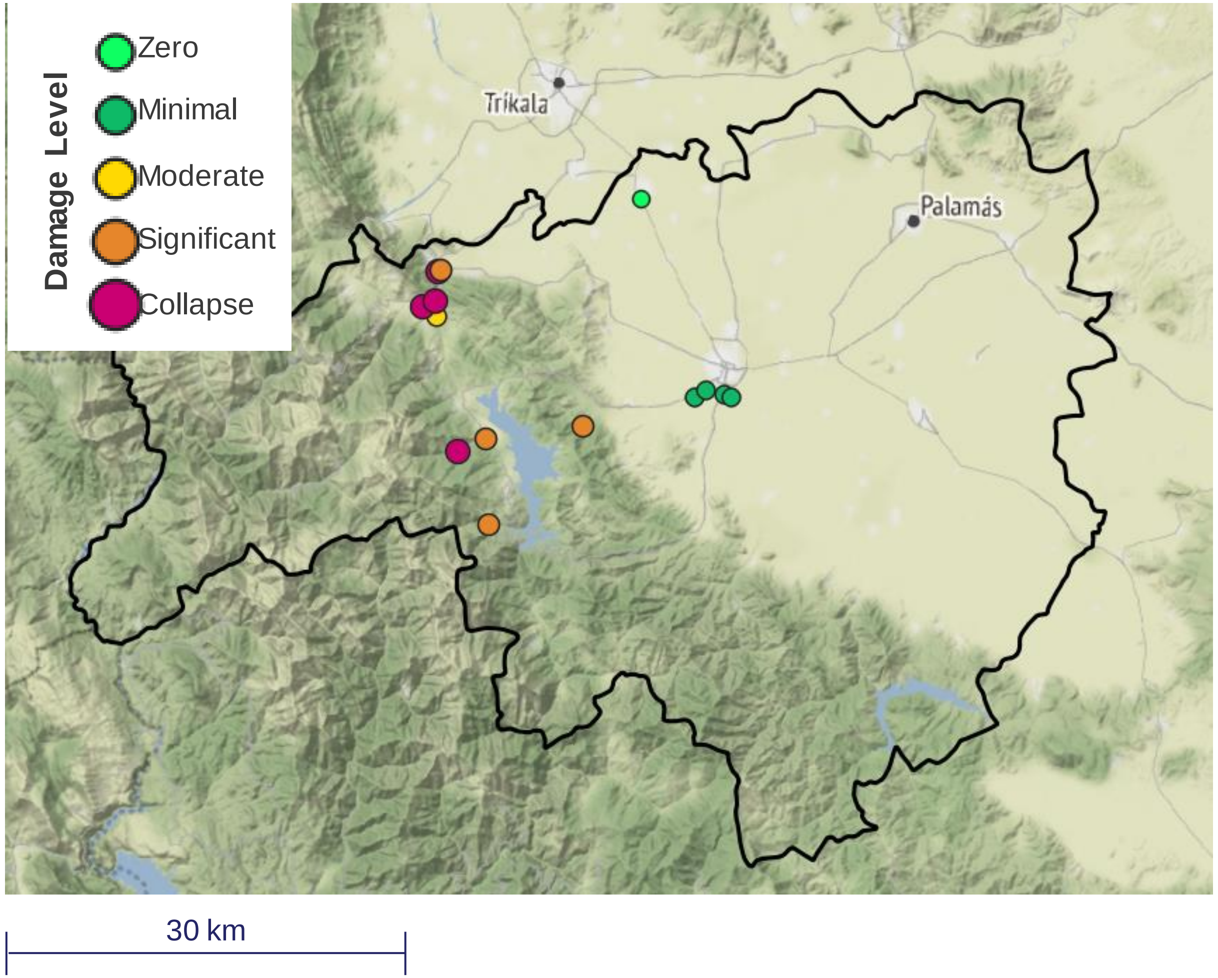
3D point-cloud (2 weeks after)

The town's medical centre

Causing…

A surprising variety of bridge damages

Inspection data for 16 structures



A field reconnaissance mission of impressive scale

Rapidly launched

Involving 6 universities, 3 organizations, and 3 companies

30 researchers

A field reconnaissance mission of impressive scale
Rapidly launched

Involving 6 universities, 3 organizations, and 3 companies

We invested on digital tools to make this work

DRONES

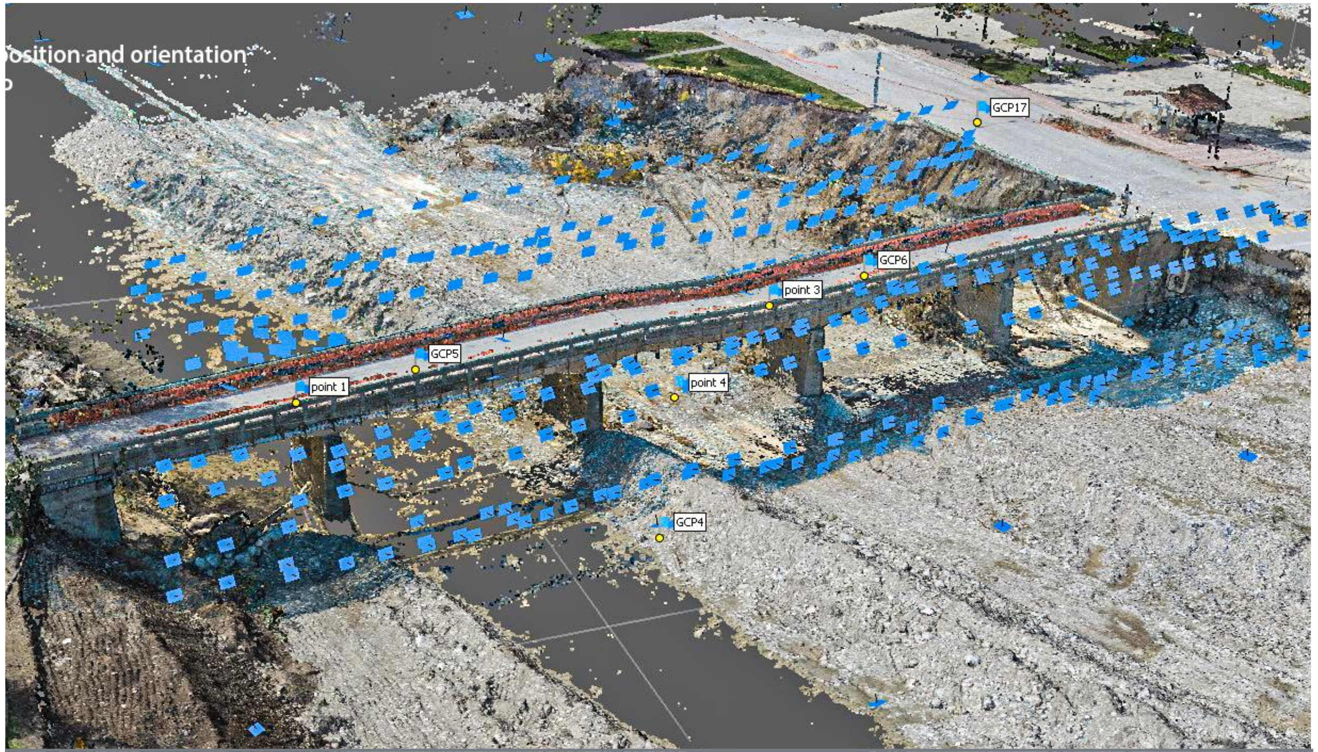
Drones turned out to be the key to successfully carrying out one of the most ambitious disaster reconnaissance studies in Europe

They helped us see, process, and interpret crucial information very quickly and very effectively.

- ✓ Accurate damage assessment
- ✓ Easy reproduction of 3D geometry for numerical modelling
- ✓ Timely completion of investigations and mapping efforts
- ✓ Overcoming the widespread transportation disruptions due to failures in the local road network.

We used drones

To map five different damaged bridges in 4 days



- A DJI Phantom 4 Professional quadcopter coupled with an optical camera
- 33,000 aerial images with res. 0.3 to 1.1 cm/pixel
- Surveying of 60 ground control points

We used drones

Developed 3D digital models

Using the Structure-from-Motion technique

2

What we saw

THE HOTSPOT

In the town of Mouzaki, 5 bridges failed within a radius of less than 2 Miles, causing fatalities and sustained isolation of local communities

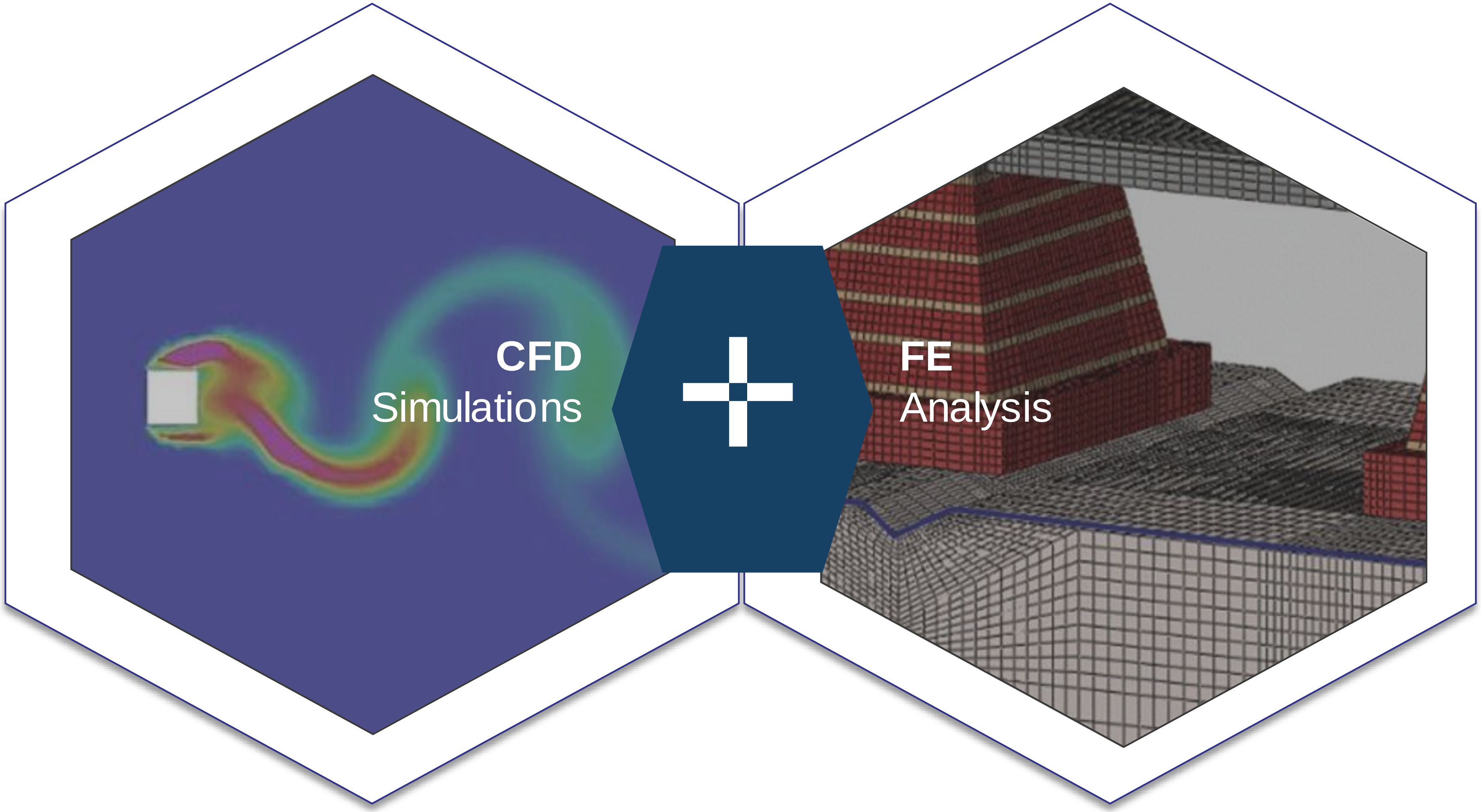
THE HOTSPOT

THE HOTSPOT

3

What we learned

NUMERICAL INVESTIGATIONS

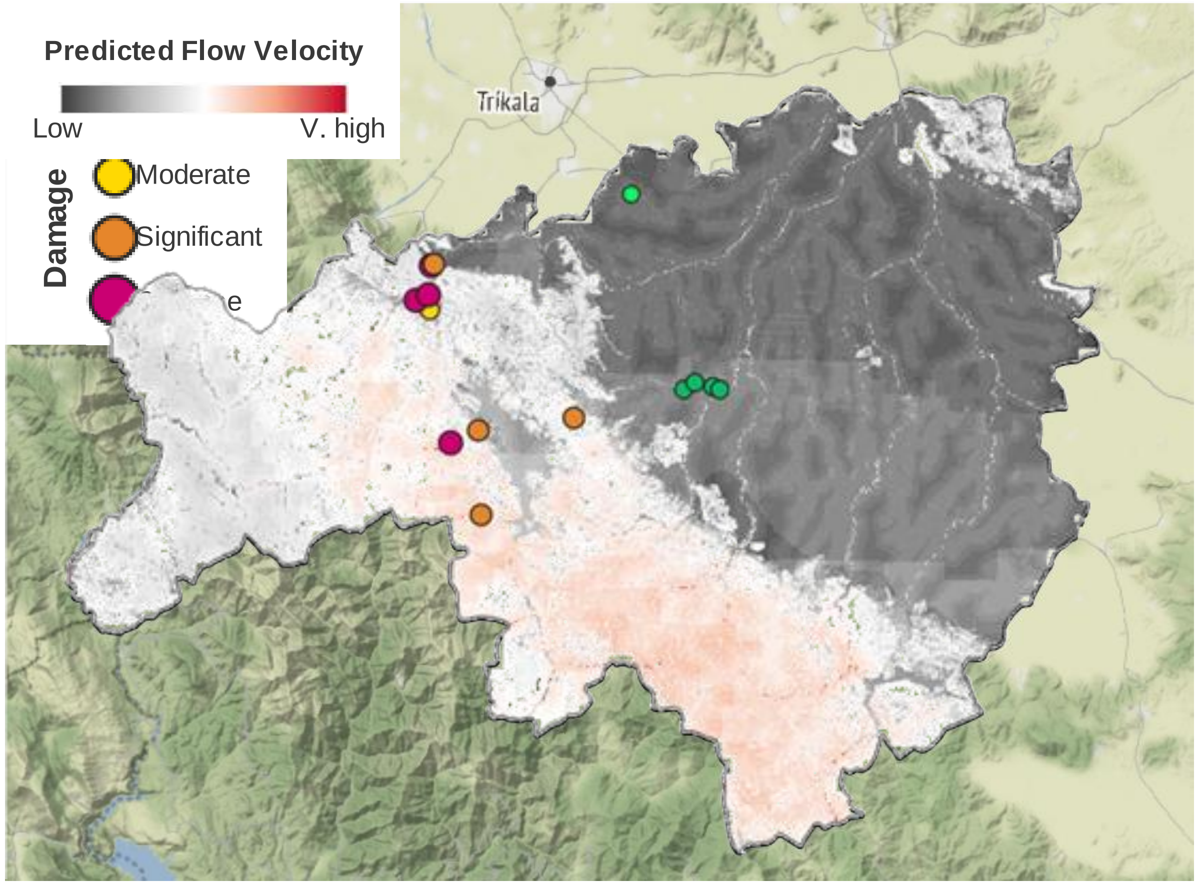


LESSON 1

Flood depth alone is not an adequate **metric of flood hazard impact on bridges**

GRID ENGINEERS

Inspection data for 16 structures

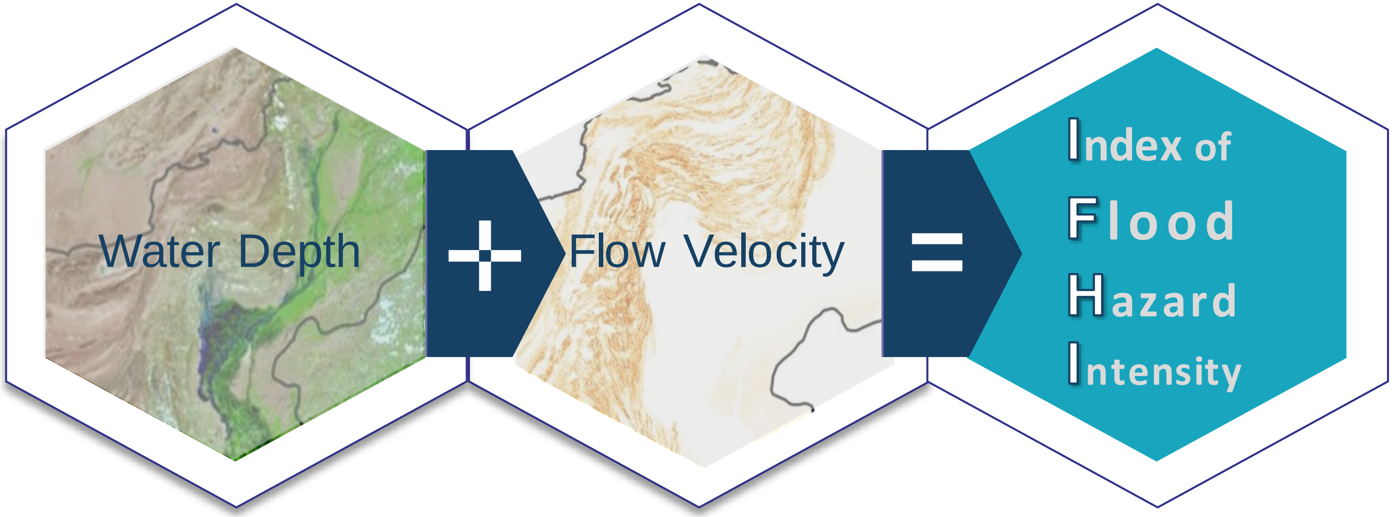


- ✓ 5/16 bridges showed zero to minimal damage — All are in the flat fields of the Thessaly Plain (East).
- ✓ 10/16 bridges showed from severe damage to ultimate collapse — All are in the mountainous region (West).

Damage correlation to ground slope pointed to **the key role of flow velocity**

LESSON 1

Novel guidelines for bridge-specific flood hazard assessment



- ✓ One indicator integrating the effect of hydraulic impacts on bridge structures.

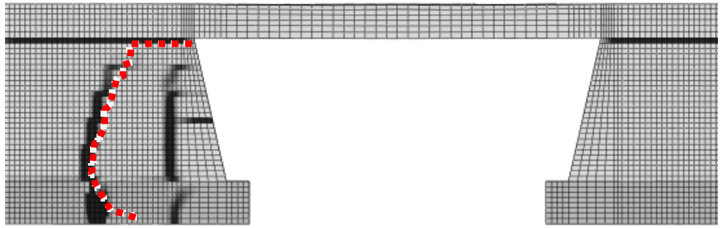
LESSON 2

Flow blockage in single-span bridges

Numerical Investigation: Back-analysis and parametric investigation

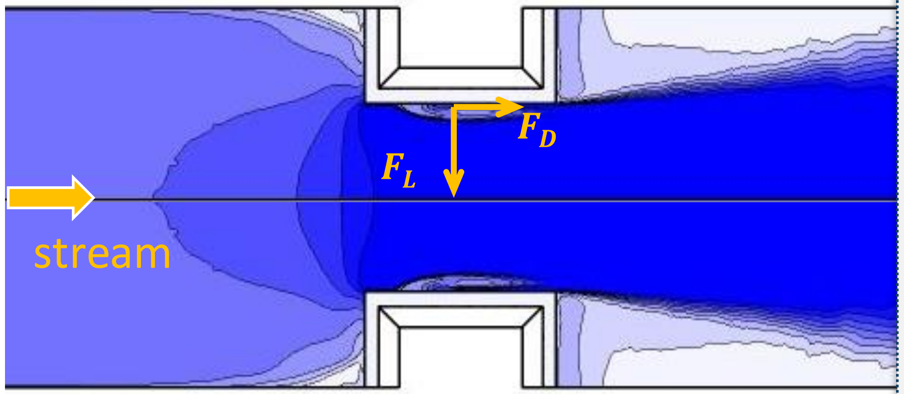
Side view

3D point-cloud



3D Finite Element model

Side view



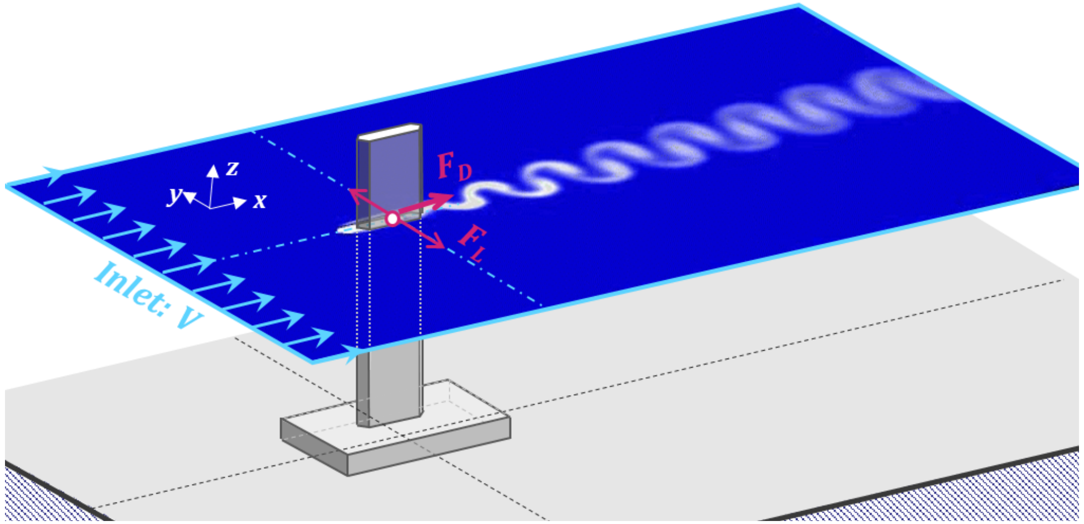
3D CFD Simulation

- ✓ **Hydrodynamic forces** develop because the rigid structure acts as an obstacle causing contraction of the flow leading to a local increase of stream velocity.
- ✓ Their magnitude can be large enough to **cause collapse of the structure**
- ✓ It is a function of geometry:

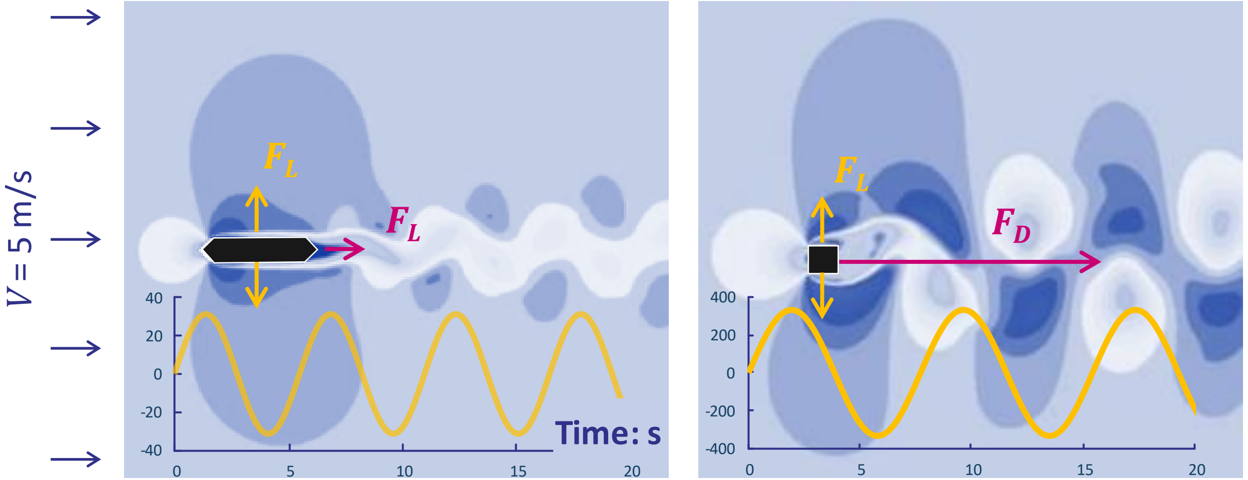
$$Blockage\ Ratio = \frac{Support\ (wet)\ width}{Channel\ length}$$

LESSON 3

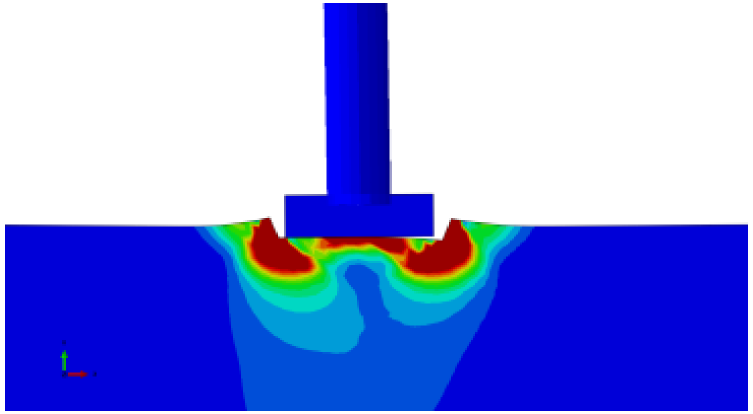
Geometric blockage similarly affects the response of **mid-stream piers**



Shape effects



Foundation displacements



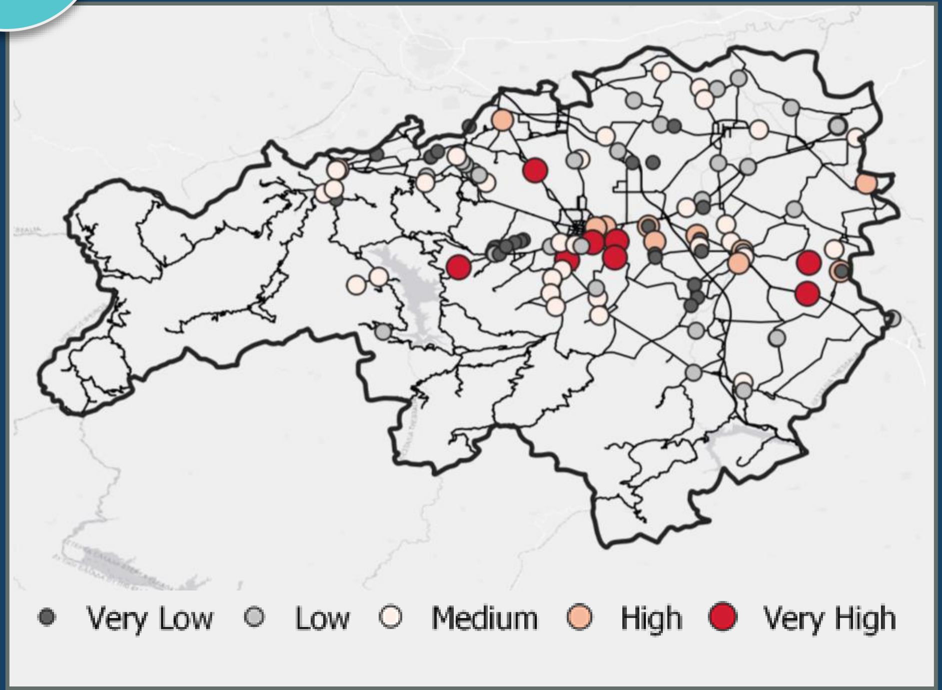
- Dynamic foundation **sinking**
- After a few hours of flooding, sinking **settlements can reach the order of meters.**

4

New methodology

FLOOD RISK ASSESSMENT OF ROAD INFRASTRUCTURE

R Risk of flood induced bridge failures in a transport network



H Comprehensive, bridge-specific analysis of Hazard

V Rapid, operationally feasible assessment of Vulnerability

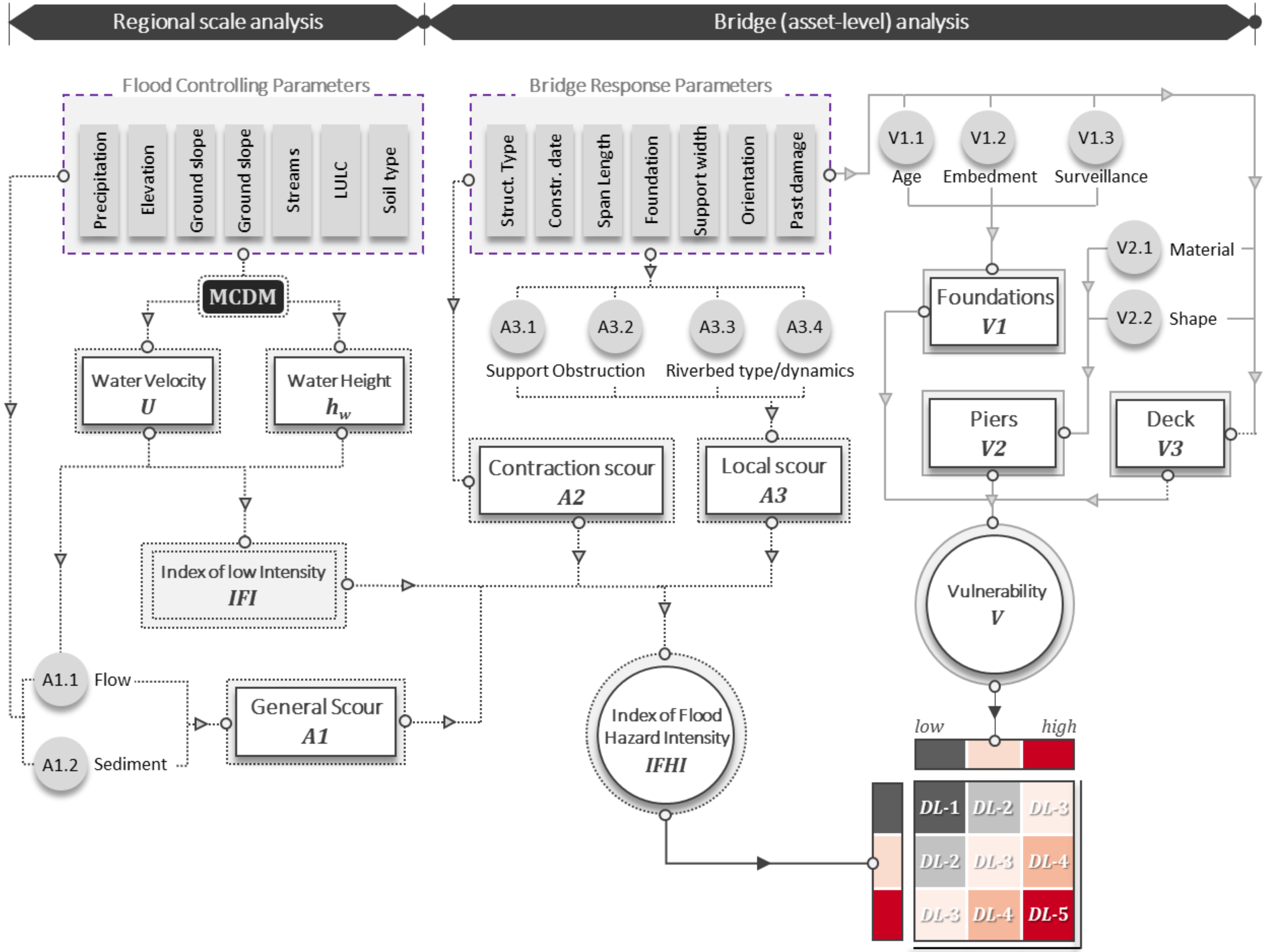
D Realistic prediction of bridge asset damage

Methodological framework

Incorporates key parameters:

- ✓ Flow velocity
- ✓ Geometric flow blockage
- ✓ Pier – flow interaction
- ✓ Scour susceptibility

Loli M., Kefalas G., Dafis S., Mitoulis S.A., Schmidt F. (2022). Bridge-specific flood risk assessment of transport networks using GIS and remotely sensed data. Science of the Total Environment.



Validation

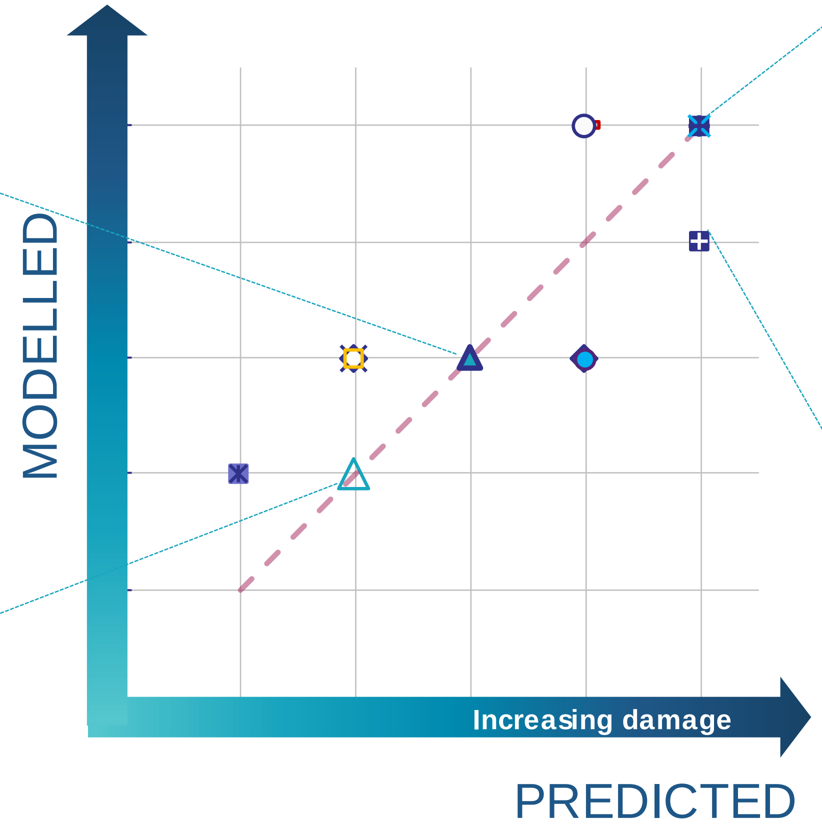
GRID ENGINEERS

A record of 16 bridge inspections after severe flooding

- ✓Good agreement with field observations
- ✓Consistent location of highly susceptible assets
- ✓Very advantageous reliability compared to previous methods.


Severe - Repairable


Minimal



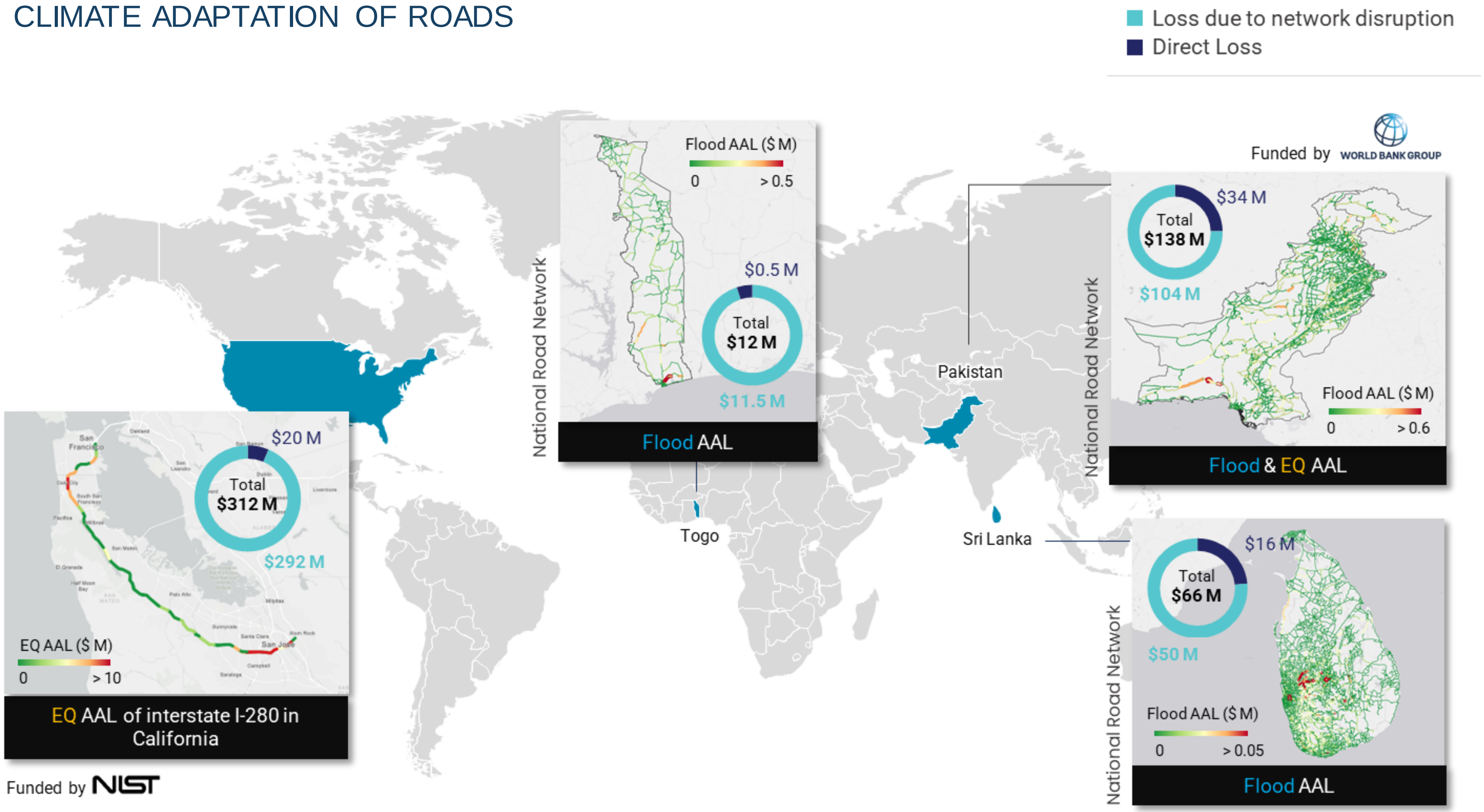

Collapse


Severe - Nonrepairable

5

Planning tool

ANALYSIS OF INVESTMENTS IN RISK MITIGATION & CLIMATE ADAPTATION OF ROADS



KEY FEATURES

1 Automatic network generation

- ✓Fast acquisition and cleaning
- ✓Rational link & asset classification allowing technical analysis

2 Dynamic traffic analysis

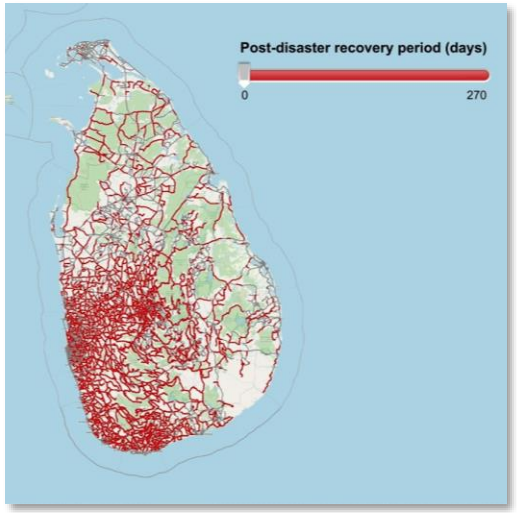
- ✓Daily Car/Truck traffic loads under normal and disrupted conditions

3 Probabilistic hazard mapping

- ✓High-resolution flood depth predictions, across a wide range of return periods
- ✓Encompassing fluvial, pluvial, and coastal flooding

4 Comprehensive prediction of impact

- ✓Damage models specific to infrastructure class and type.
- ✓Recovery time and operational disruption

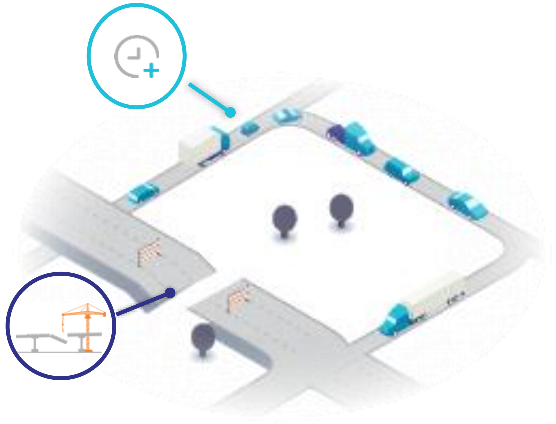


5 Design of upgrades

- ✓Identification of high priority links
- ✓Following international best practices.

6 Direct & indirect loss assessment

- ✓Country- and asset-specific cost functions
- ✓Indirect costs: increased travel time, vehicle operation & inventory losses
- ✓Average Annual Loss (AAL)

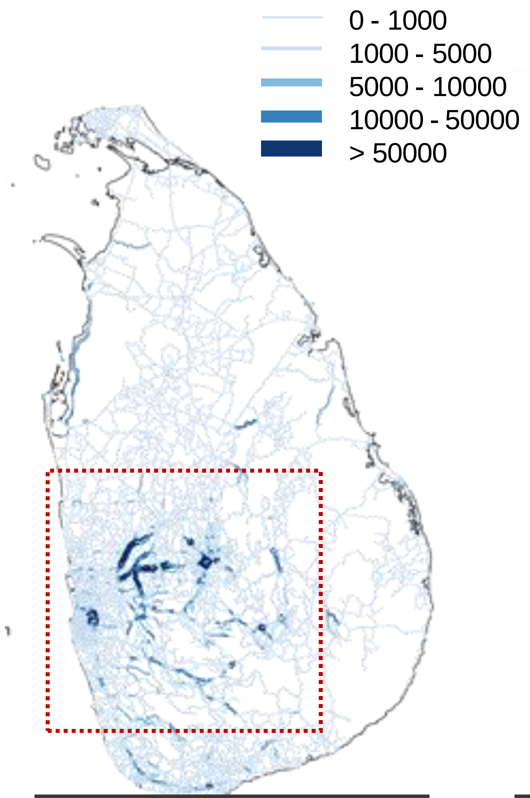


7 Economic appraisal and decision

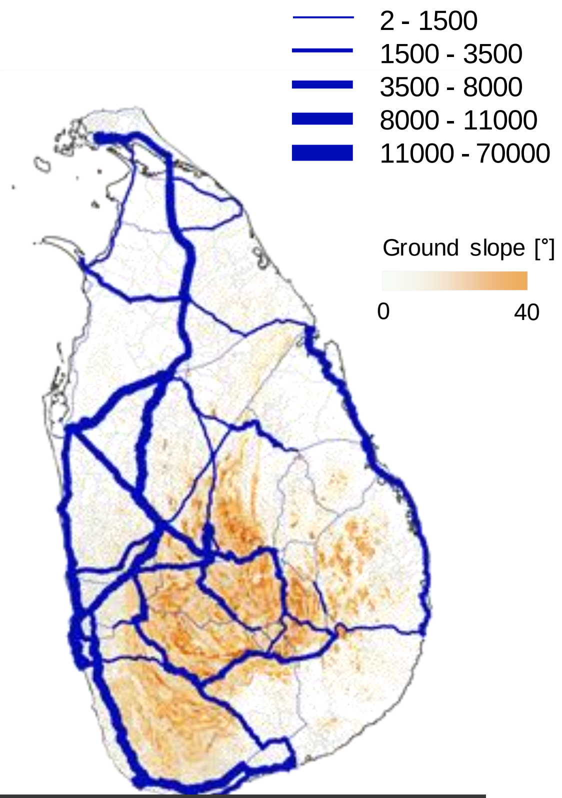
- ✓Cost-Benefit analysis of investment strategies.
- ✓Assessment based on economic metrics: *Cost–Benefit Ratio, Net Present Value, Return on Investment*

Country-scale applications in South Asia

SRI LANKA



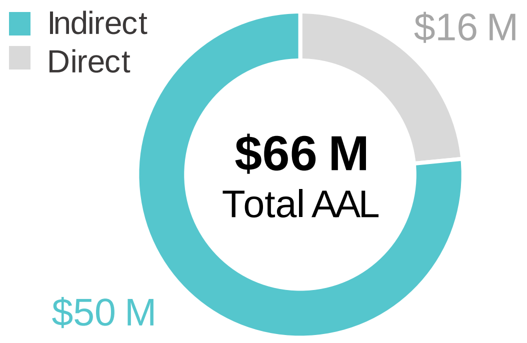
Average Annual Loss ($)



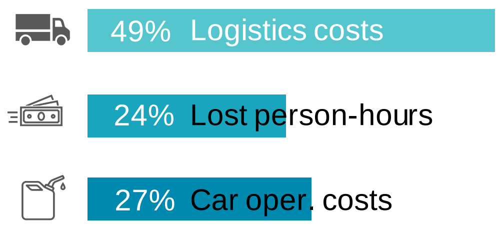
Average Daily Traffic (veh/day)

Losses concentrated in the heavily traveled links of central districts, where the hilly terrain causes high flood velocities and magnifies physical damage.

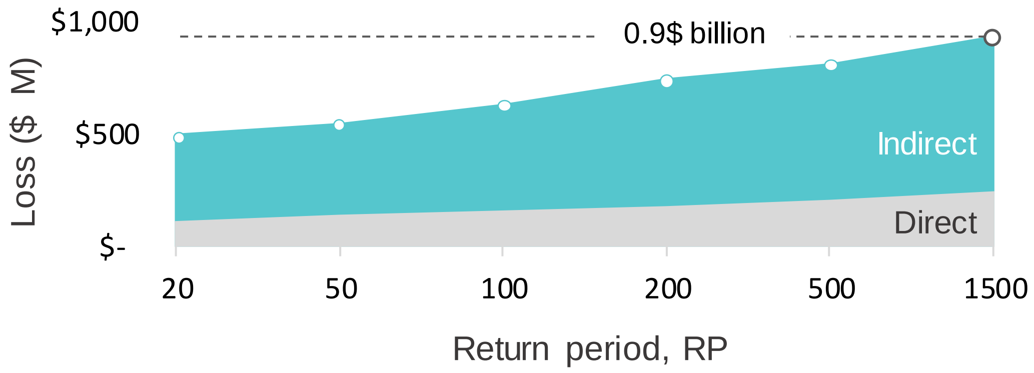
Country-wide **annual average economic flood loss**



$50 m indirect costs, of which:



- **Disruptions due to a likely severe (1500-year) flood event** can cause up to $0.9 billion in direct and indirect losses



Thank you !

Do not hesitate to get in contact

m.loli@grid-engineers.com

Evaluating Bridge Hit Impacts and Mitigation Strategies

Zizhao He | 7/16/2024

Webinar Sponsor: AMR20, AMR10, AT060

Part 1. DMV Crash Data

Allocating CLEAR Bridge Strike Events to Bridge Locations

Crash Location and Engineering Analysis Repository (CLEAR) System

- NYSDOT Safety management system
- Maintained by Office of Traffic Safety and Mobility
- Available Information:
    - Crash Details
    - Crash Locations
    - Road Characteristics
    - Apparent Contributing Factors of the Crashes
    - Allows to access NYSDOT crash reports

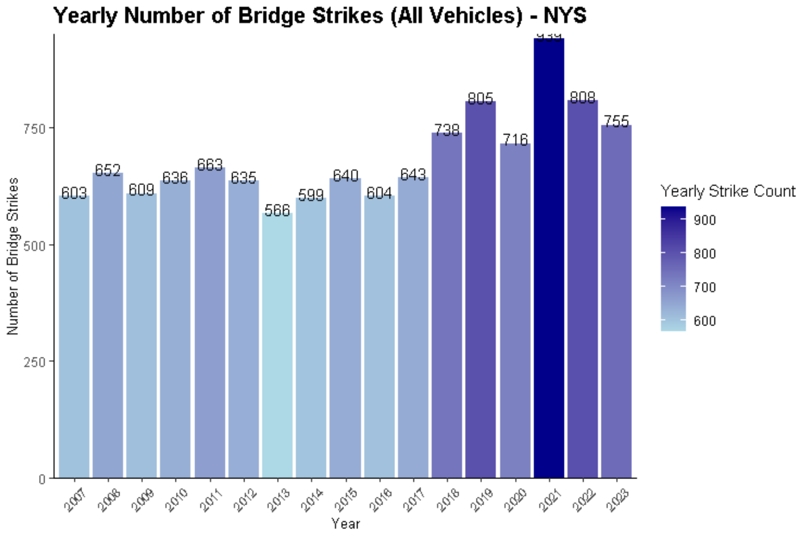
Data Used for Analysis

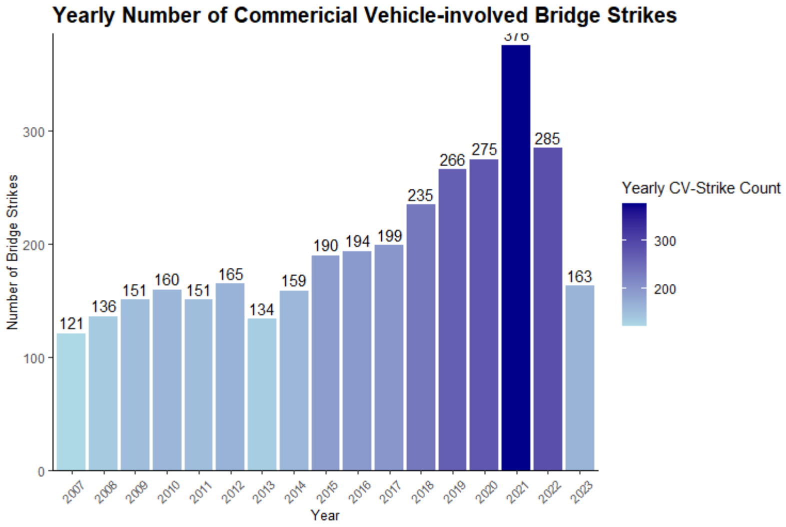
CLEAR data

- Crash type: Collision with Bridge Structure
- Date range: 1/1/2007 to 12/31/2023
- Total number of bridge hits (all vehicles): 11,461
- 3,321 commercial vehicle-involved hits

Other data

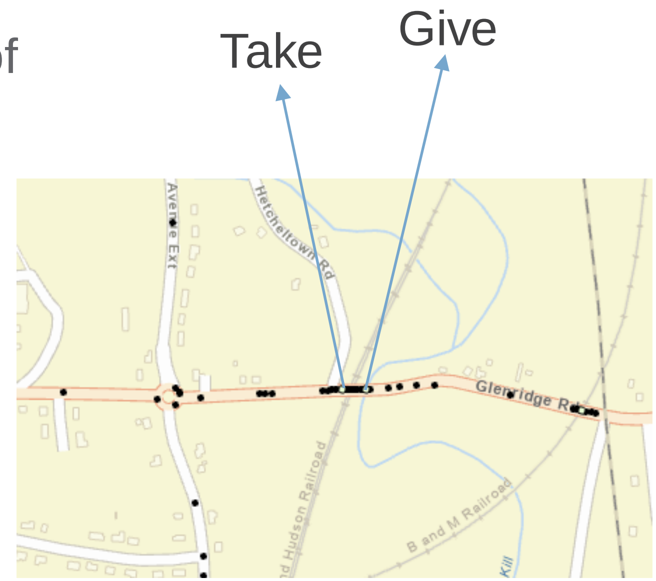
- NYSDOT road network
- NY state bridge structures
- NYSDOT water body data





Bridge Strike Allocation to the Correct Bridge

- Step 1. Relocated each bridge hit incident to closest road segment.
- Step 2. Got all possible associations between pairs of bridge strikes and bridges.
- Step 3. Selected the closest bridge for each strike.
- Step 4. For the bridges on the same routes in 100 meters, re-allocated bridge hit events based on the criteria (described in the next slide). 491 pairs of bridges have the re-allocation relationship.
- Step 5. Looked for the unique beginning of each chain and drew all chains out.
- Step 6. Based on the chain relationship, re-allocated the bridge hit events.



Pairs

A → B
B → C
D → C

Chains

A → B → C
D → C

Re-distribution Criteria

- The bridge above water body should have their associated bridge hit events re-distributed to the bridge not above water body.

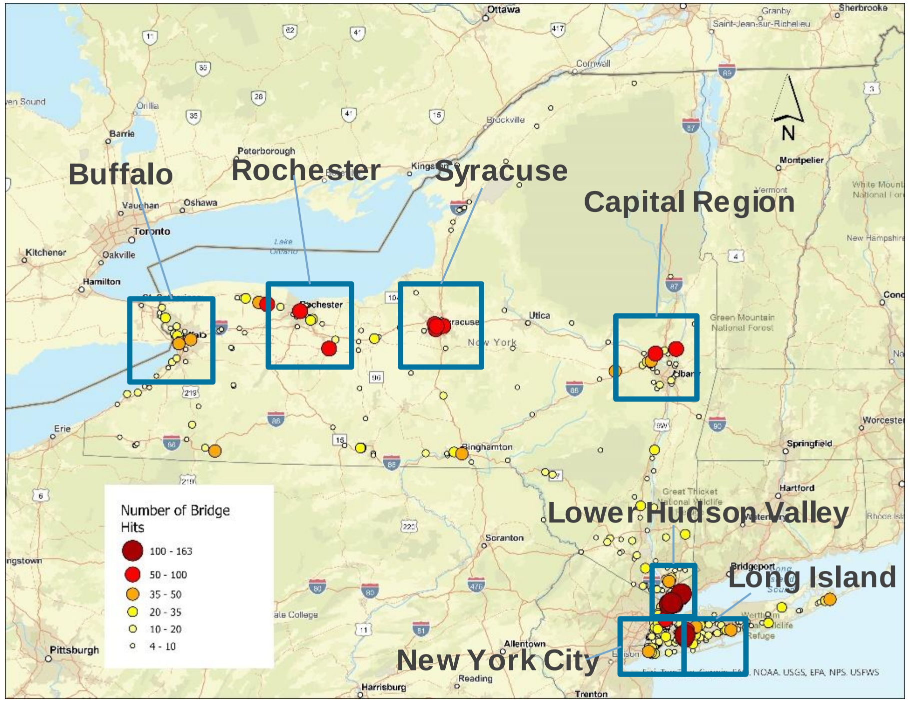
If both bridges are above or not above water:

- The bridge whose minimum vertical clearance is unknown or equal to 0 should have their associated bridge hit events re-distributed to the bridge whose clearance is larger than 0.

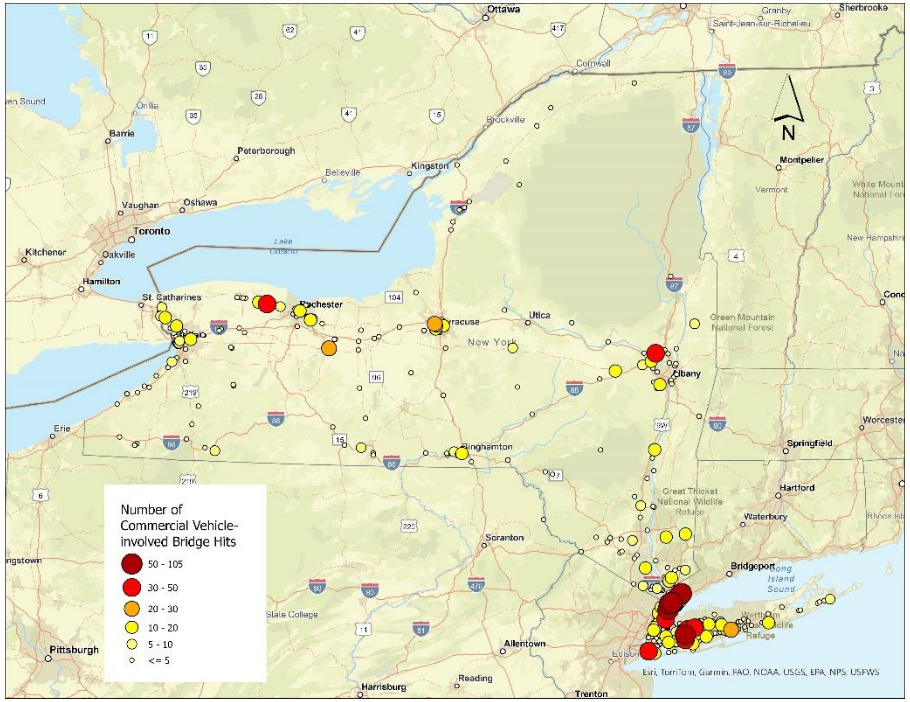
Source: Google street view

- When the minimum vertical clearances of both bridges are unknown/equal to 0/larger than 0, no re-distribution happens.
- When the minimum vertical clearance of one bridge is unknown but equal to 0 for the other one, no re-distribution happens.

Results



Number of Bridge Hits (All Vehicles)



Number of Commercial Vehicle Involved Bridge Hits

- 6054 out of 11461 (53%) all-type bridge hits @ low bridges (< 14 feet)
- 2359 out of 3321 (71%) Commercial Vehicle-involved bridge hits @ low bridges (< 14 feet)
- Top 2 bridges with most strikes are both on Hutchinson River Parkway (built before interstate standards) in Lower Hudson Valley area

Part 2. Bridge Hit Impacts

Before/After Comparison Using
Speed/Travel Time/Emissions Data

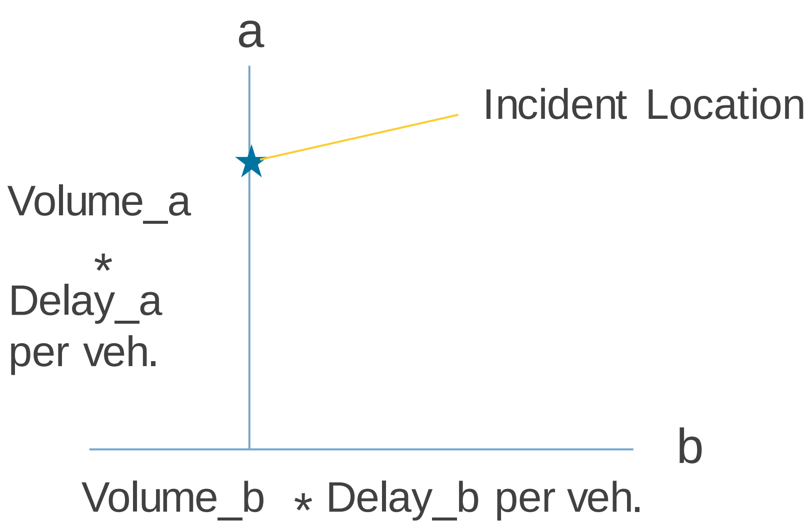
National Performance Management Research Data

- Data Provider: INRIX
- Speed, Travel Time, Hours of Delay, Emissions, etc. from Jan 1, 2016 – May 21, 2024
- Temporal Resolution: 5 minutes
- Spatial Resolution: Traffic Message Channel (TMC) segment
- Geographical Coverage: National Highway System

Analyzing Impacts of Bridge Hits with Historic Speed Data

- Associate specific incidents to changes in observed speeds (from INRIX/NPMRDS)
- Identify network impacts on speed over incident duration of bridge hits
- Explore cost calculation methods for network impacts

- Baseline calculator for traffic delay = Sum of Unit-Time [Traffic Volume* Observed Delay per Vehicle] on Impacted Segments



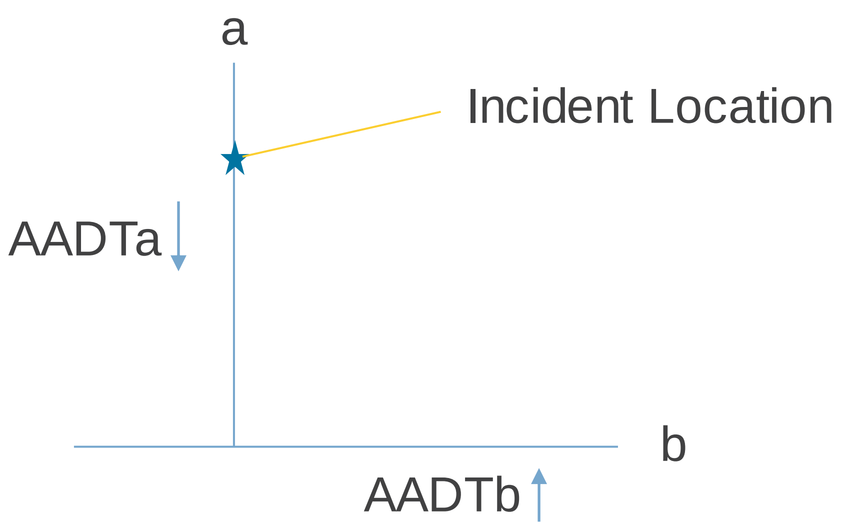
Economic Evaluation of Bridge Strike Impacts

- COCA2 Model by NYSDOT (~$35.85 per hour of delay)
  - Total Cost per Hour of Delay = (AVO*Sa)*(1-Pt/100)+(St)*(Pt)+(GFD)
    - AVO = Average Passenger Vehicle Occupancy
    - Sa = Value of Time for Persons Traveling
    - Pt = Percent of Heavy Trucks
    - St = Value of Heavy Truck Hourly Operations
    - GFD = Value of Fuel per hour of delay
- Damage Costs of Carbon Dioxide Emissions
  - $228 per Metric Ton recommended by USDOT

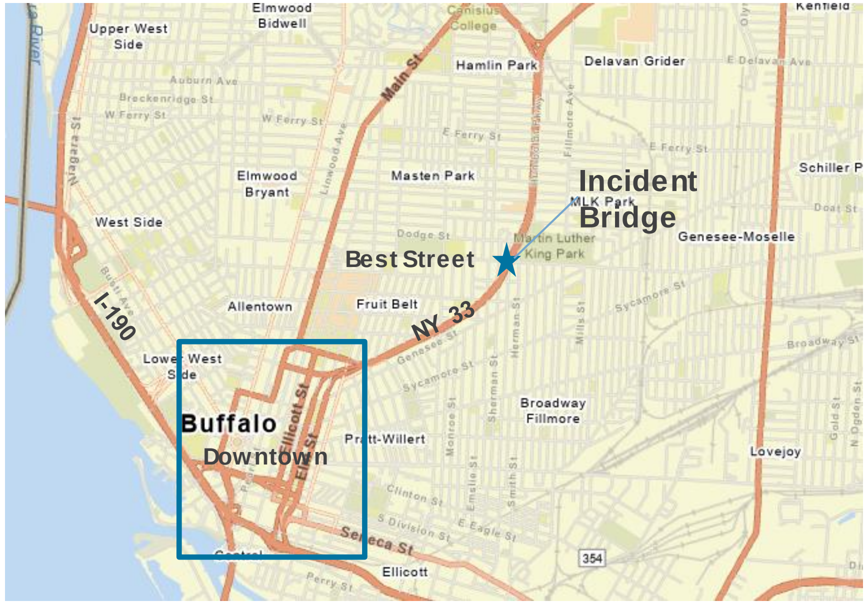
Limitations in Methods of Economic Evaluation

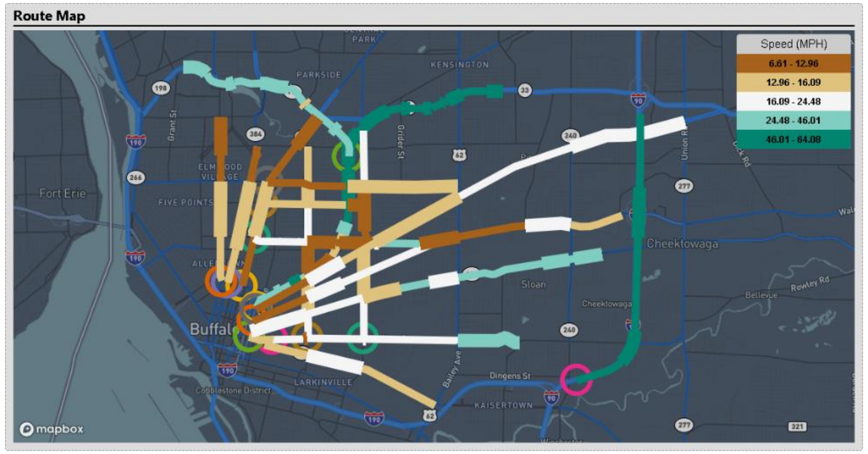
Costs not including in the estimates:

- Delay, mileage, & fuel costs of diverted traffic from main route to alternative routes
- Damage Costs
  - Vehicles
  - Product
  - Infrastructure
- Response Costs
  - Tow Trucks
  - Emergency Service Vehicles
  - Law Enforcement e.g. Police
  - Bridge Inspection
  - Road Operations e.g. Spill Remediation



Crash Location: NY-33 E at Best Street

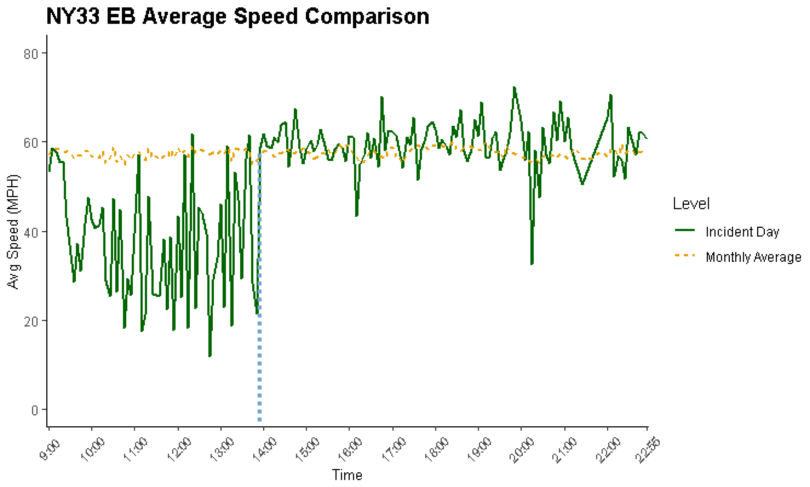


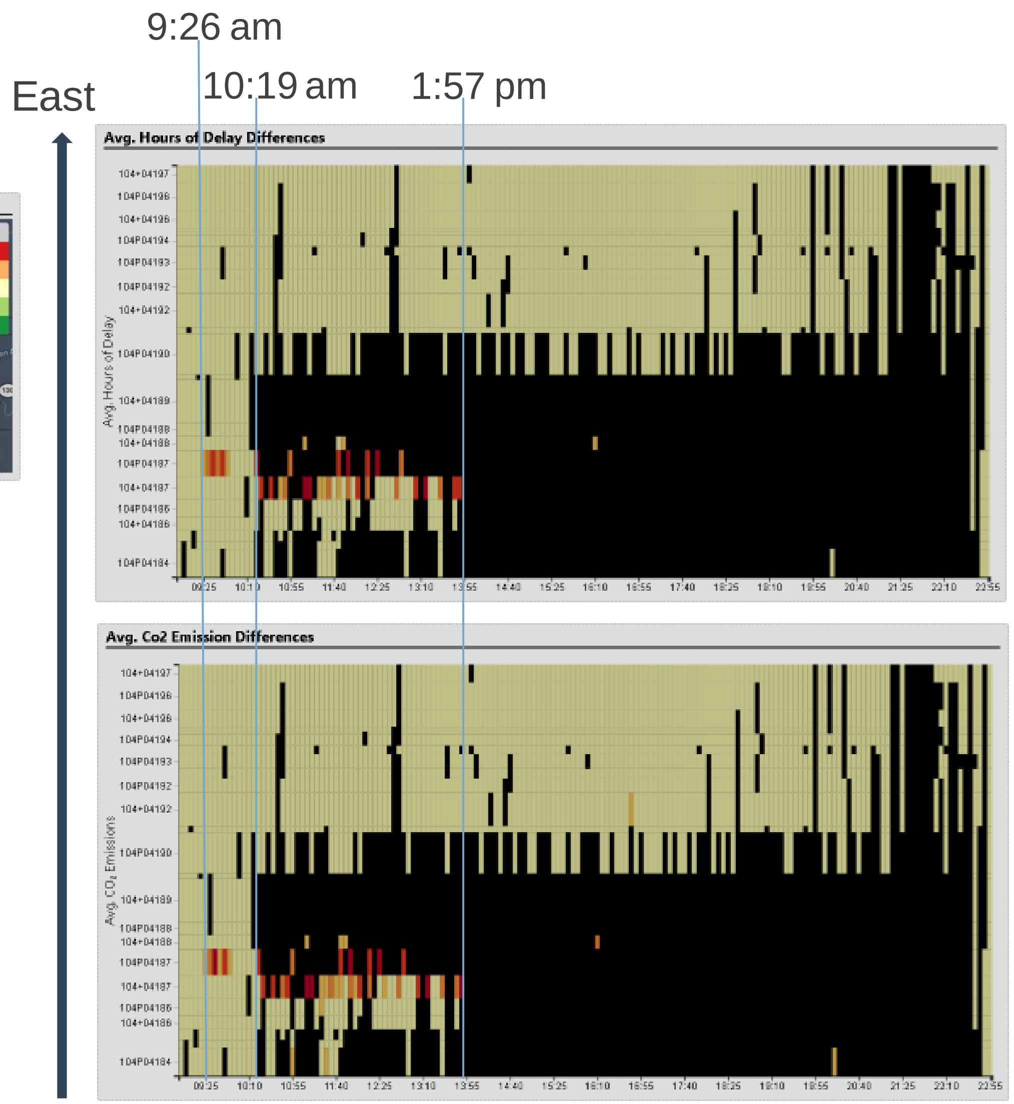


Incident and Operations Info:

- Incident Date: Mar 1st, 2023
- Occur Time: 9:26 am
- All roadways shut down at Best Street: 10:19 am
- Route 33 EB (Downtown to Best Street part) closed: 1:57 pm
- All roadways re-opened: 10:46 pm
- Incident Impact Duration: ~13.5 hours

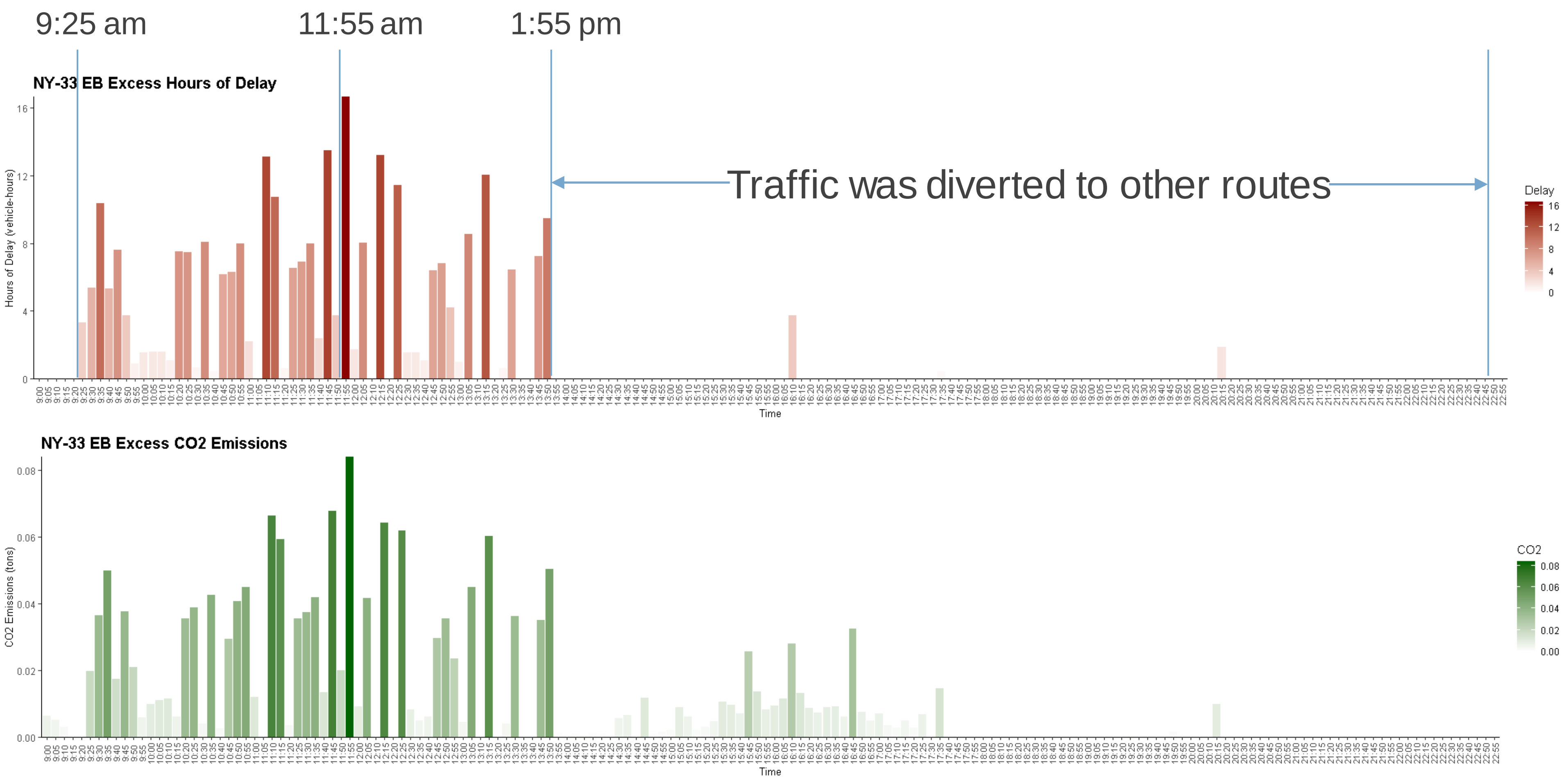
NY 33 EB





- Estimated by AADT for the closed segments, on incident day, about 33,284 vehicles were diverted.

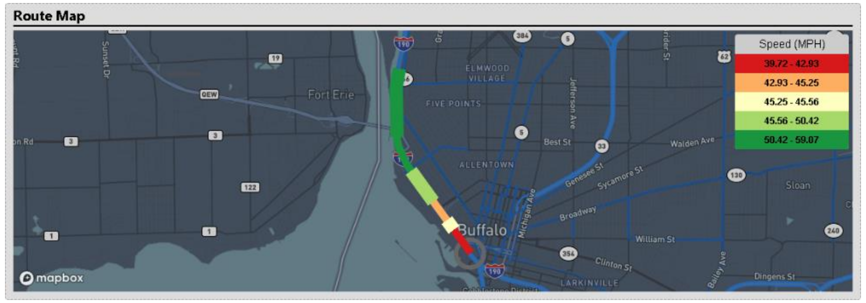
NY 33 EB

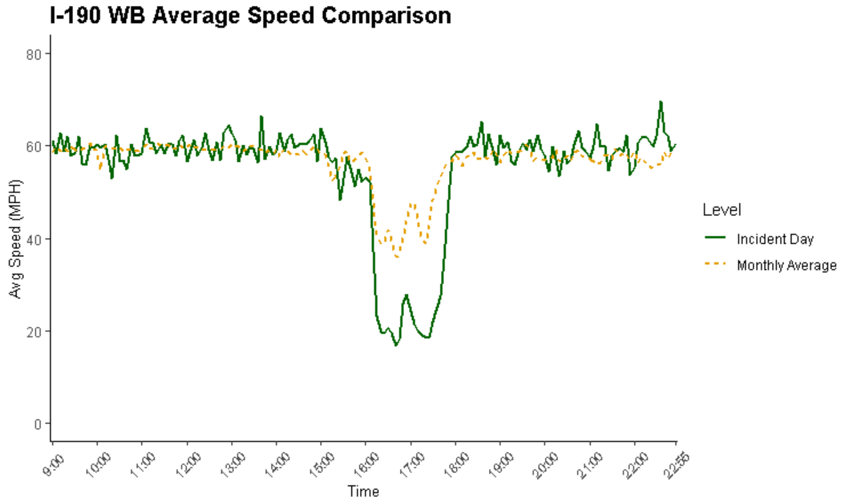


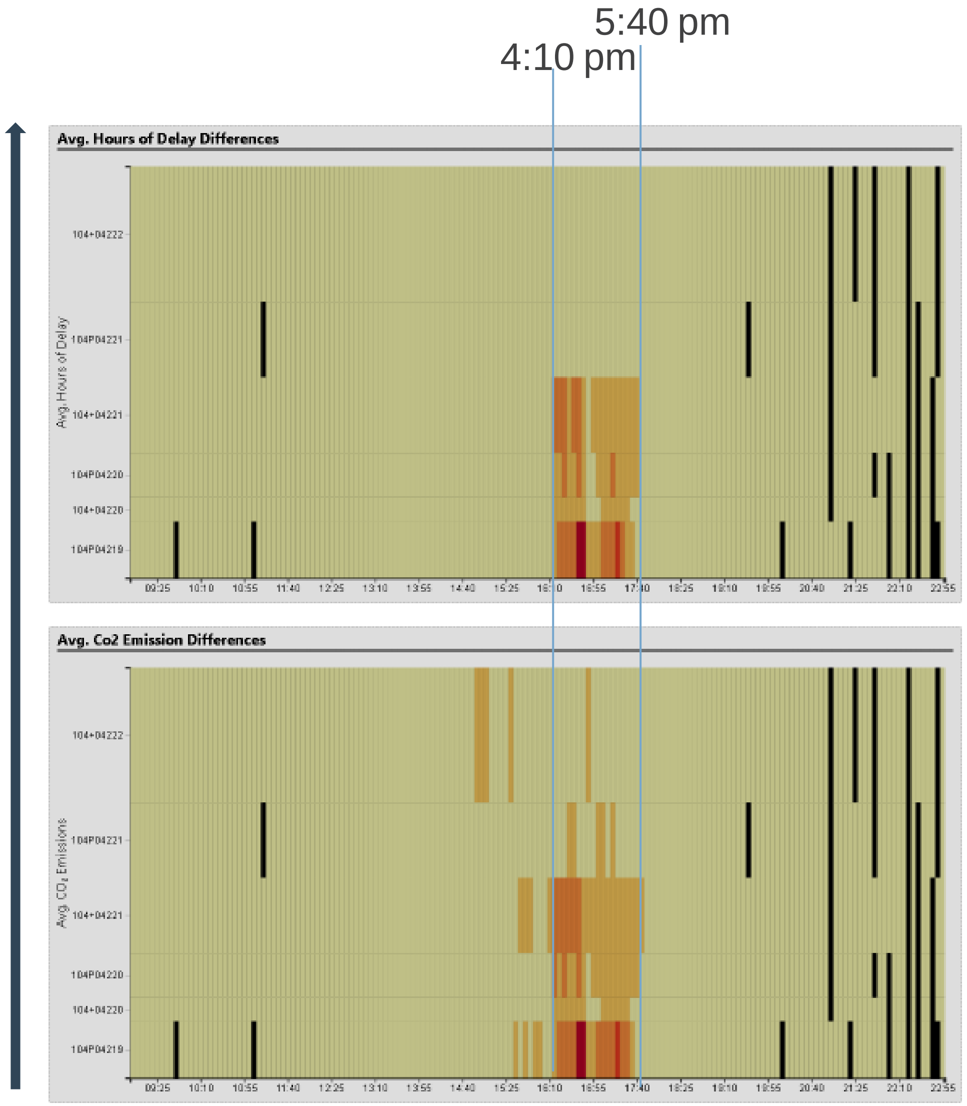
- Excess Hours of Delay: 278.4 vehicle-hours = $9,980.6
- Excess CO2 Emission: 1.78 tons = $405.8

- Total cost of travel time delay & carbon emissions is $10,386.4

I-190 WB


Route Map
Speed (MPH)
39.72 - 42.93
42.93 - 45.25
45.25 - 45.56
45.56 - 50.42
50.42 - 59.07
Fort Erie
Buffalo
mapbox

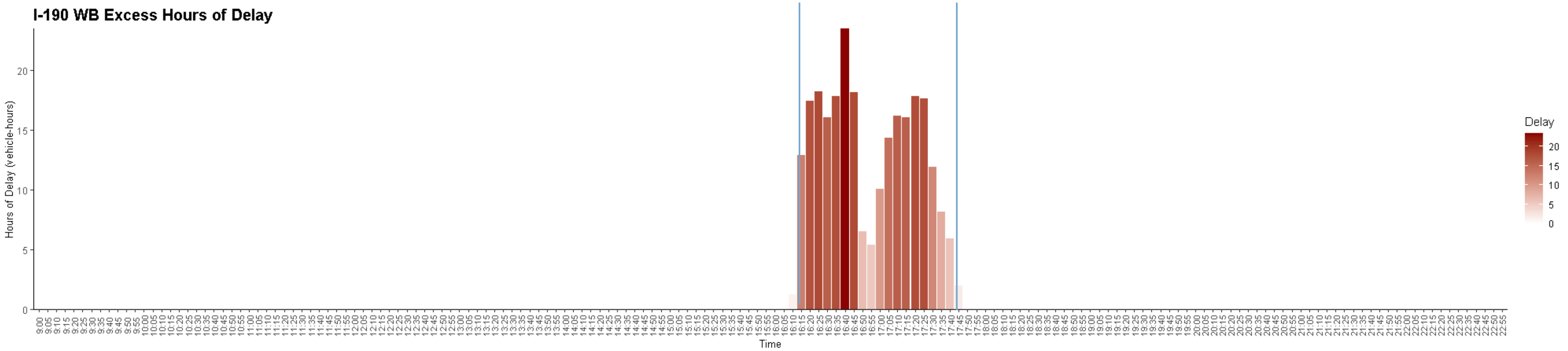

I-190 WB Average Speed Comparison
Avg Speed (MPH)
Time
Level
Incident Day
Monthly Average

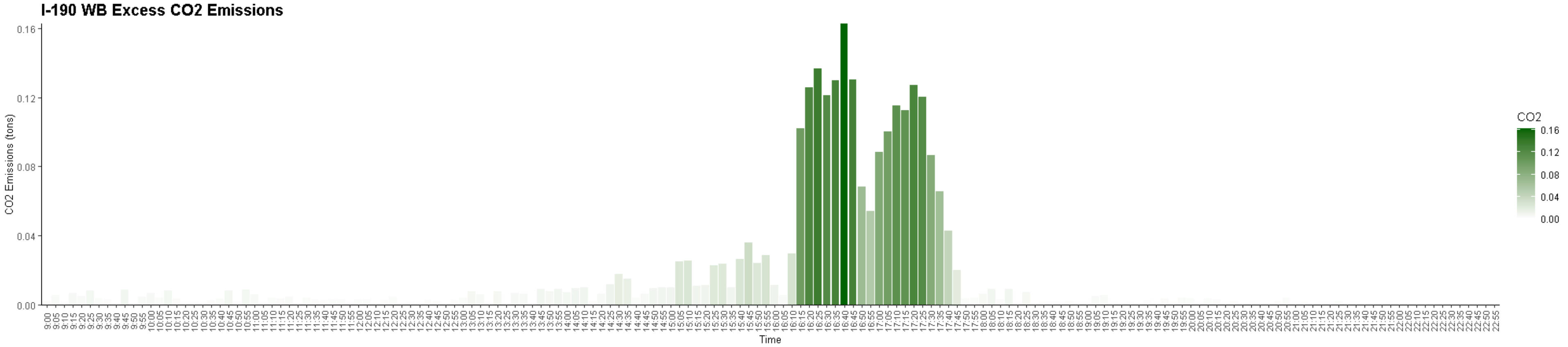

5:40 pm
4:10 pm
Avg. Hours of Delay Differences
Avg. Hours of Delay
Avg. Co2 Emission Differences
Avg. CO2 Emissions

I-190 WB

Diverted Traffic

4:10 pm 5:40 pm



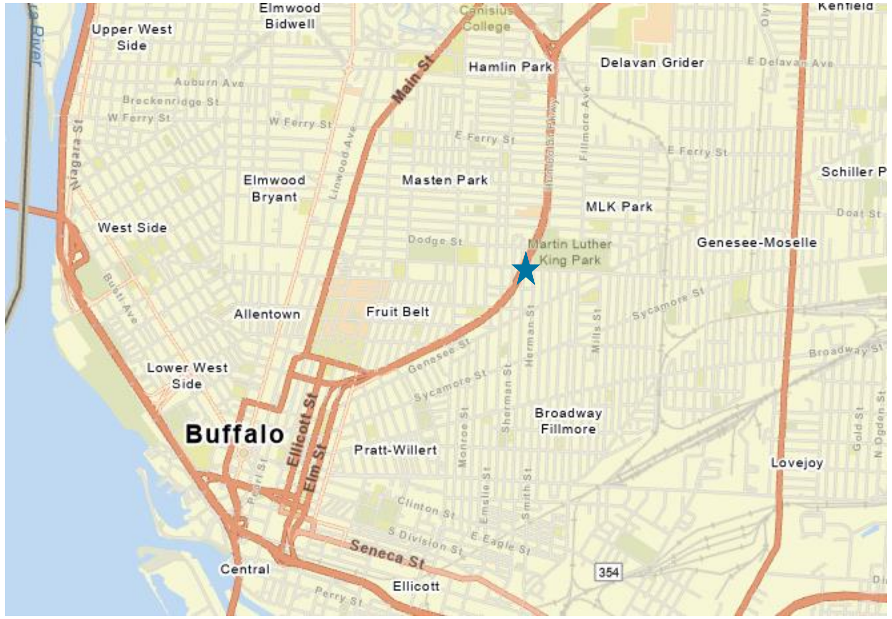


- Excess Car Delay: 257.1 vehicle-hours = $9,217
- Excess CO2 Emission: 2.7 tons = $615.6

- Total cost of travel time delay & carbon emissions is $9,832.6

Department of Transportation

Incident Impacts



Economic Evaluation Results:

- Excess Hours of Delay: 1,904.6 vehicle-hours = $68,279.9
- Excess CO2 Emission: 12.4 tons = $2,827.2

- Total cost of travel time delay & carbon emissions is $71,107.1

Part 3. Application of Mitigation Methods

Before/After Number of Bridge Hits Comparison

Glenridge Road Bridge Hits Mitigation Project

- Minimum vertical clearance: 11’-11’’
- Completion time: 10/18/2023

Aug 2021 Source: Google street view

Aug 2022 Source: Google street view

Before-After Comparison (preliminary results)

- Comparison period – before: 8/17/2023 – 10/17/2023
  - Number of bridge hits (commercial-vehicle involved): 2
- Comparison period – after: 10/19/2023 – 12/19/2023
  - Number of bridge hits (commercial-vehicle involved): 0
- 30 commercial-vehicle involved bridge hits in last 5 years (2019 – 2023)

Future Research Needs

- Further improve the allocation methods for CLEAR data
- Improve the methods for economic evaluation of bridge hit impacts
  - Estimate/Capture diversion costs
  - Value non-delay factors
    - Fuel consumption
    - Damages
    - Response
- Design/Define before-after analysis methods for mitigation projects
  - E.g. video analysis/archiving
- Look for the possible bridge hits factors

Thank you for listening!

Impacts, Lessons, and Insights from Recent Roadway Structure Failures

Dan Murray
Senior Vice President

American Transportation Research Institute

ATRI

ATRI is TRUCKING's not-for-profit research organization, whose mission is to provide the data and analysis to improve the industry's safety and productivity

All of ATRI's research is available at no cost on our website:

www.TruckingResearch.org

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GT

J&M Tank Lines est. 1948

ATA American Trucking Associations

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Florida Atlantic University Freight Mobility Research Institute

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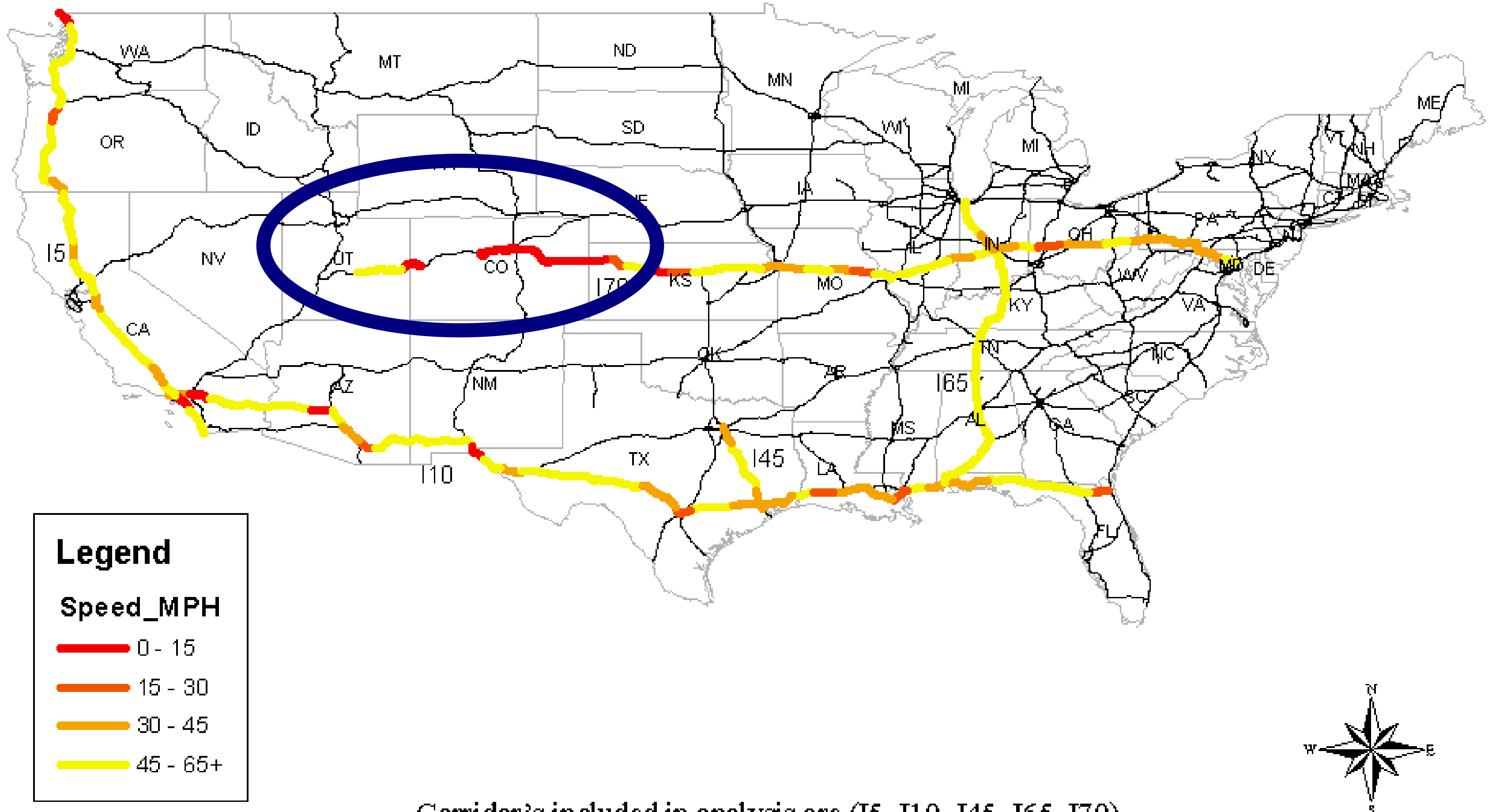
Corridor Data Based on March 19, 2003

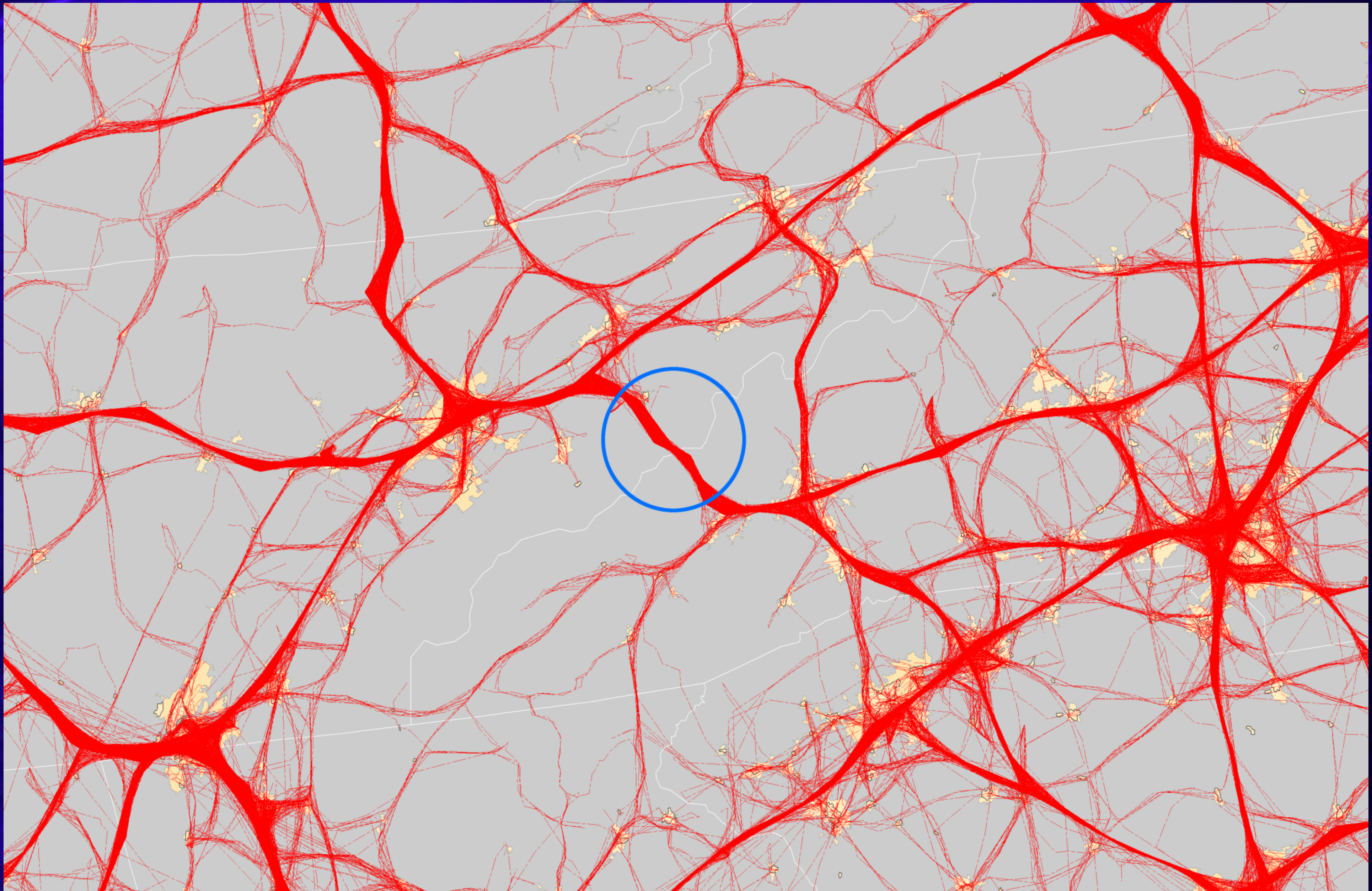
From 12:00pm - 4:00pm PST

Truck Speed Calculation Based on 50-mile increments

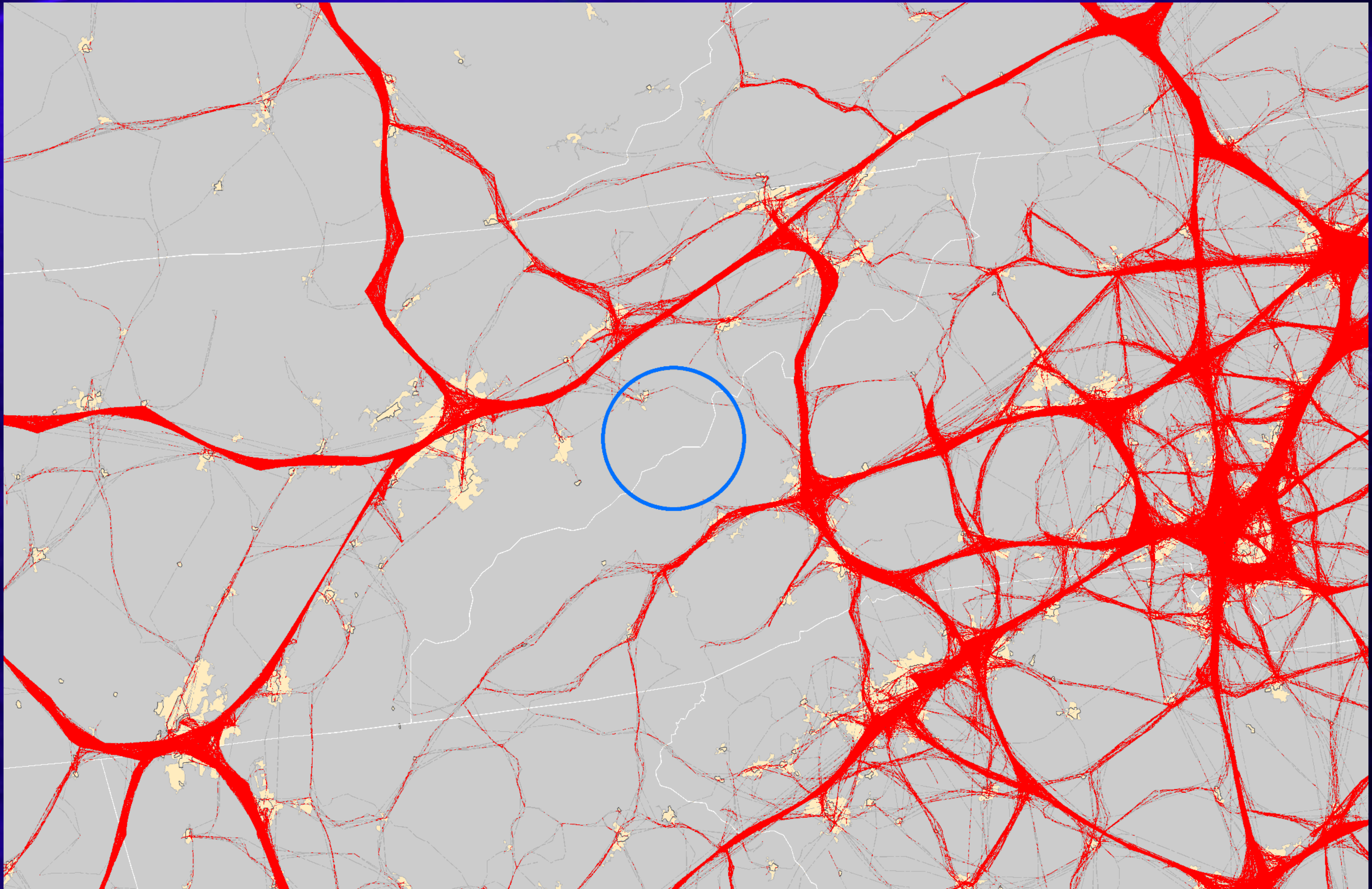


Corridor's included in analysis are (I5, I10, I45, I65, I70)

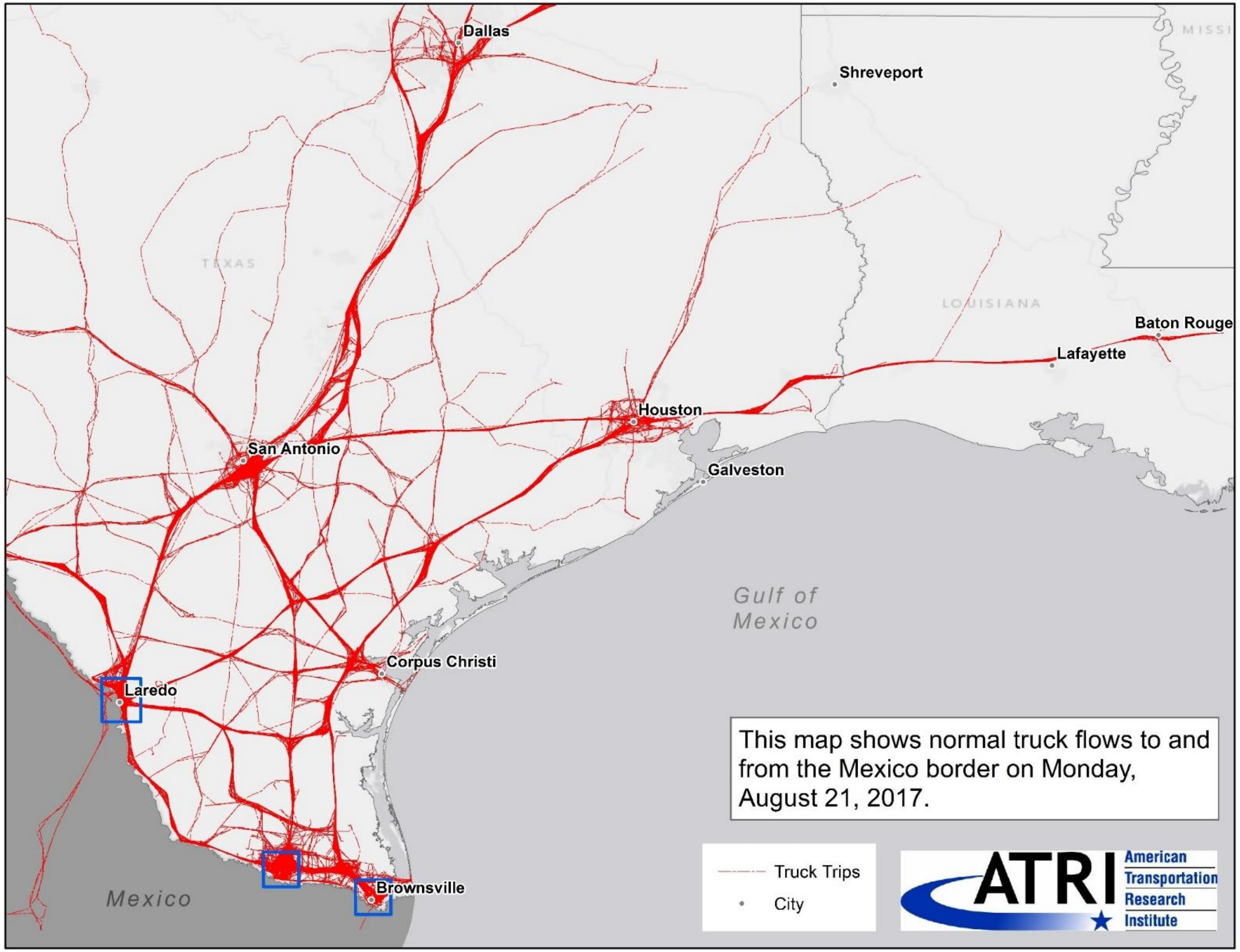
Truck Flow Analysis Before I-40 Rockslide



Truck Flow Analysis After I-40 Rockslide



United States and Mexico Border Crossing Truck Flows: Before, During and After Hurricane Harvey


Dallas
Shreveport
TEXAS
LOUISIANA
Baton Rouge
Lafayette
Houston
San Antonio
Galveston
Gulf of Mexico
Corpus Christi
Laredo
Brownsville
Mexico
This map shows normal truck flows to and from the Mexico border on Monday, August 21, 2017.
Truck Trips
City
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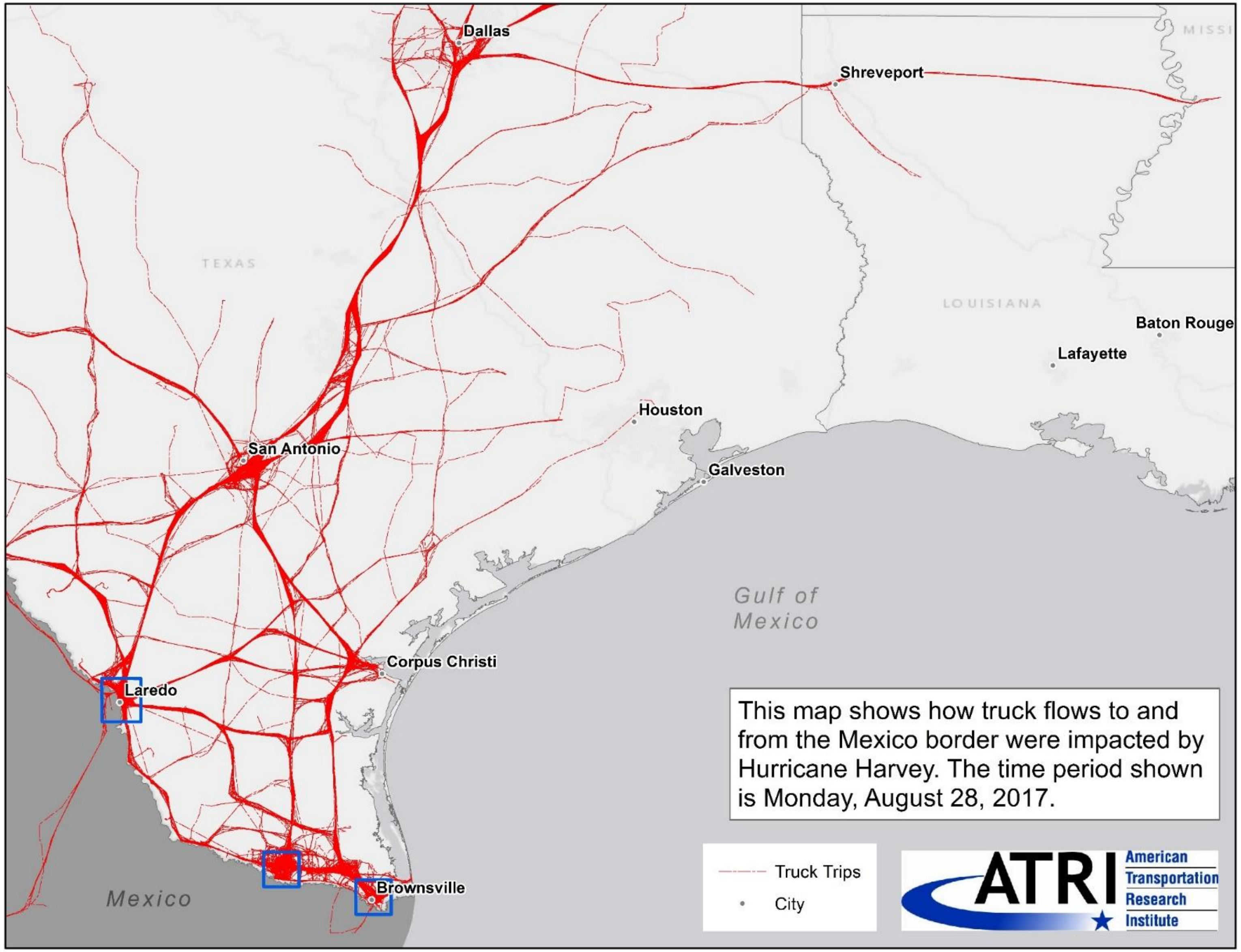
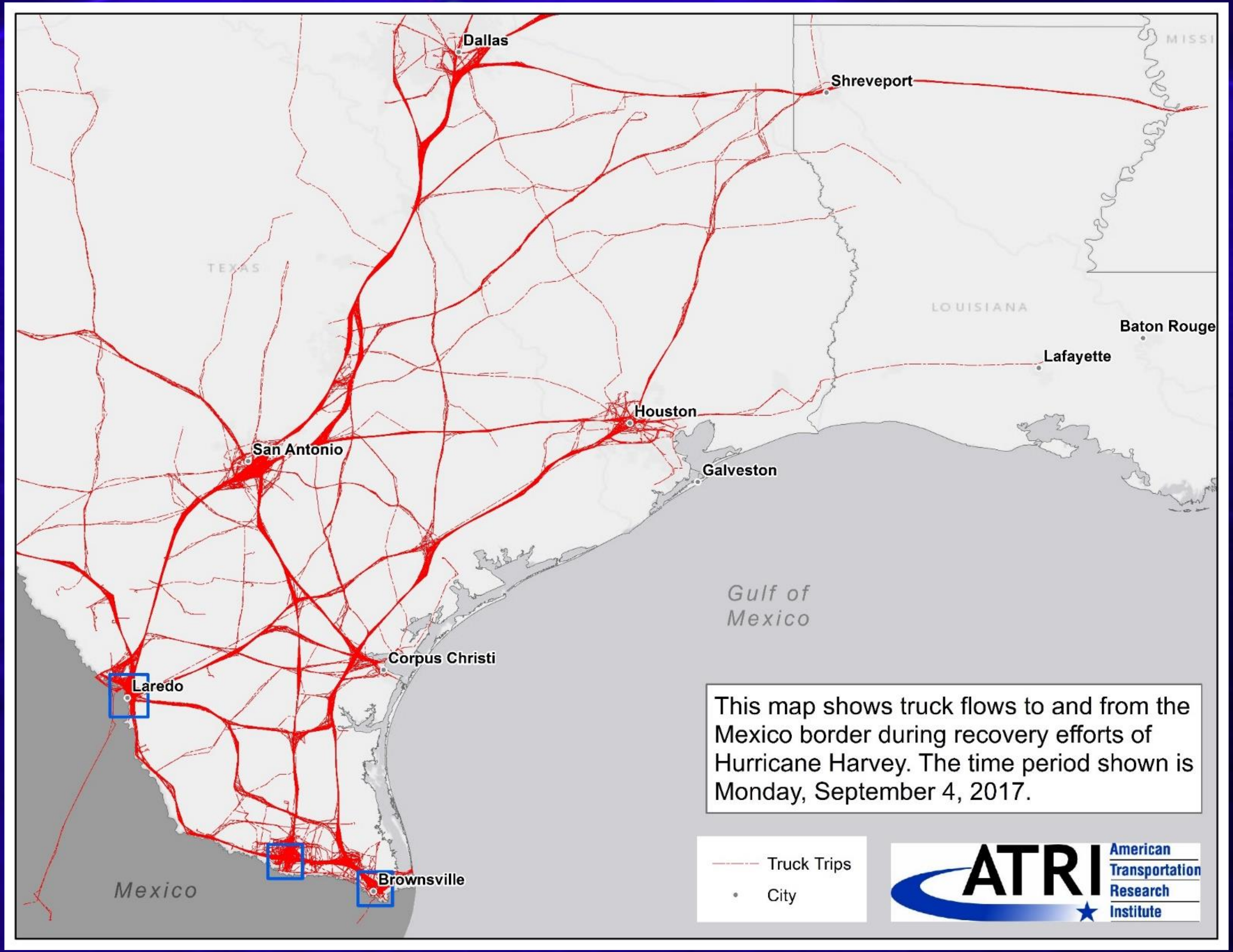


This map shows how truck flows to and from the Mexico border were impacted by Hurricane Harvey. The time period shown is Monday, August 28, 2017.


Dallas
Shreveport
MISSI
TEXAS
LOUISIANA
Baton Rouge
Lafayette
Houston
San Antonio
Galveston
Gulf of
Mexico
Corpus Christi
Laredo
Brownsville
Mexico
This map shows truck flows to and from the Mexico border during recovery efforts of Hurricane Harvey. The time period shown is Monday, September 4, 2017.
Truck Trips
City
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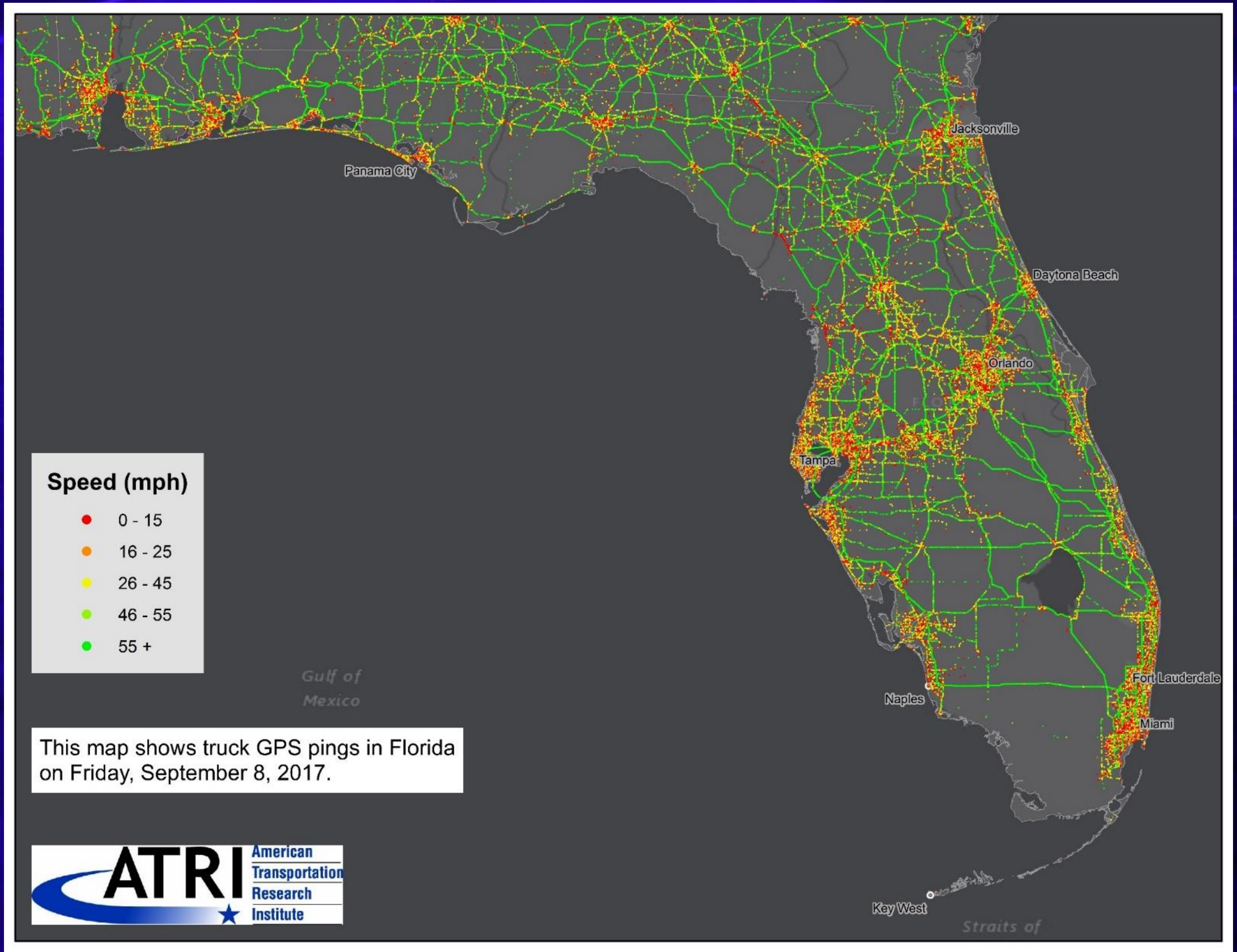
Institute

Florida Truck GPS Pings:
Before, During and After Hurricane Irma



Jacksonville
Panama City
Daytona Beach
Orlando
Tampa
Speed (mph)
0 - 15
16 - 25
26 - 45
46 - 55
55 +
Gulf of
Mexico
Fort Lauderdale
Naples
Miami
This map shows truck GPS pings in Florida on Friday, September 8, 2017.
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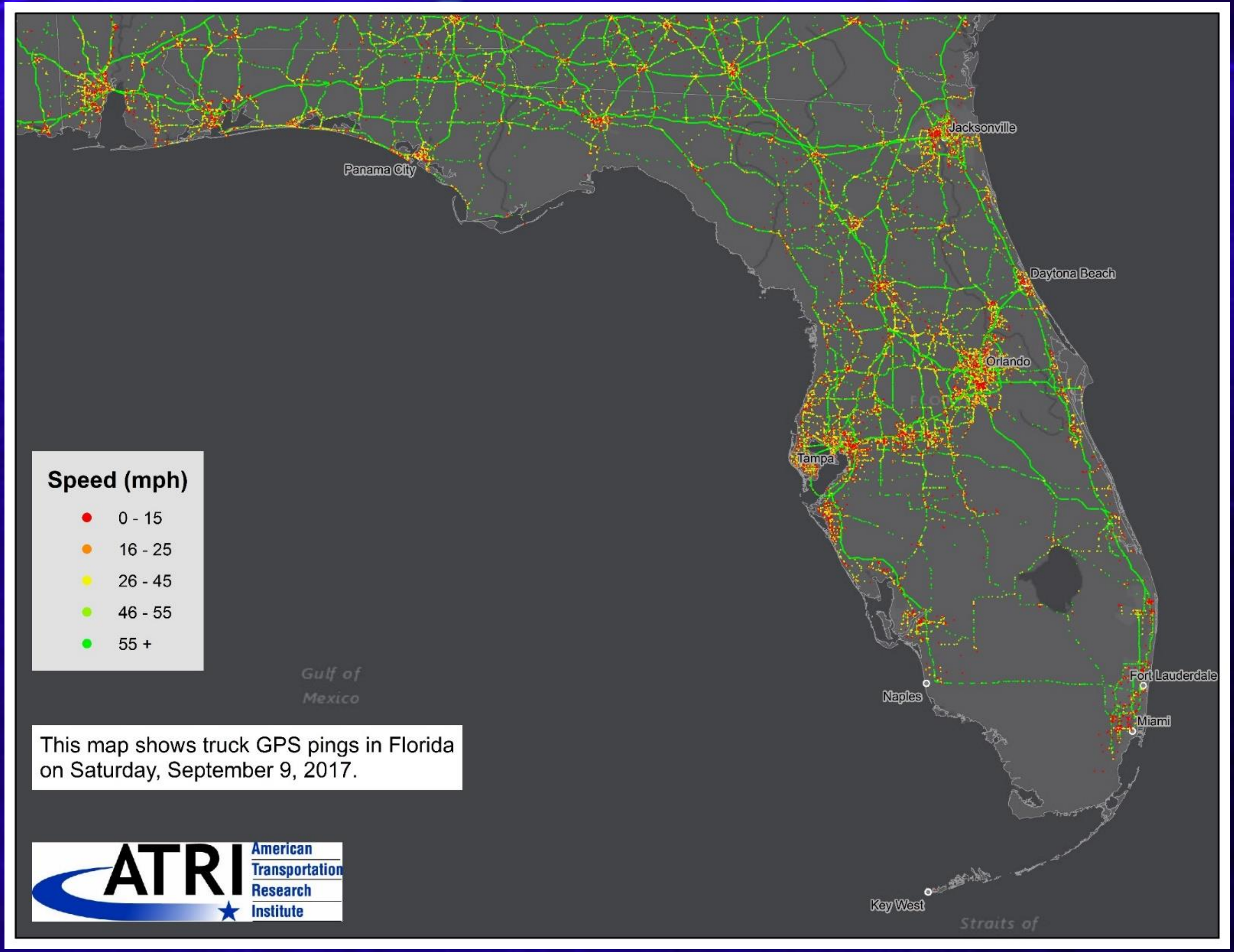
Key West
Straits of



Jacksonville
Panama City
Daytona Beach
Orlando
Tampa
Naples
Fort Lauderdale
Miami
Key West
Gulf of Mexico
Straits of
Speed (mph)
0 - 15
16 - 25
26 - 45
46 - 55
55 +
This map shows truck GPS pings in Florida on Saturday, September 9, 2017.
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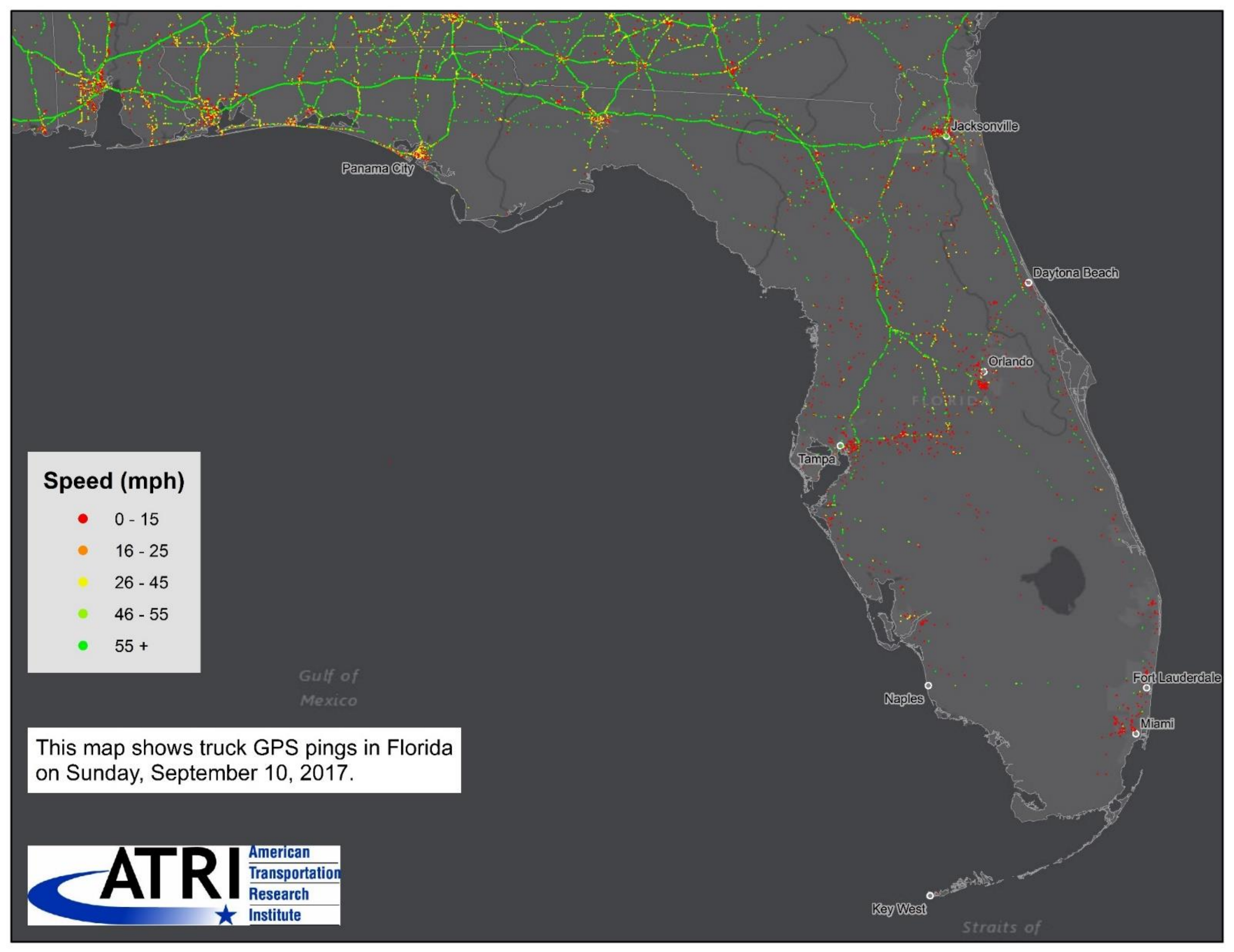
Jacksonville
Panama City
Daytona Beach
Orlando
Tampa
Speed (mph)
0 - 15
16 - 25
26 - 45
46 - 55
55 +
Gulf of Mexico
Fort Lauderdale
Naples
Miami
This map shows truck GPS pings in Florida on Sunday, September 10, 2017.
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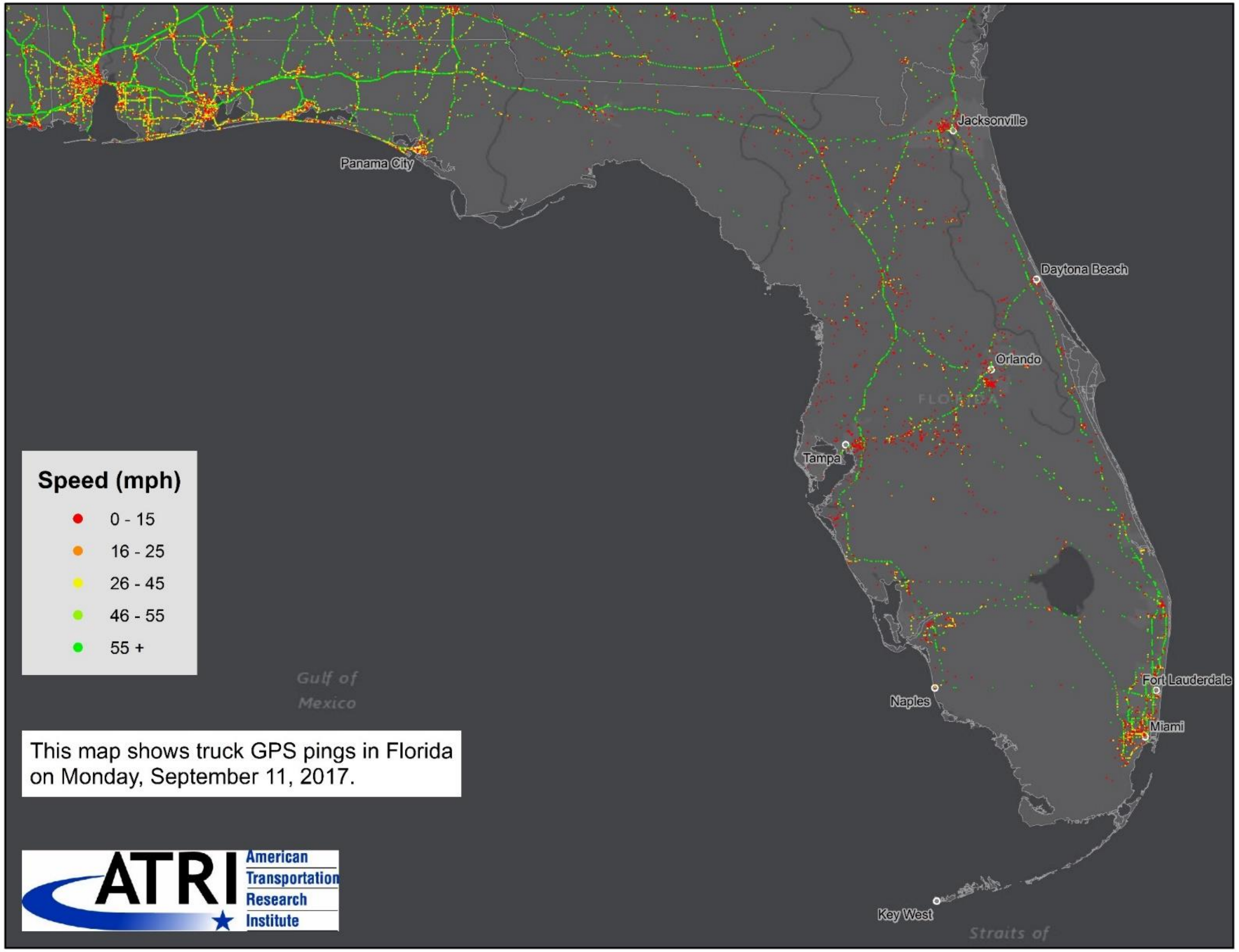
Key West
Straits of


Speed (mph)
0 - 15
16 - 25
26 - 45
46 - 55
55 +
Jacksonville
Panama City
Daytona Beach
Orlando
Tampa
Naples
Fort Lauderdale
Miami
Key West
Gulf of Mexico
Straits of
This map shows truck GPS pings in Florida on Monday, September 11, 2017.
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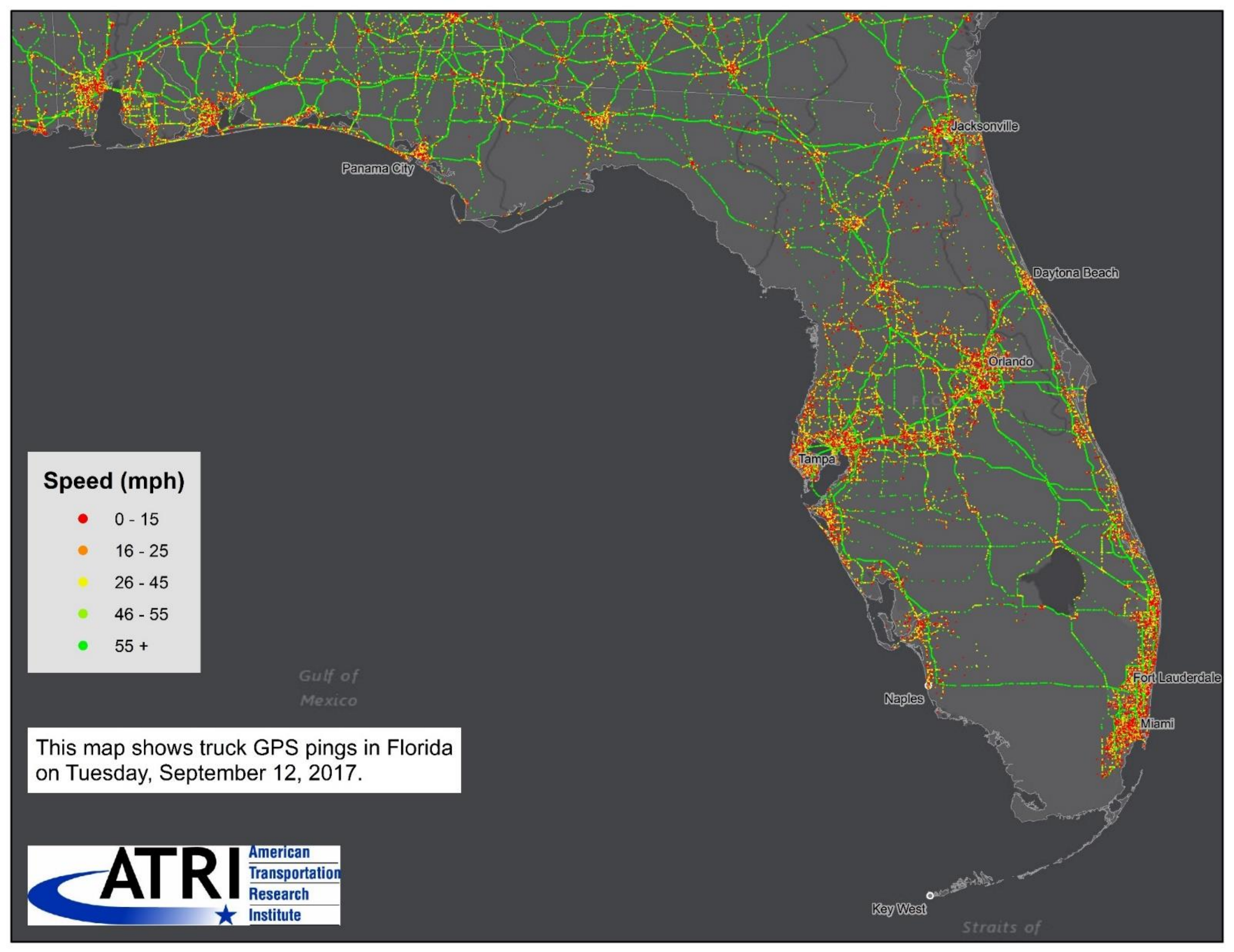

Jacksonville
Panama City
Daytona Beach
Orlando
Tampa
Fort Lauderdale
Miami
Naples
Key West
Gulf of Mexico
Straits of
Speed (mph)
0 - 15
16 - 25
26 - 45
46 - 55
55 +
This map shows truck GPS pings in Florida on Tuesday, September 12, 2017.
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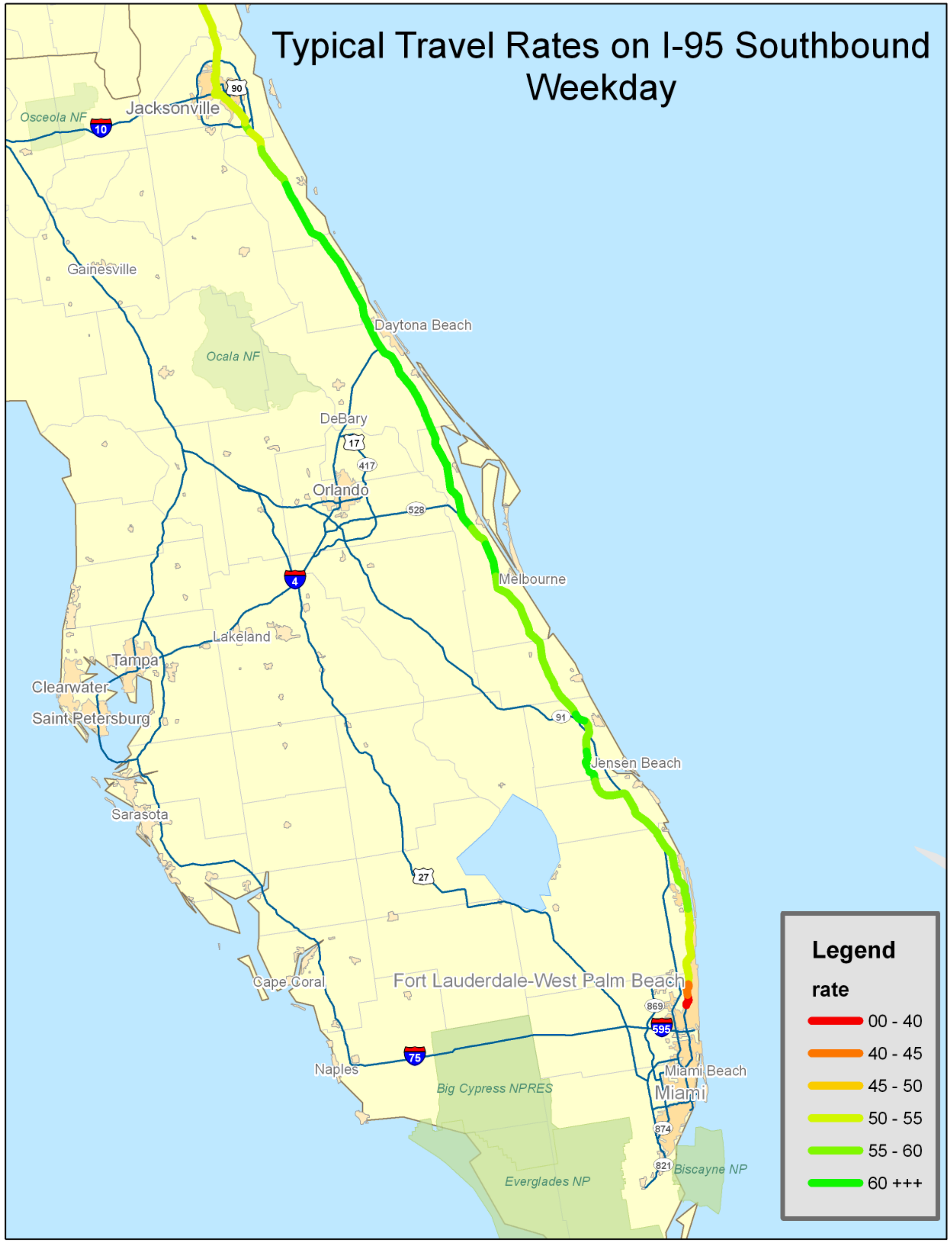
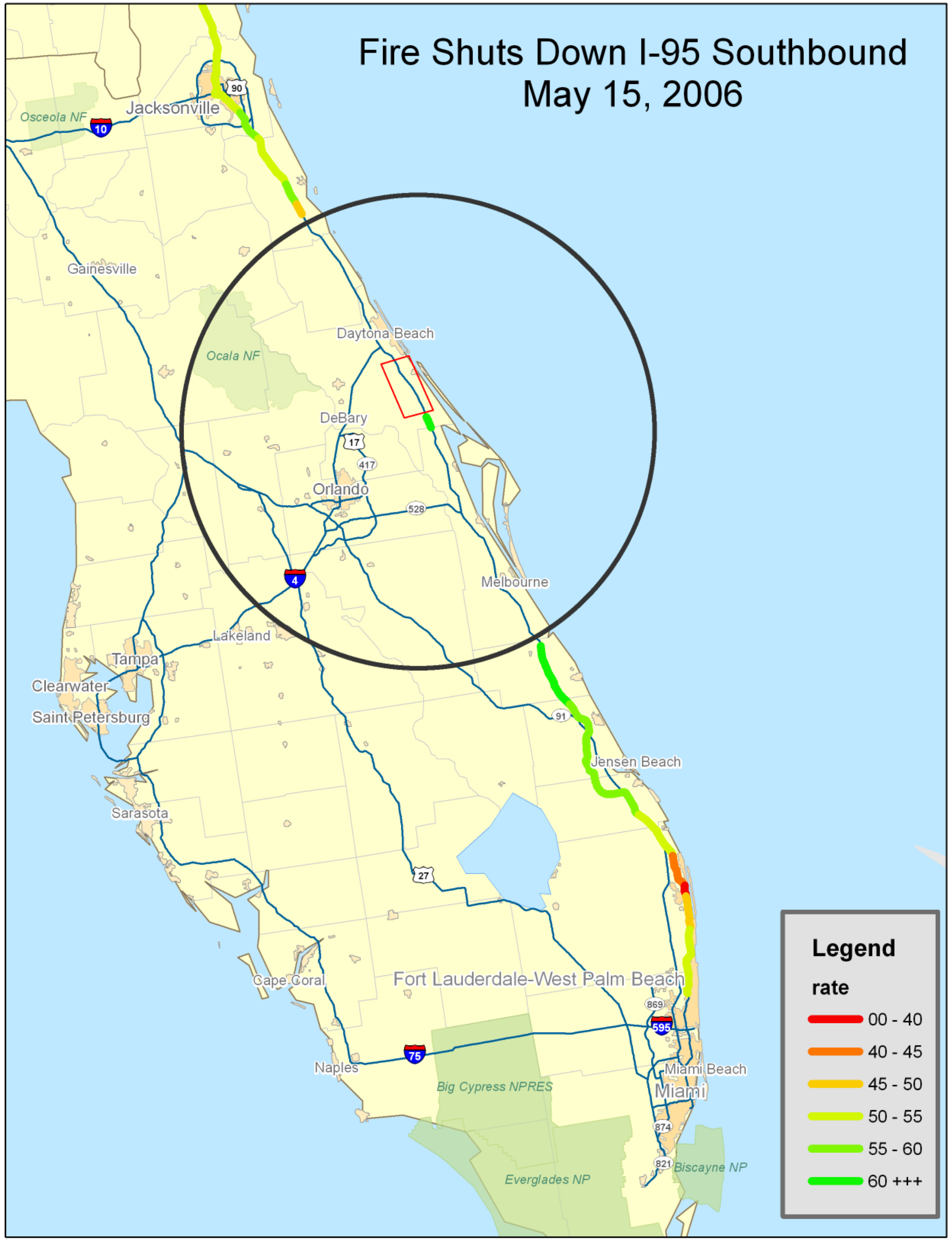
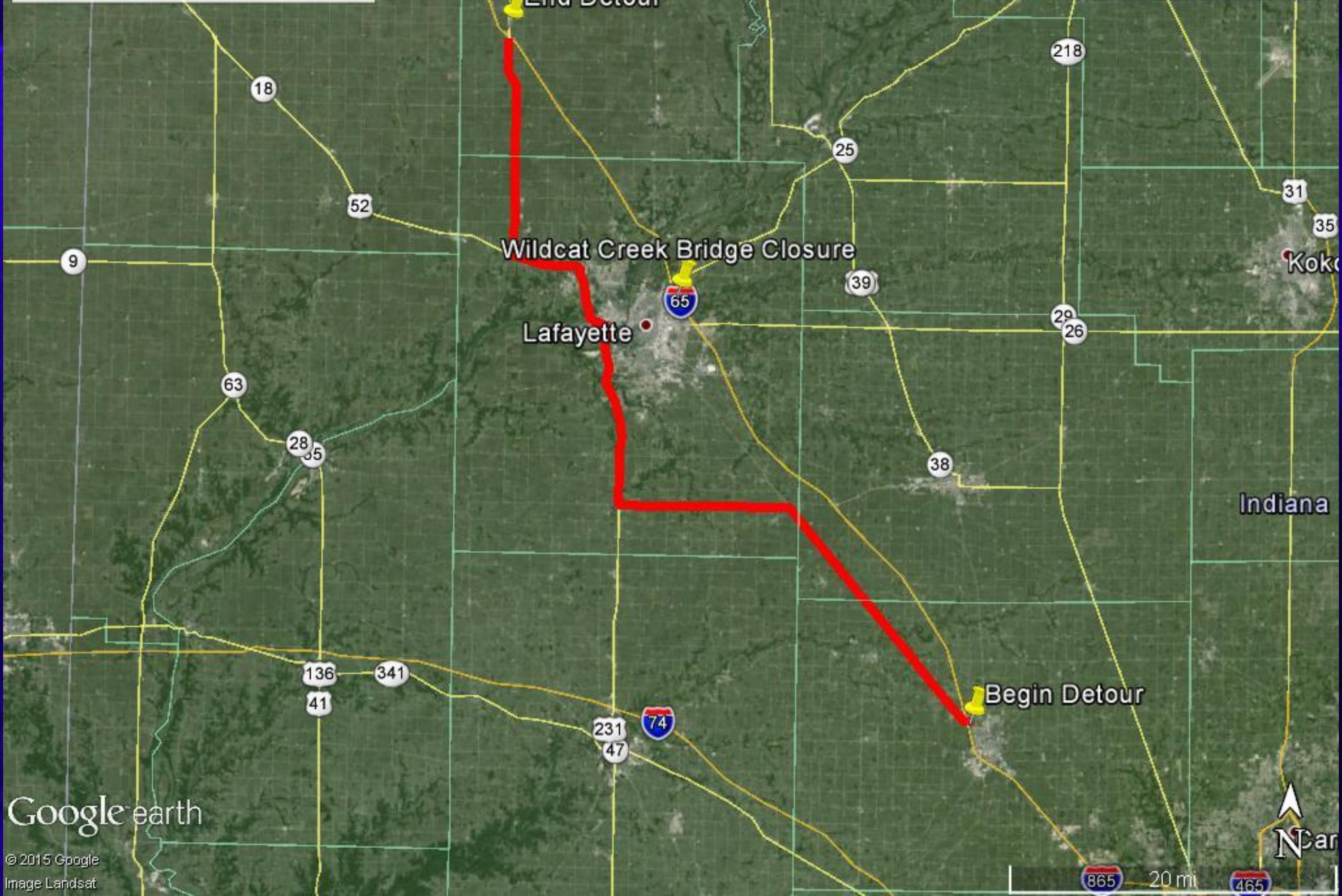
Wildfire Impacts



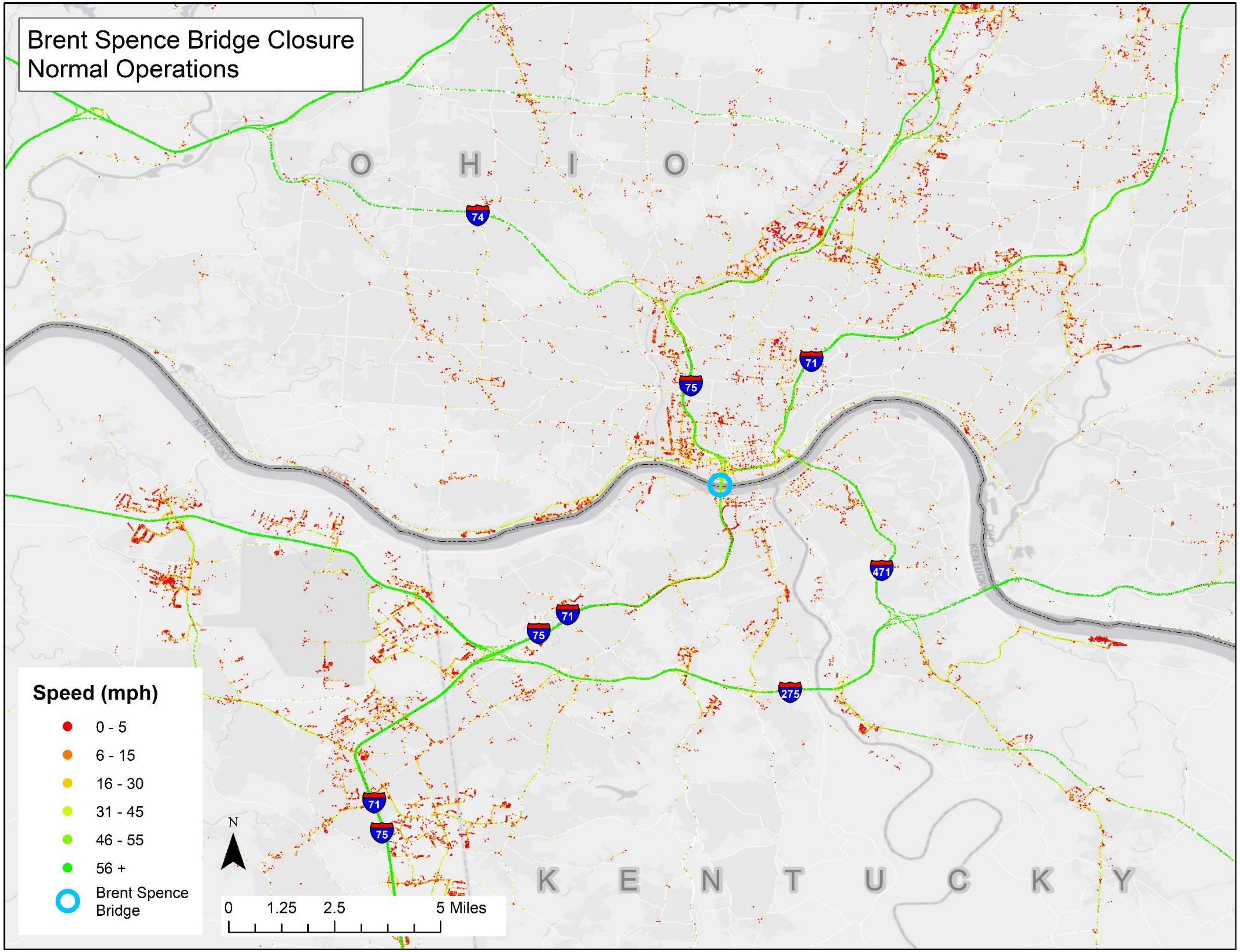
Wildfire Impacts

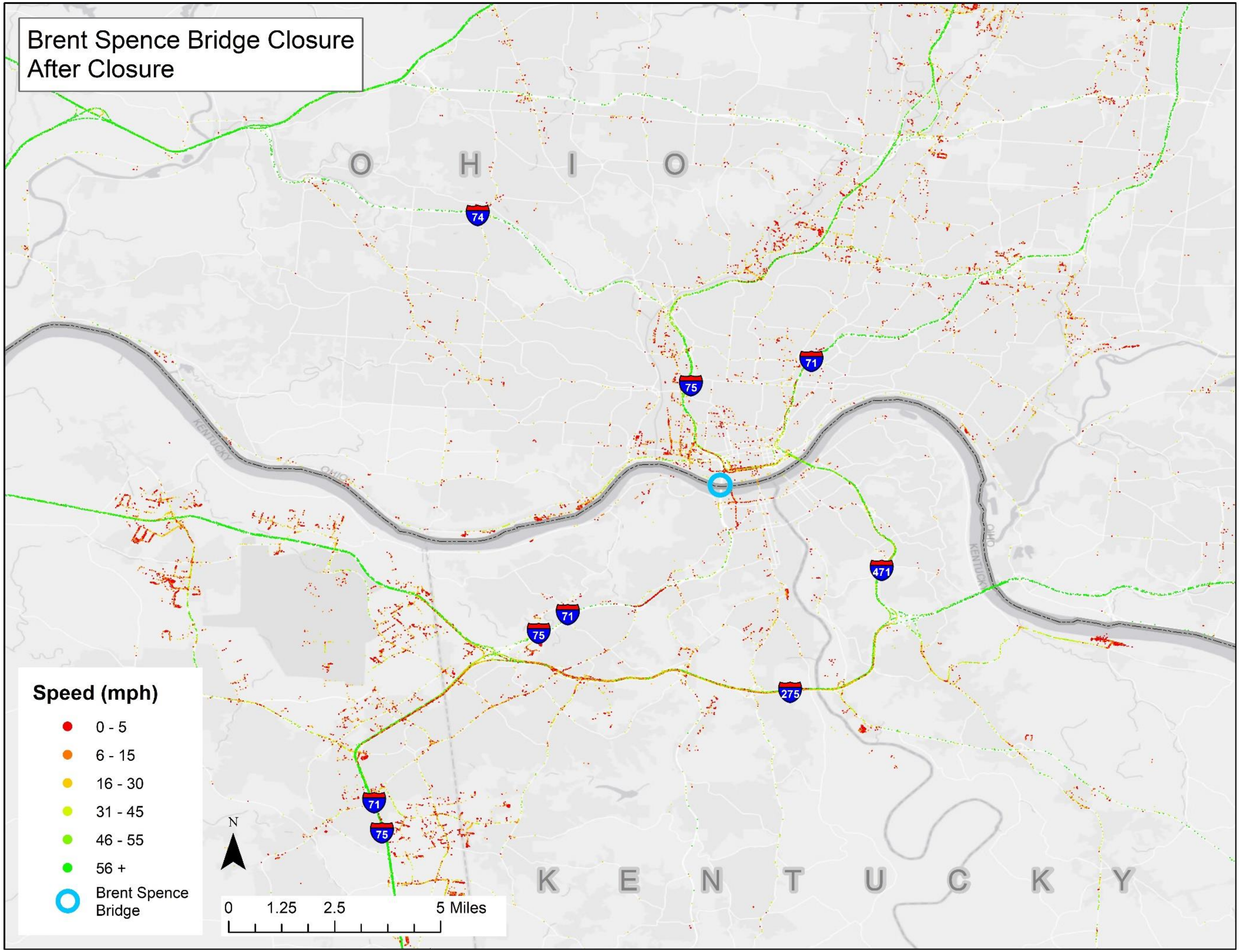


Official Detour (Local)

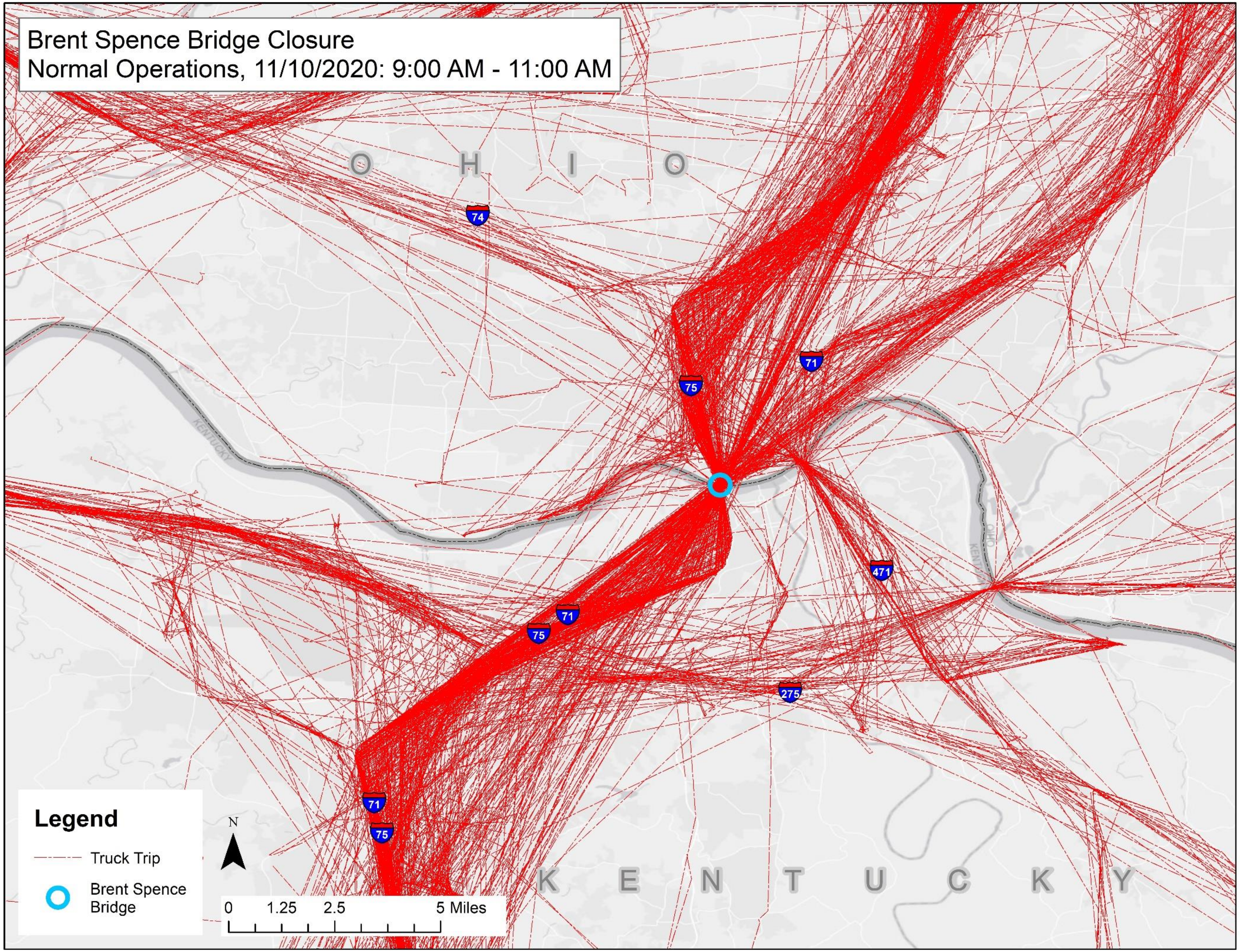


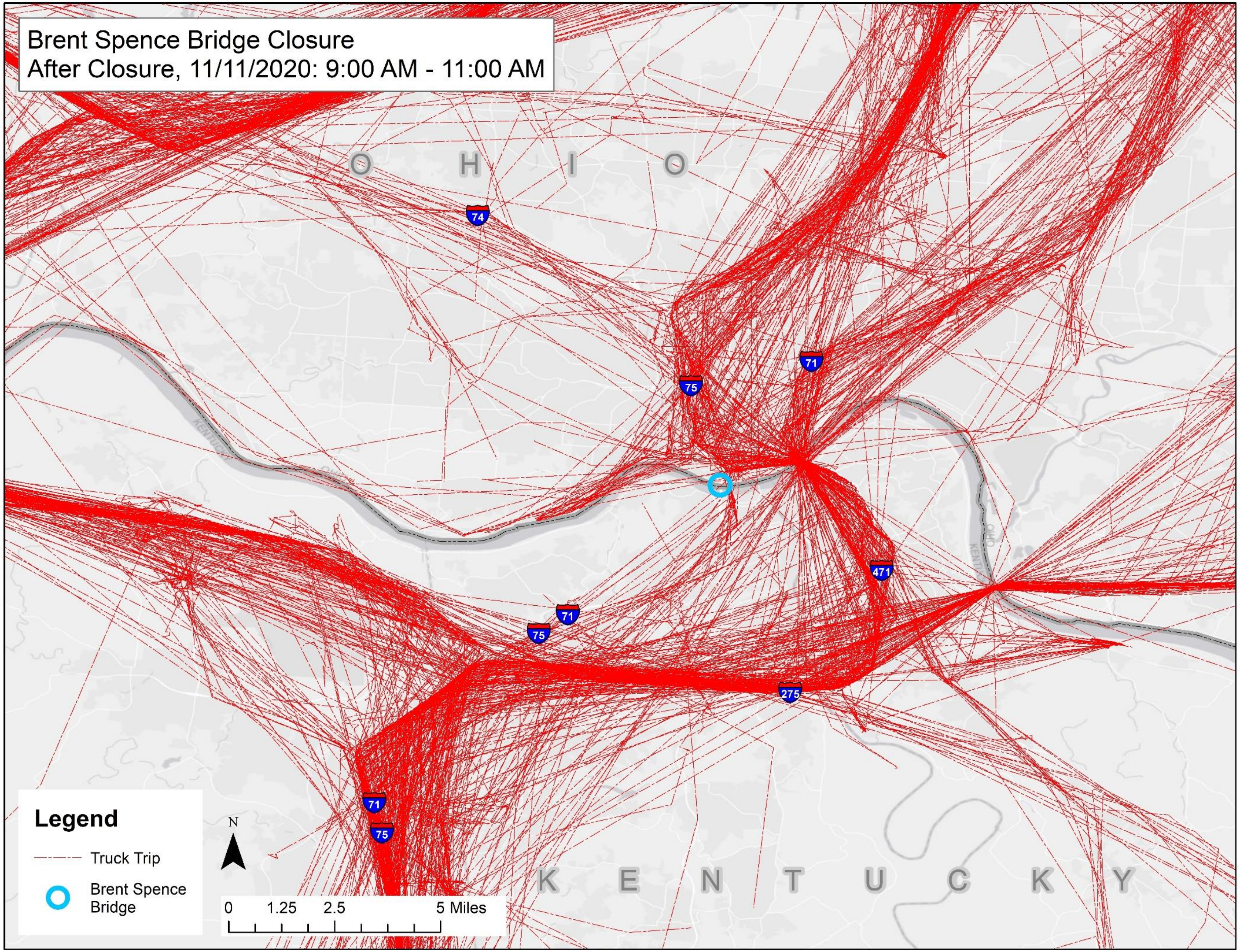
	Segments	Distance	Average Speed	Travel Time	Cost Per Hour	Trip Cost per Truck	Trucks Per Week	Cost Per Week
	US 52	17.2	48.9	21.10	$ 67.00	$ 23.57		
	SR 28	10.49	42.5	14.81	$ 67.00	$ 16.54		
	US 231 A	10.6	44.5	14.29	$ 67.00	$ 15.96		
	US 231 B	5	40.5	7.41	$ 67.00	$ 8.27		
	US 231 C	4.07	41.1	5.94	$ 67.00	$ 6.63		
	US 231 D	13.8	48.7	17.00	$ 67.00	$ 18.99		
Detour	**Total**	**61.16**	**44.37**			$ 89.96	30,000	$ 2,698,656.41
Normal	**I-65**	**51.8**	**62**	50.13	$ 67.00	$ 55.98	30,000	$ 1,679,322.58
							Additional Cost per Week--->	**$ 1,019,333.83**

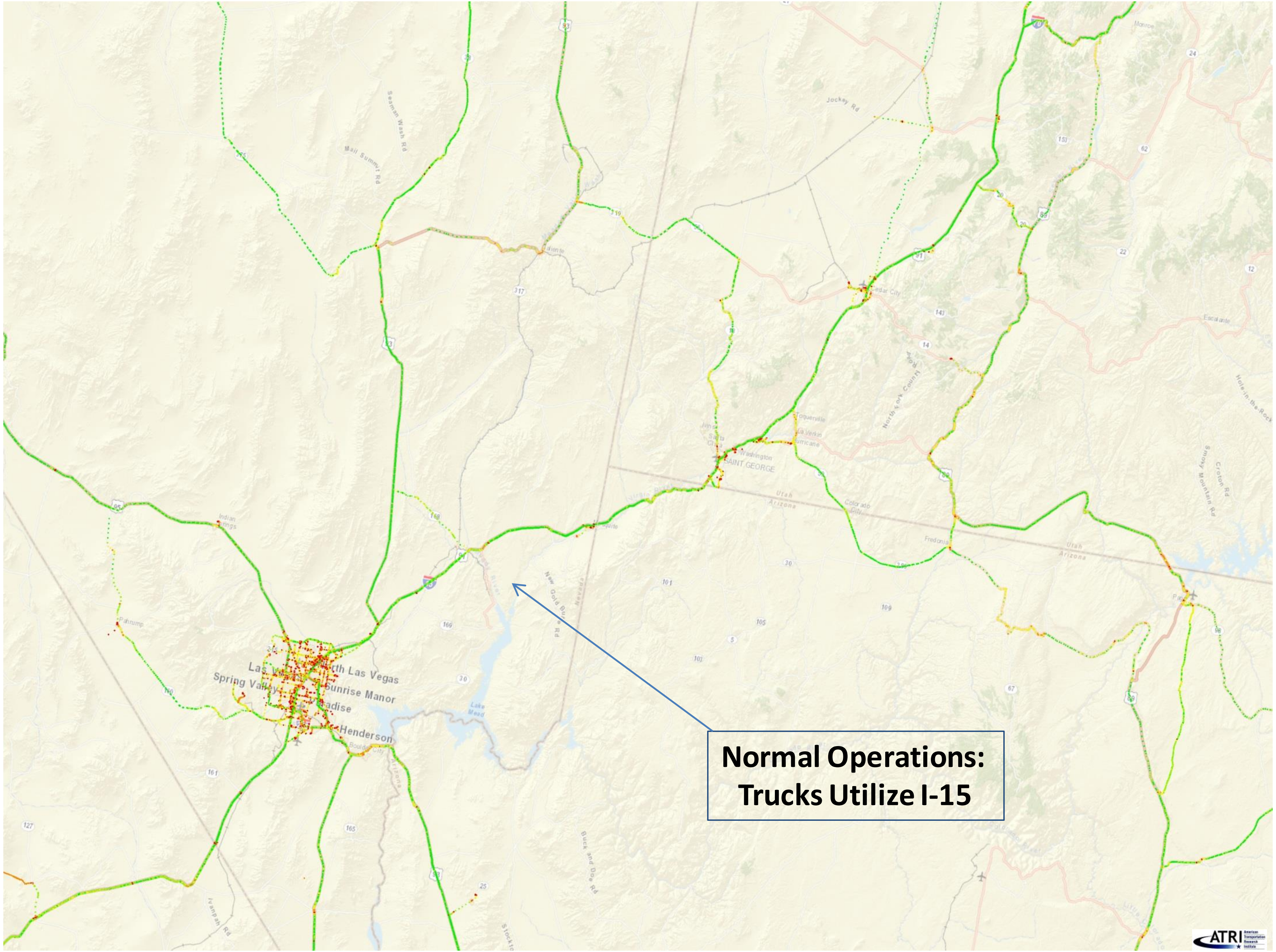

Brent Spence Bridge Closure
Normal Operations
O H I O
K E N T U C K Y
74
75
71
471
275
Speed (mph)
0 - 5
6 - 15
16 - 30
31 - 45
46 - 55
56 +
Brent Spence Bridge
N
0
1.25
2.5
5 Miles

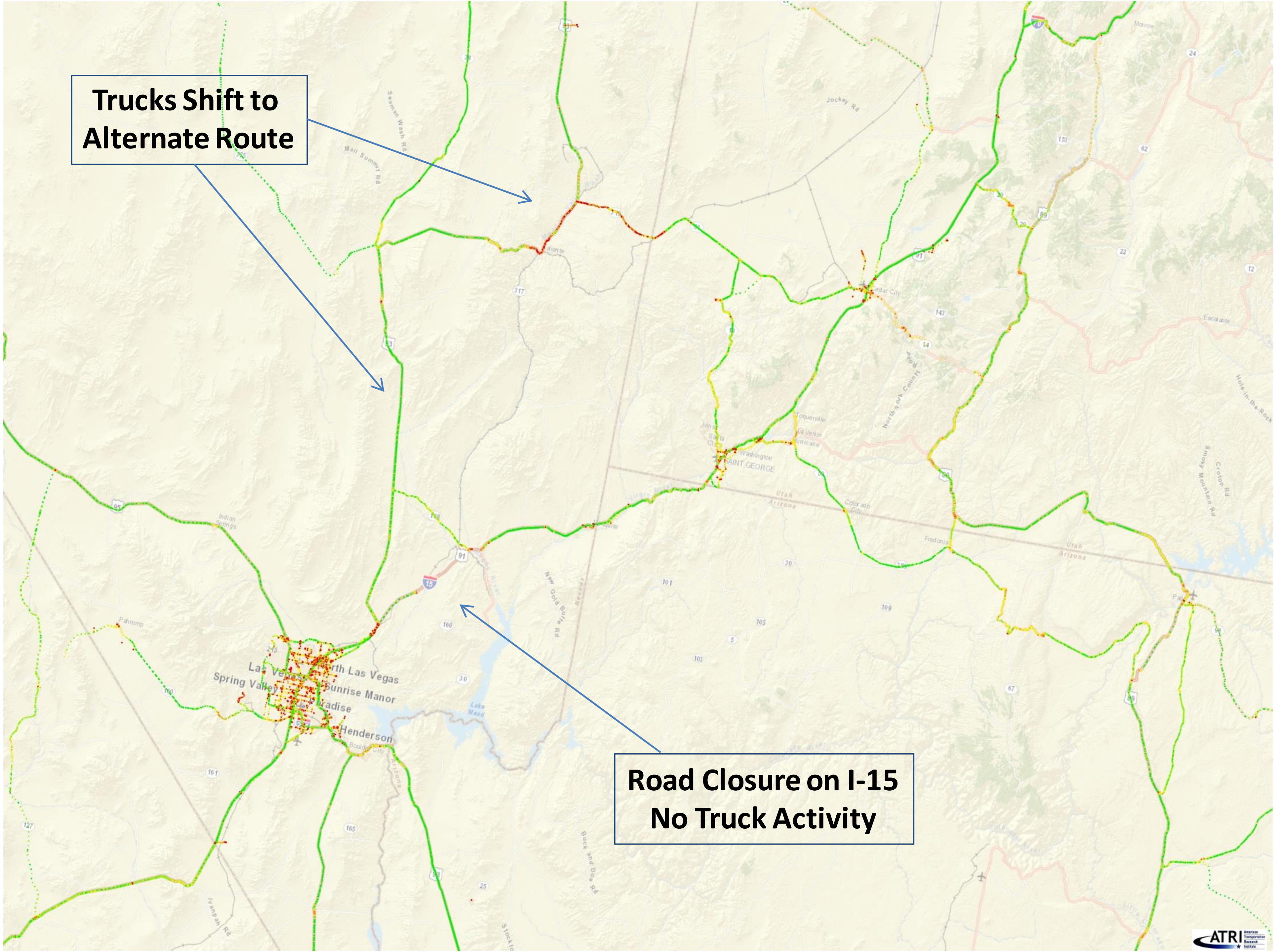


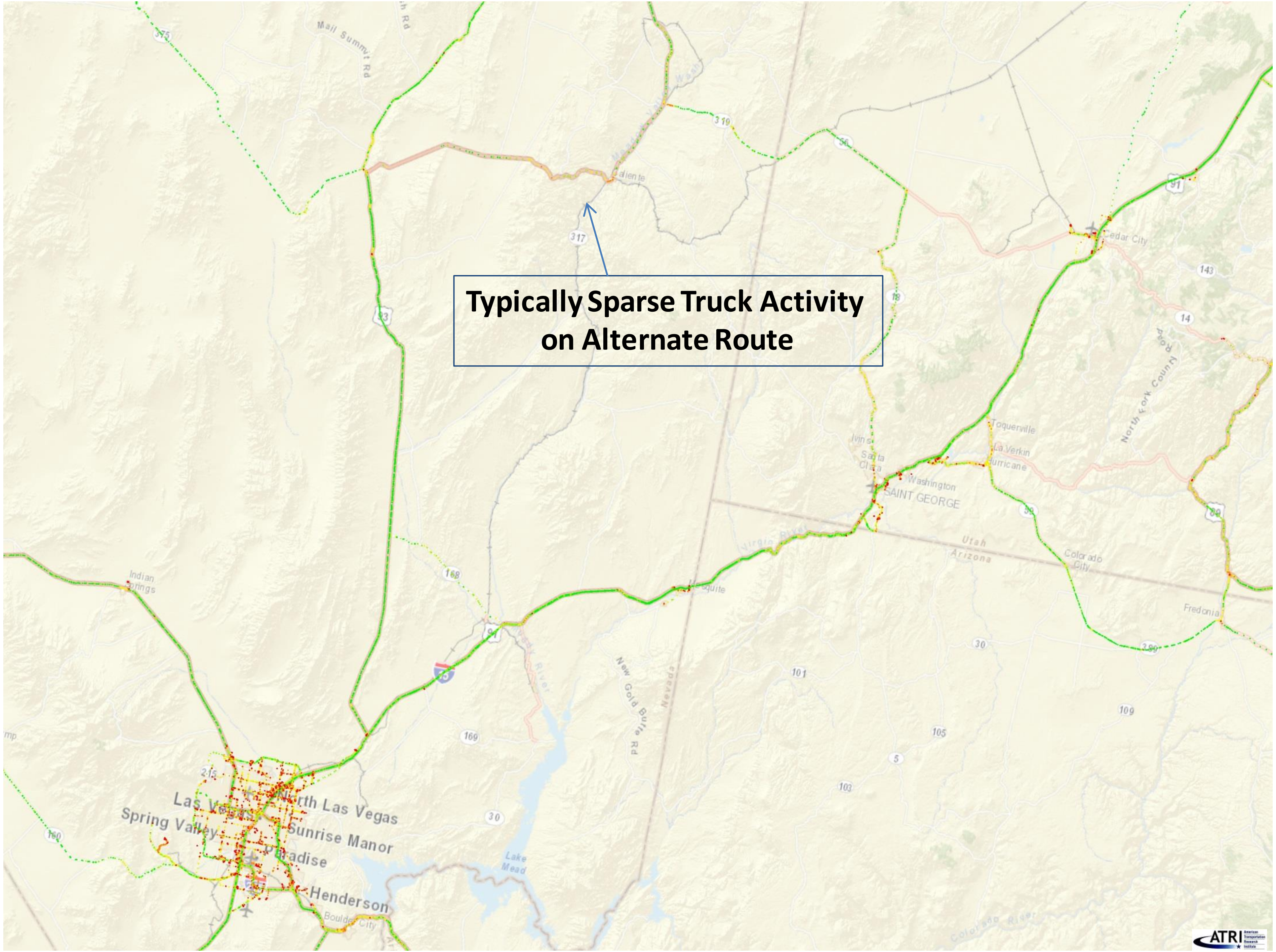
Brent Spence Bridge Closure
After Closure
OHIO
KENTUCKY
74
75
71
471
275
Speed (mph)
0 - 5
6 - 15
16 - 30
31 - 45
46 - 55
56 +
Brent Spence Bridge
N
0
1.25
2.5
5 Miles

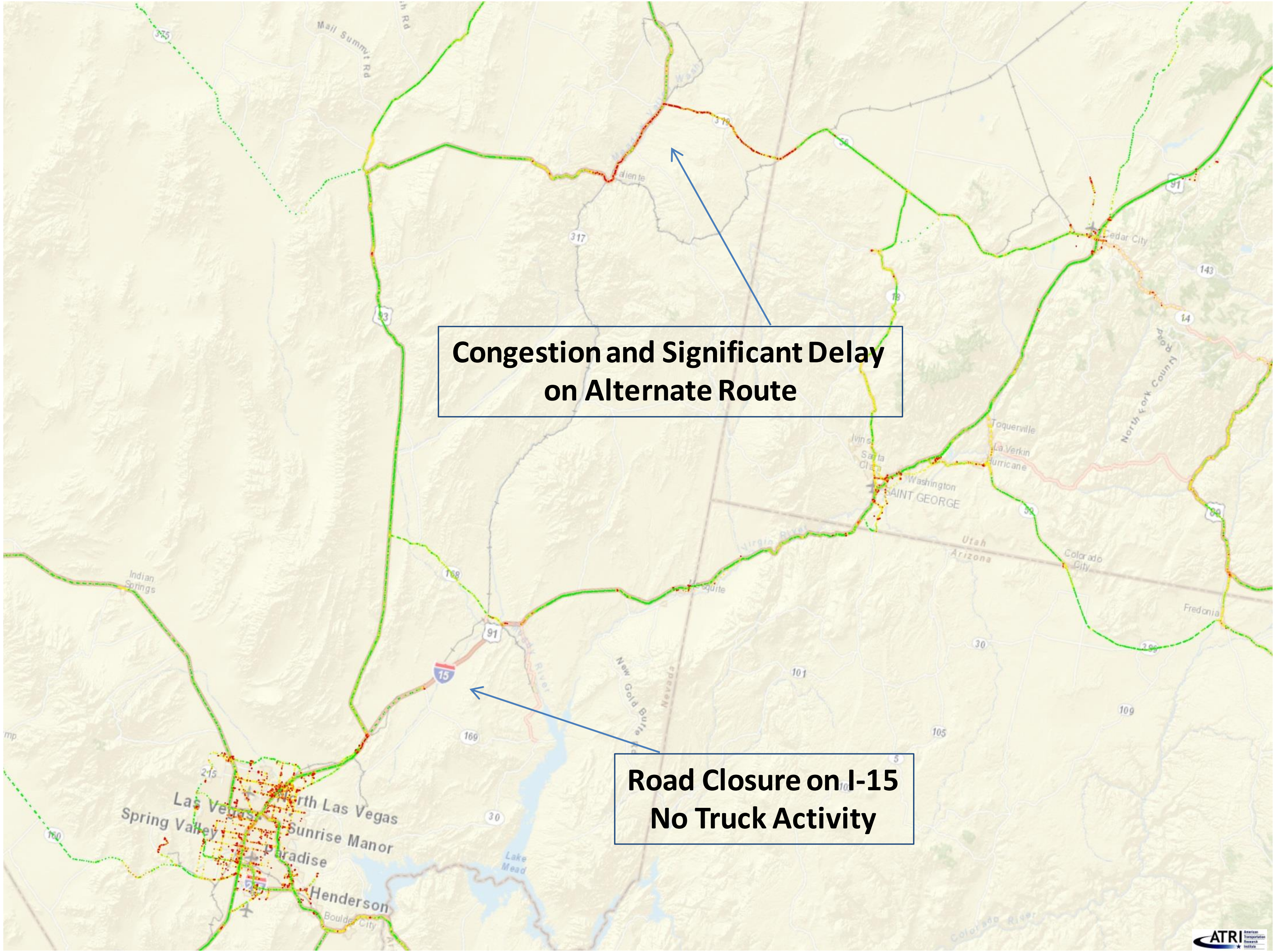

Brent Spence Bridge Closure
Normal Operations, 11/10/2020: 9:00 AM - 11:00 AM
O H I O
K E N T U C K Y
74
75
71
471
275
Legend
Truck Trip
Brent Spence Bridge
N
0 1.25 2.5 5 Miles


Brent Spence Bridge Closure
After Closure, 11/11/2020: 9:00 AM - 11:00 AM
O H I O
74
75
71
471
71
75
275
71
75
K E N T U C K Y
Legend
Truck Trip
Brent Spence Bridge
N
0
1.25
2.5
5 Miles

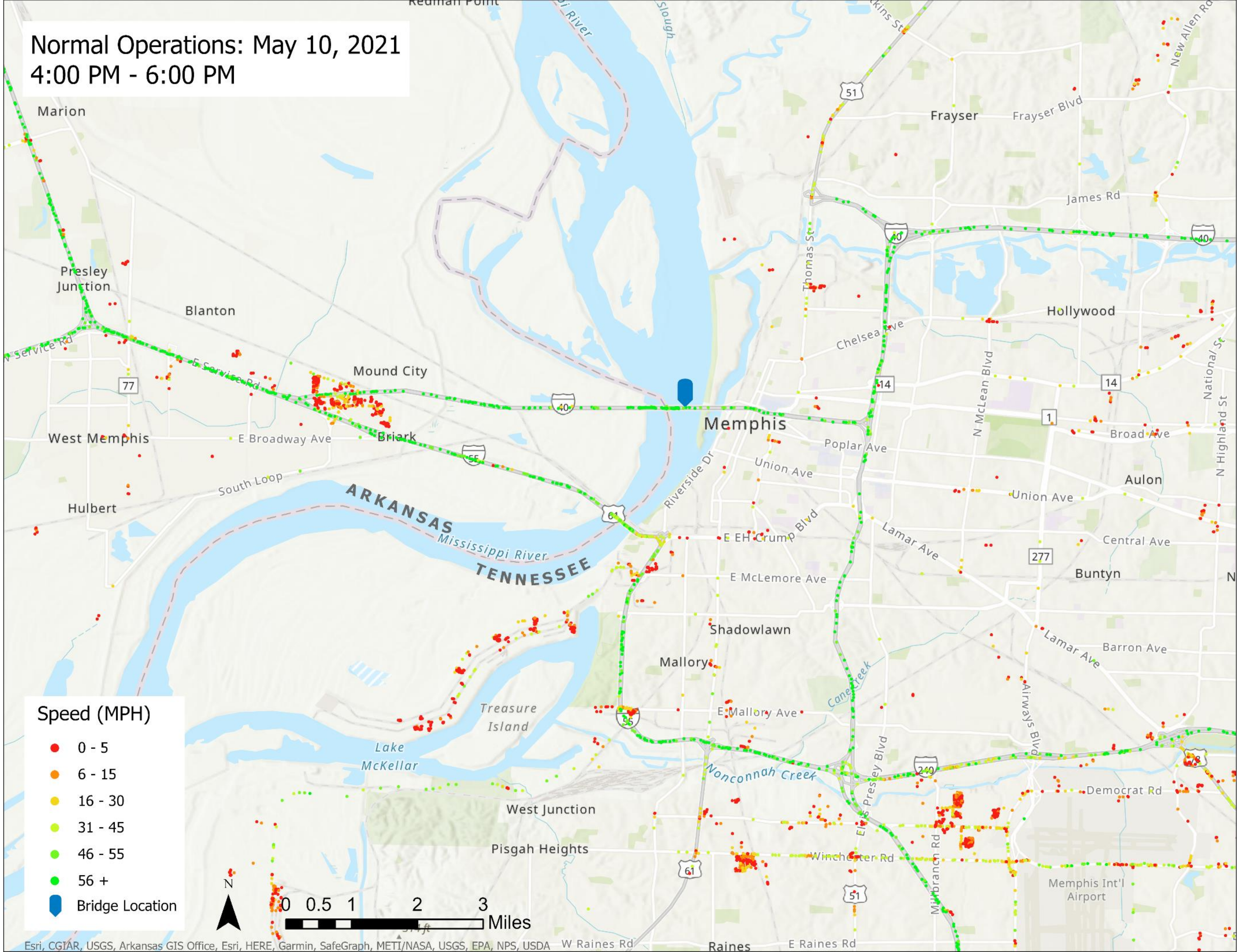

North Las Vegas
Sunrise Manor
Spring Valley
Henderson
SAINT GEORGE
Normal Operations:
Trucks Utilize I-15

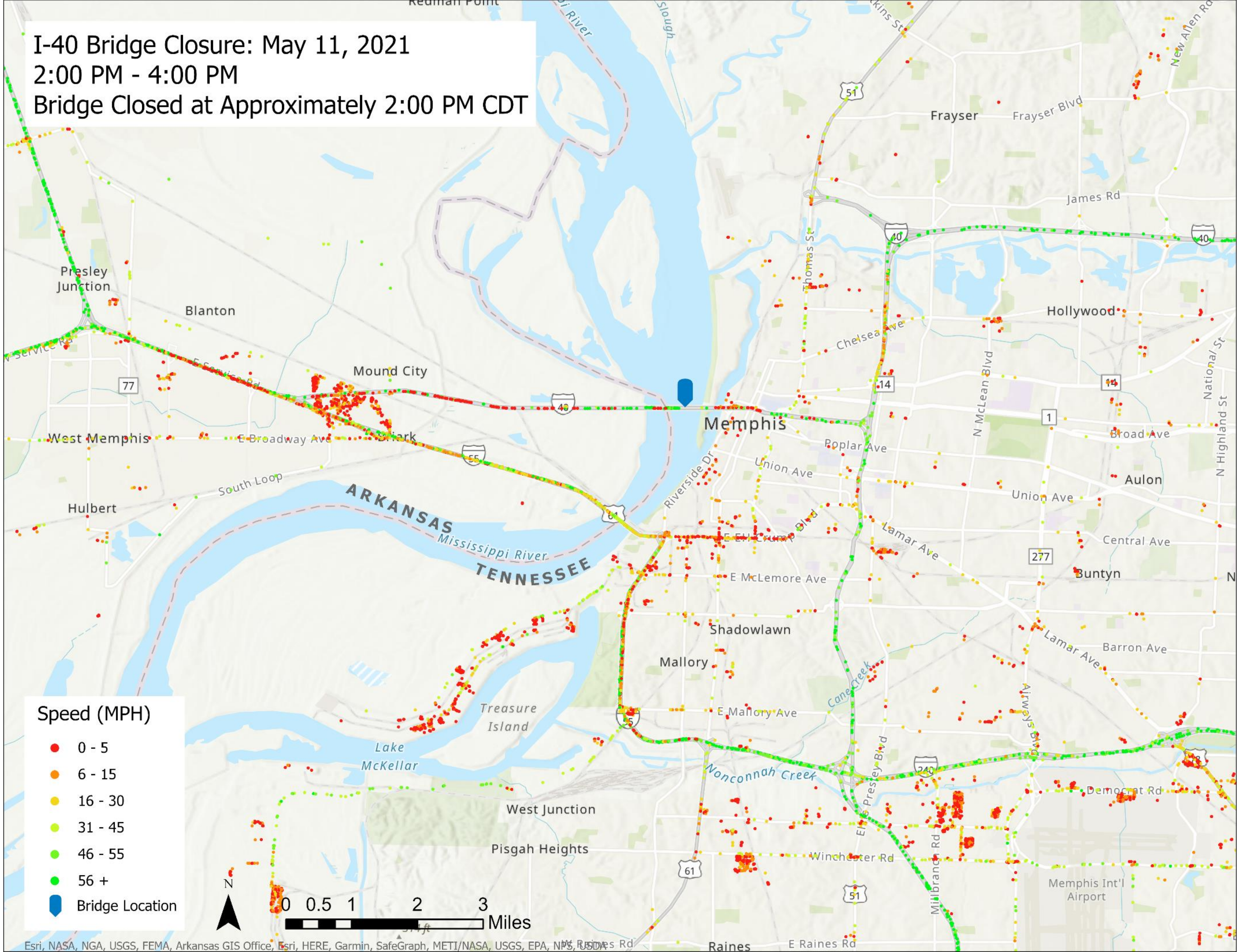

Trucks Shift to Alternate Route
Road Closure on I-15
No Truck Activity
North Las Vegas
Spring Valley
Sunrise Manor
Henderson
SAINT GEORGE
Washington
Utah
Arizona
ATRI


Typically Sparse Truck Activity on Alternate Route
Caliente
Cedar City
Toquerville
La Verkin
Hurricane
Washington
SAINT GEORGE
Utah
Arizona
Colorado City
Fredonia
Mesquite
Indian Springs
Las Vegas
North Las Vegas
Spring Valley
Sunrise Manor
Paradise
Henderson
Boulder City
Lake Mead
North Fork County Road
New Gold Butte Rd
Nevada
Virgin River
Mail Summit Rd
ATRI

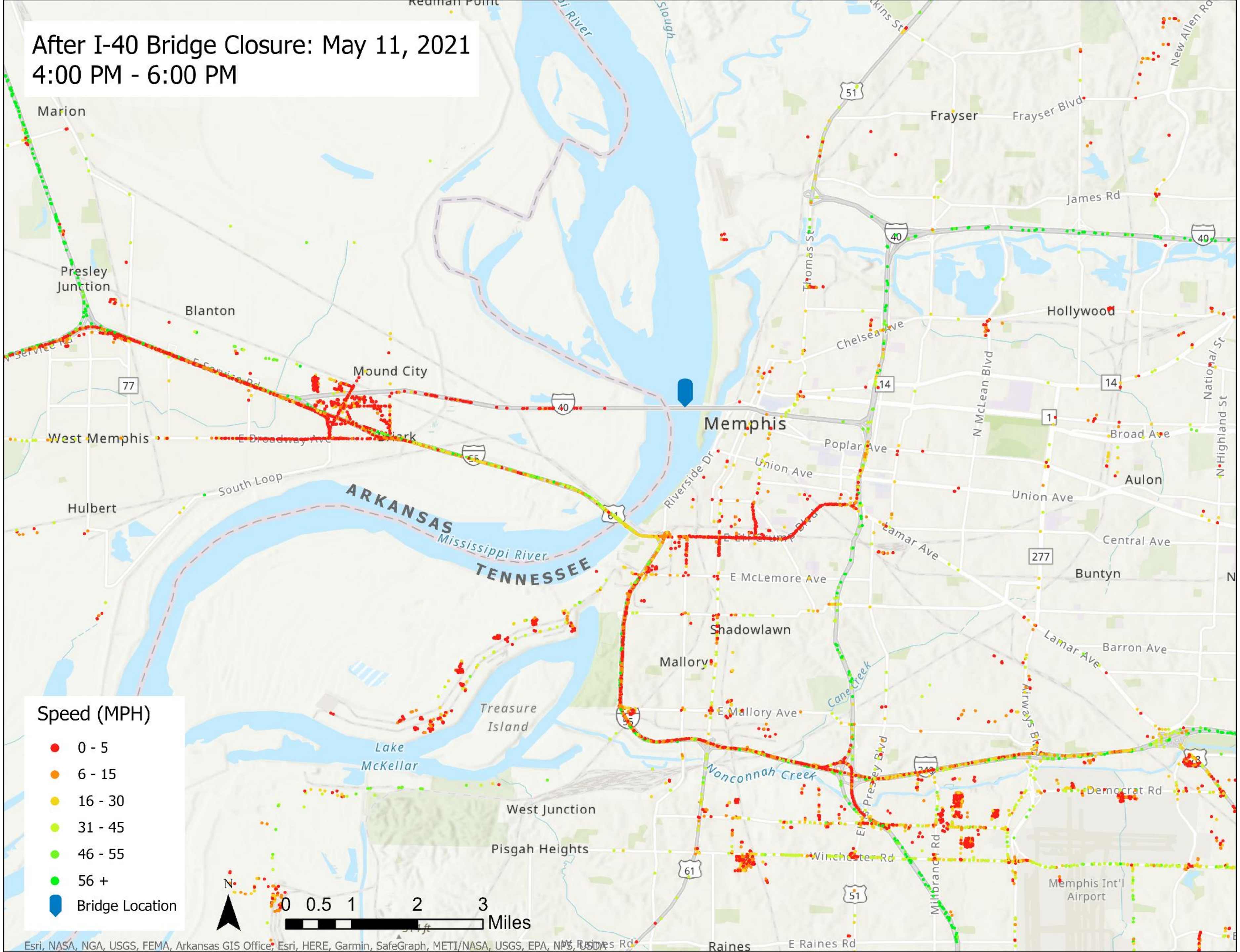


Congestion and Significant Delay on Alternate Route
Road Closure on I-15 No Truck Activity
North Las Vegas
Spring Valley
Sunrise Manor
Paradise
Henderson
Lake Mead
Cedar City
Toquerville
La Verkin
Hurricane
Washington
SAINT GEORGE
Utah
Arizona
Colorado City
Fredonia
Indian Springs
North Fork Country Road
ATRI


Normal Operations: May 10, 2021
4:00 PM - 6:00 PM
Speed (MPH)
0 - 5
6 - 15
16 - 30
31 - 45
46 - 55
56 +
Bridge Location
0 0.5 1 2 3
Miles
N
Marion
Presley Junction
Blanton
Mound City
West Memphis
E Broadway Ave
Briark
South Loop
Hulbert
ARKANSAS
TENNESSEE
Mississippi River
Treasure Island
Lake McKellar
West Junction
Pisgah Heights
Memphis
Frayser
Frayser Blvd
James Rd
Hollywood
Chelsea Ave
Poplar Ave
Union Ave
Riverside Dr
E EH Crump Blvd
E McLemore Ave
Shadowlawn
Mallory
E Mallory Ave
Lamar Ave
Broad Ave
Aulon
Central Ave
Buntyn
Barron Ave
Nonconnah Creek
Democrat Rd
Winchester Rd
Memphis Int'l Airport
Raines
E Raines Rd
W Raines Rd
N McLean Blvd
N Highland St
Airways Blvd
Elvis Presley Blvd
Millbranch Rd
Thomas St
New Allen Rd
National St
Esri, CGIAR, USGS, Arkansas GIS Office, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA



I-40 Bridge Closure: May 11, 2021
2:00 PM - 4:00 PM
Bridge Closed at Approximately 2:00 PM CDT
Speed (MPH)
0 - 5
6 - 15
16 - 30
31 - 45
46 - 55
56 +
Bridge Location
0 0.5 1 2 3 Miles
N
Memphis
West Memphis
Presley Junction
Blanton
Mound City
Hulbert
Frayser
Hollywood
Aulon
Buntyn
Shadowlawn
Mallory
Treasure Island
Lake McKellar
West Junction
Pisgah Heights
Memphis Int'l Airport
Raines
ARKANSAS
TENNESSEE
Mississippi River
Esri, NASA, NGA, USGS, FEMA, Arkansas GIS Office, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA


After I-40 Bridge Closure: May 11, 2021
4:00 PM - 6:00 PM
Speed (MPH)
0 - 5
6 - 15
16 - 30
31 - 45
46 - 55
56 +
Bridge Location
0 0.5 1 2 3
Miles
N
Marion
Presley Junction
Blanton
Mound City
West Memphis
Hulbert
Memphis
Frayser
Hollywood
Aulon
Buntyn
Shadowlawn
Mallory
Treasure Island
Lake McKellar
West Junction
Pisgah Heights
Raines
Memphis Int'l Airport
ARKANSAS
TENNESSEE
Mississippi River
Nonconnah Creek
Frayser Blvd
James Rd
Chelsea Ave
Poplar Ave
Union Ave
Broad Ave
Central Ave
Lamar Ave
Barron Ave
E McLemore Ave
E Mallory Ave
Winchester Rd
Democrat Rd
E Raines Rd
South Loop
Riverside Dr
Esri, NASA, NGA, USGS, FEMA, Arkansas GIS Office, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, EPA, NPS, USDA

Average Carrier Costs per Mile

Motor Carrier Costs	2019	2020	2021	2022	2023
Vehicle-based					
Fuel Costs	$0.384	$0.308	$0.417	$0.641	$0.553
Truck/Trailer Lease or Purchase Payments	$0.256	$0.271	$0.279	$0.331	$0.360
Repair & Maintenance	$0.149	$0.148	$0.175	$0.196	$0.202
Truck Insurance Premiums	$0.071	$0.087	$0.086	$0.088	$0.099
Permits and Licenses	$0.020	$0.016	$0.016	$0.015	$0.009
Tires	$0.039	$0.043	$0.041	$0.045	$0.046
Tolls	$0.035	$0.037	$0.032	$0.028	$0.034
Driver-based					
Driver Wages	$0.554	$0.566	$0.627	$0.724	$0.779
Driver Benefits	$0.190	$0.171	$0.182	$0.183	$0.188
TOTAL	**$1.699**	**$1.646**	**$1.855**	**$2.251**	**$2.270**

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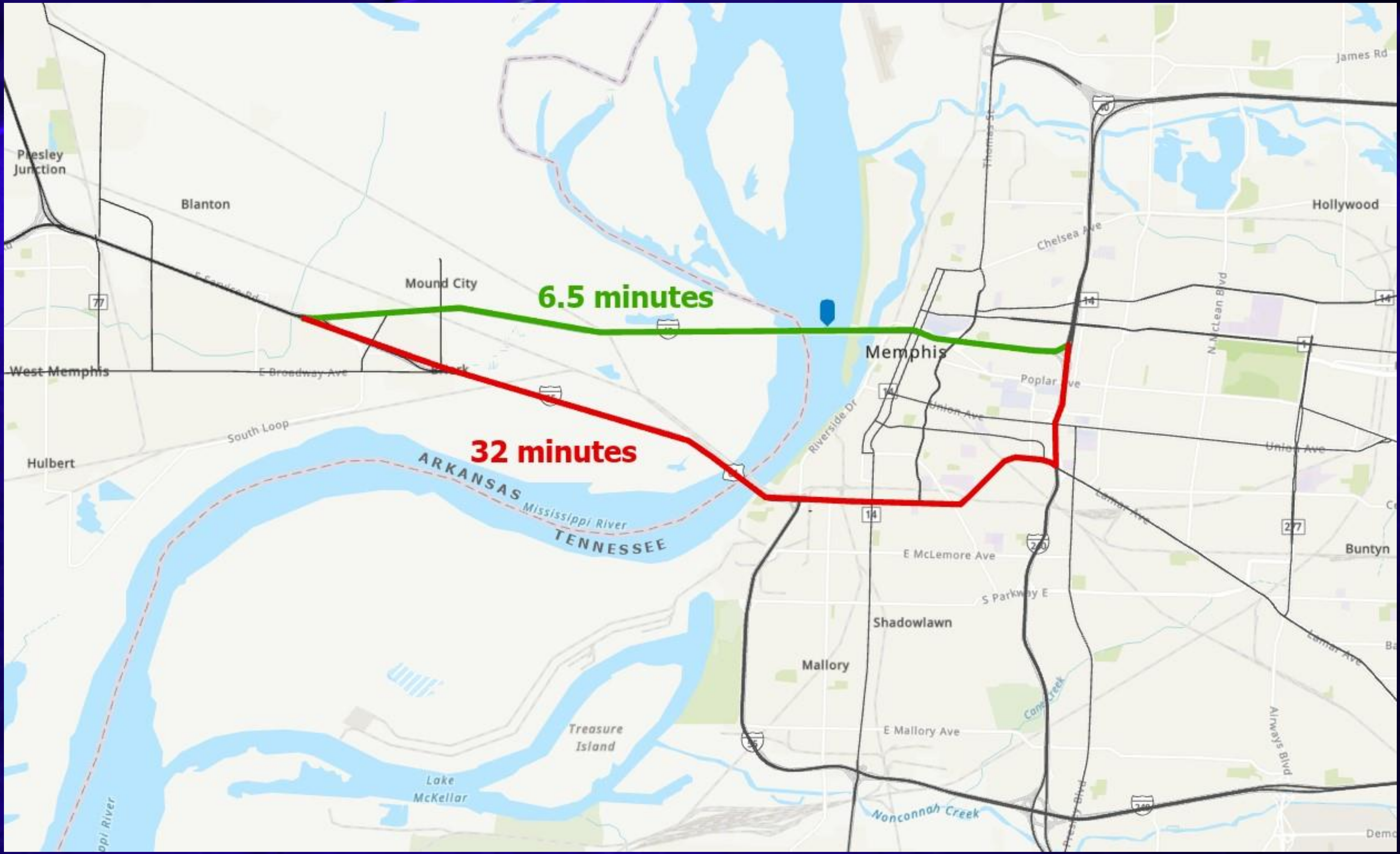

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Key Findings

- Supply chains & trucking require extremely efficient routing
  - 95% vs 80%
  - Faster but longer routing is common
- Unintended consequences: Slower & longer = more air quality issues
- Rely on truck driver / moto carrier input for Alt Routing
- Alternative routing adds bottom line costs to products and services (inflationary)

ATRI American Transportation Research Institute

Questions?

Dan Murray

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Dan Murray
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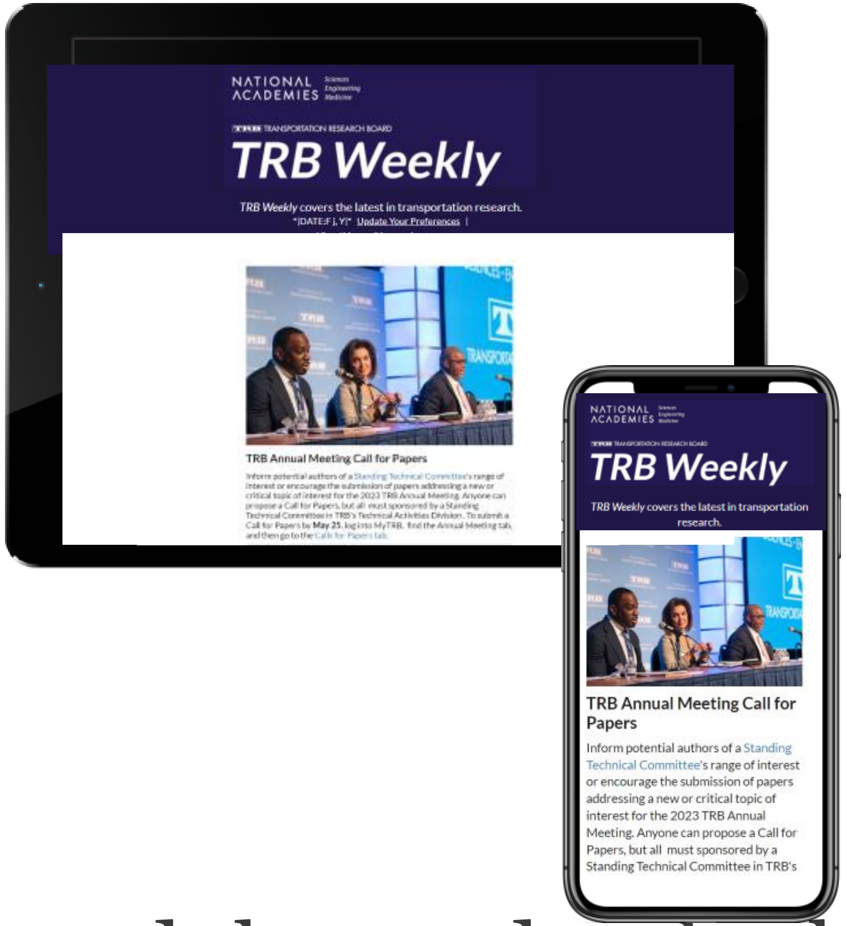

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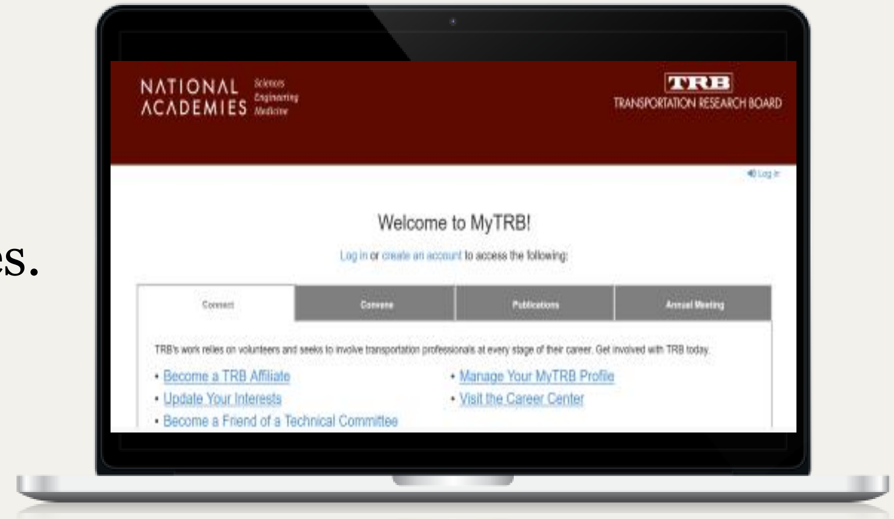

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