



Resilient Highways: Experiments in Traffic Smoothing

Dan Work
Professor

Civil & Environmental Engineering
Institute for Software Integrated Systems
Vanderbilt University

Joint work with Prof. Jonathan Sprinkle & our collaborators:

I-24 MOTION: Lee Smith, Michelle Nickerson, Said El Said, Brad Freeze (TDOT); Matt D'Angelo, Meredith Cebelak (Gresham Smith); Derek Gloudemans, Yanbing Wang, Junyi Ji, Eric Hall, Gergely Zachar, Will Barbour, Craig Philip

CIRCLES: Alex Bayen, Jonny Lee, Maria Laura Delle Monache, Benedetto Piccoli, Benjamin Seibold. Additional thanks to Rahul Bhadani, Matt Bunting, Sean McQuade, Matt Nice, Riley Wagner, Regan Williams, and many other collaborators for their production of slide materials and images.

[Research Sponsors: NSF, USDOE, US DOT, Tennessee DOT, and Vanderbilt. Views are our own]



State of mobility in the U.S.

An aerial photograph of a multi-lane highway with traffic. The highway is divided into several lanes by a central median and side medians. There are cars, trucks, and a bus on the road. The surrounding area includes green grass, trees, and some buildings in the distance. The sky is clear and blue.

Congestion cost (2021): \$81 billion

Safety: 42,338 fatalities; 19.8 million vehicles involved in crashes

Energy: 28% of total U.S. energy consumption



Technology can reduce crashes, congestion, and emissions

Having a small fraction of equipped cars on the roads can have a large effect

We don't need to wait for full self driving to have an effect today

Proof: A single autonomous vehicle can help

Dissipation of stop-and-go traffic waves via control of a single autonomous vehicle



ILLINOIS
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

RUTGERS



TEMPLE
UNIVERSITY®



THE UNIVERSITY
OF ARIZONA®

[Stern, Cui, Delle Monache, Bhadani, Bunting, Churchill, Hamilton, Haulcy, Pohlmann, Wu, Piccoli, Seibold, Sprinkle, & Work, 2018; NSF CNS-1446702 (2015-2018)]





Reviewer 3 says:

“That’s not a real road! What about lane changes?!”



Maybe ACC systems on the road today would already dampen traffic waves, if we convince drivers to turn them on.

Are Commercially Implemented Adaptive Cruise Control Systems String-Stable?

<https://arxiv.org/abs/1905.02108>

How to have believable results

Simulate 100,000 times in a computer?



At scale.
Scientifically rigorously.
With affordable cars
available today.

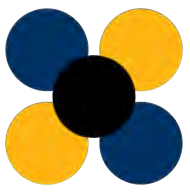


Demonstrate in
a parking lot?

2016

2022



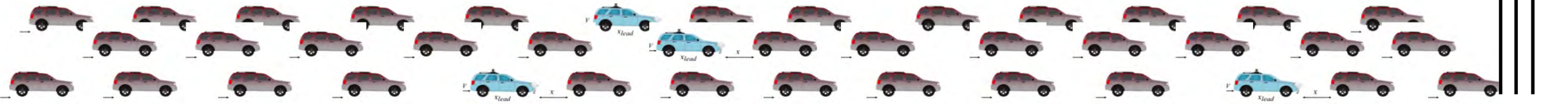


Without control: More stop-and-go, more fuel used. Some cars directly measured, all vehicles estimated

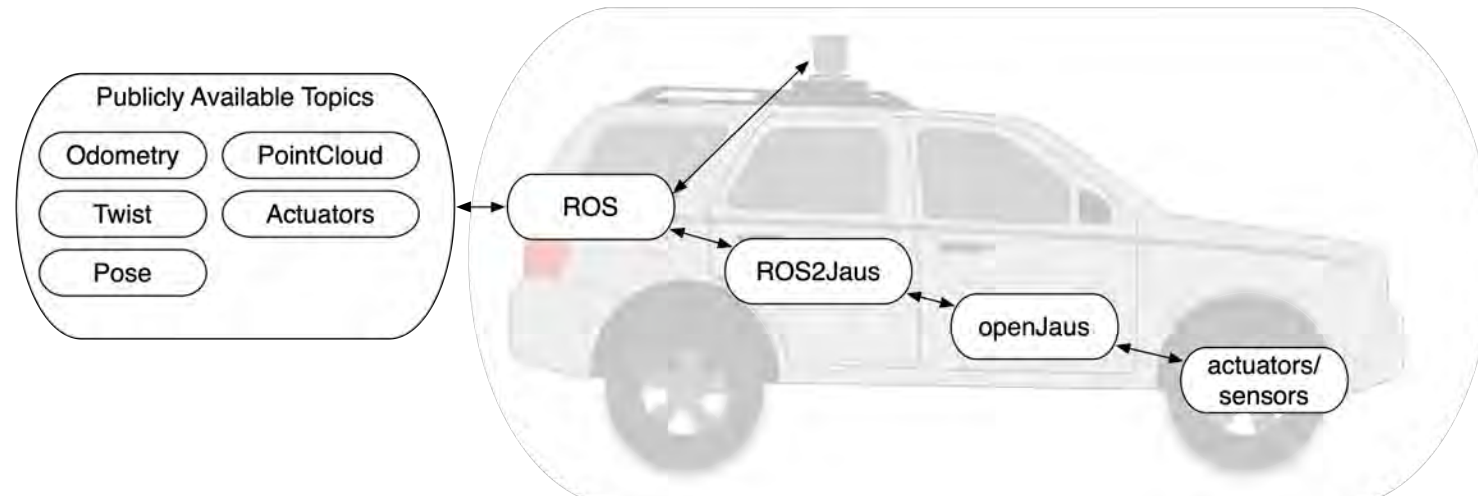


Goal: 100 actuated cars, with up to 2,000 cars affected by our intelligent system's design

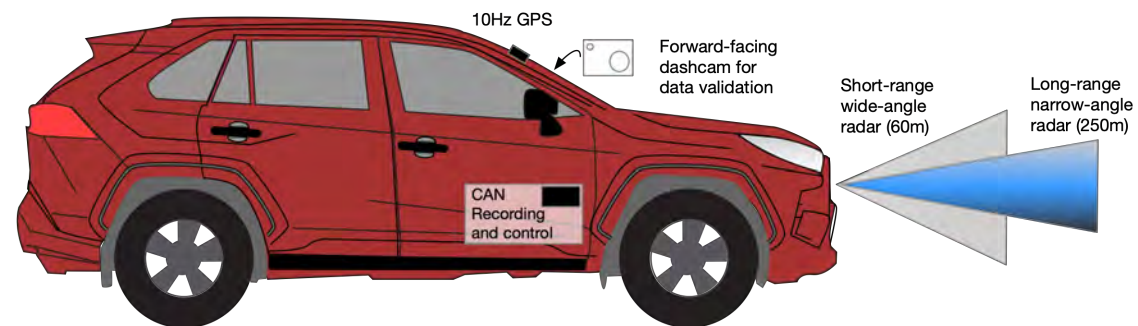
With control: More uniform flow, less fuel used. Only some cars controlled/measured, all vehicles estimated



Getting to scale



<i>Platform/cost</i>	<i>Vehicle cost</i>	<i>Data/actuation cost</i>
<i>CAT Vehicle</i>	\$35,000	\$120,000





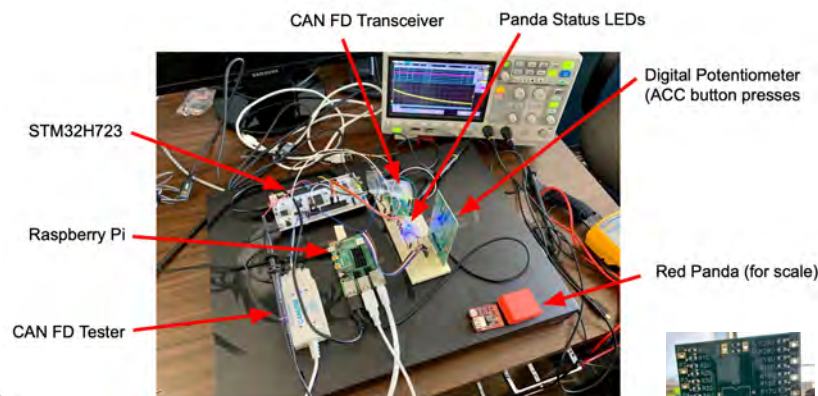
How to beat the global supply chain?



Raspberry Pi 4B



GPS Receiver



- Substantial support from purchasing staff
- In-house redesigns



Dashcam



MatHat™

Hardware assembly

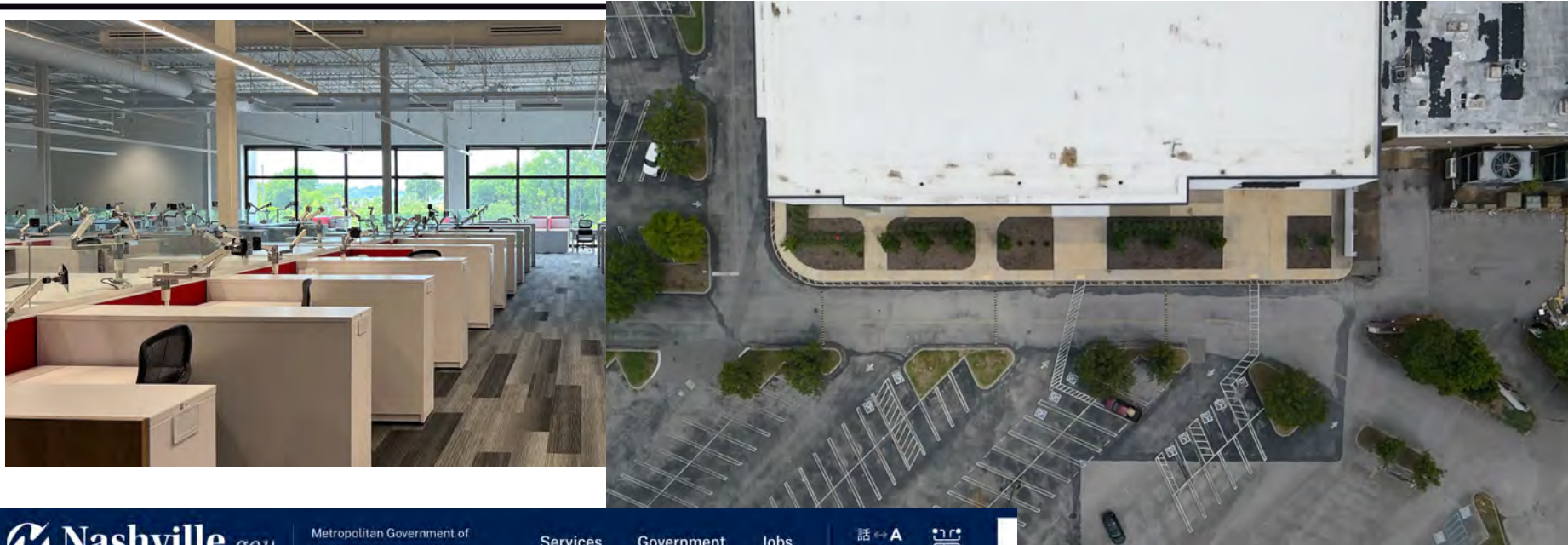


The first round trip to pick up 95 cars from Nissan's Smyrna Plant.
Total transport time to retrieve cars: 12+ hours





Partnering with Metro Nashville for Field HQ



Metropolitan Council Budget and Finance Committee Meeting, October 3, 2022

[Home](#) > [Departments](#) > [Council](#) > [Boards and Commissions](#) > [Metro Council](#) > [Board Meeting](#)

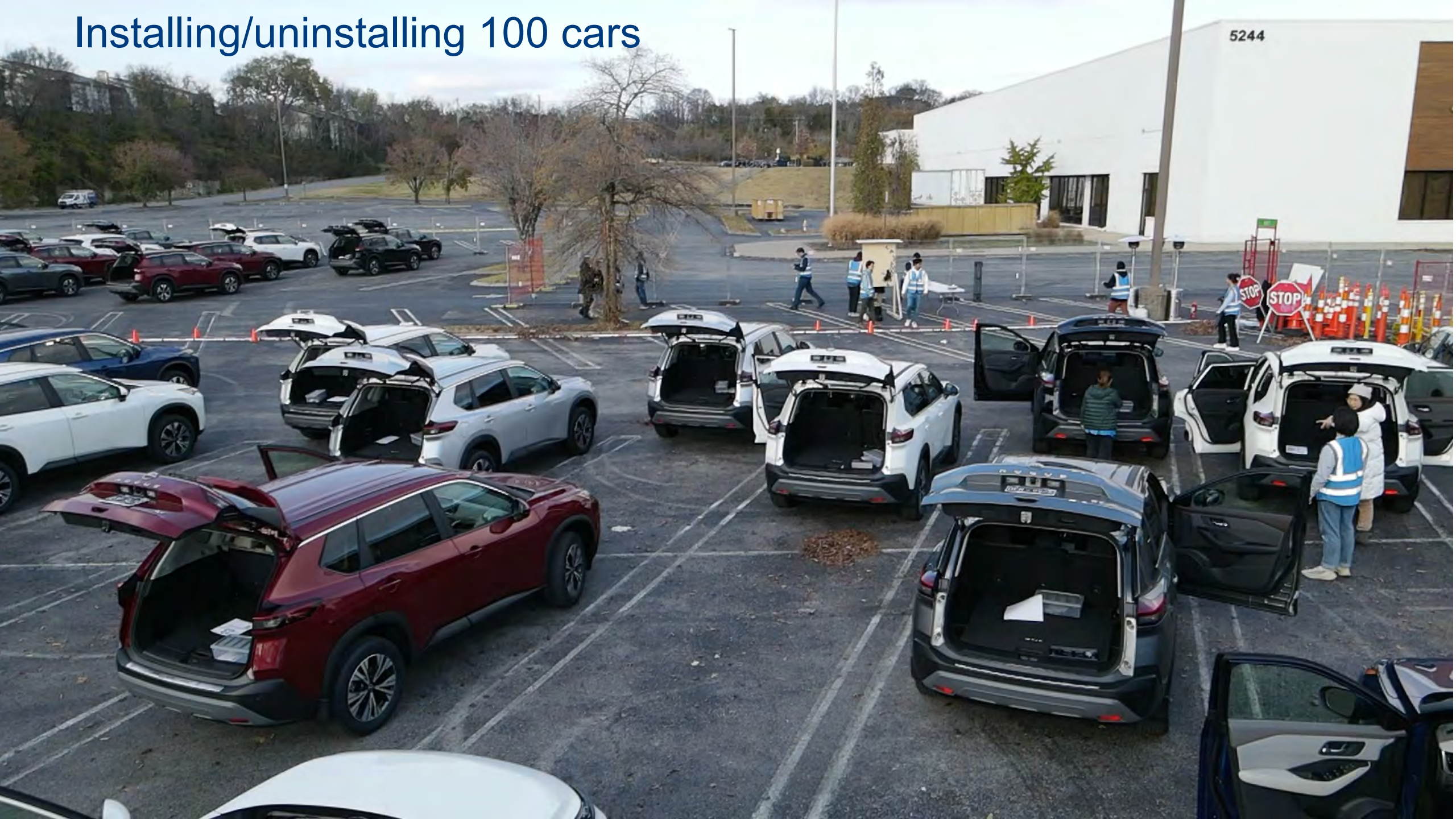
23. [BL2022-1451](#) (Styles, Rhoten, Withers)

Referred to the Budget & Finance Committee (Rhoten)
 Referred to the Planning & Zoning Committee (Withers)

Approves a license agreement between the Metropolitan Government of Nashville and Davidson County and Vanderbilt University for use office space and parking spots located at 5224 Hickory Hollow Parkway, Nashville, TN (Parcel No.16300022100) (Proposal No.2022M-033AG-001).

ACTION	FOR	AGAINST	NV

Installing/uninstalling 100 cars



During CIRCLES

- A computer in the vehicle automatically changes the cruise control settings

Adaptive Cruise: Your Settings stay on while engaged



CIRCLES Research: Settings change based on traffic conditions



The largest open-road field test in history



How do we measure effectiveness?

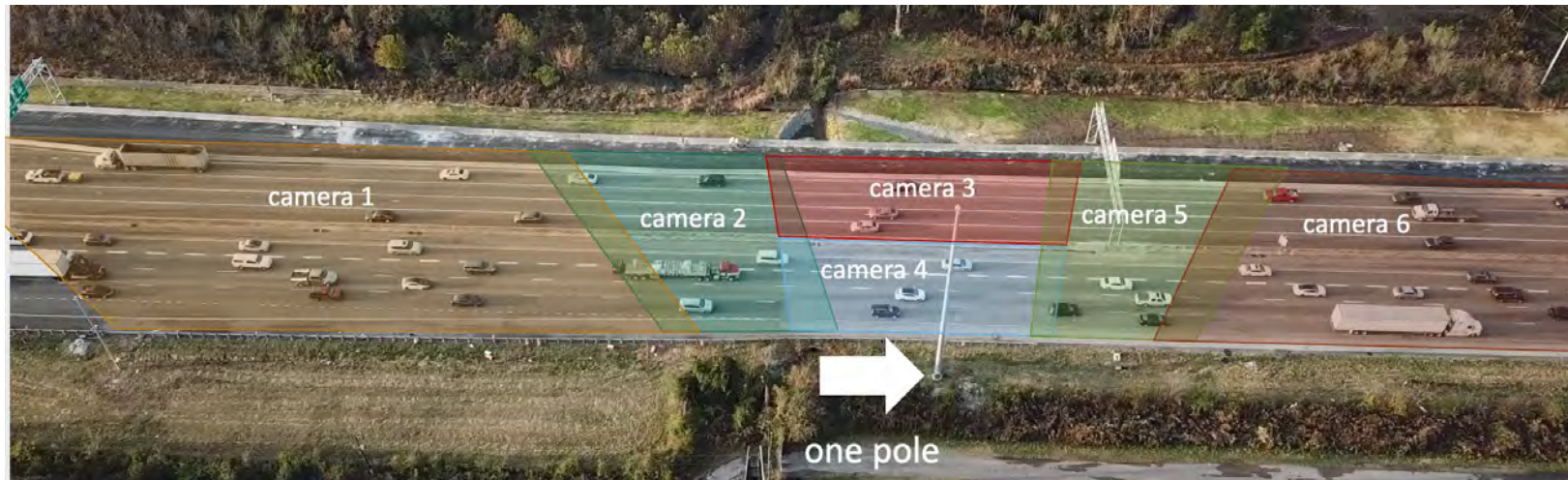


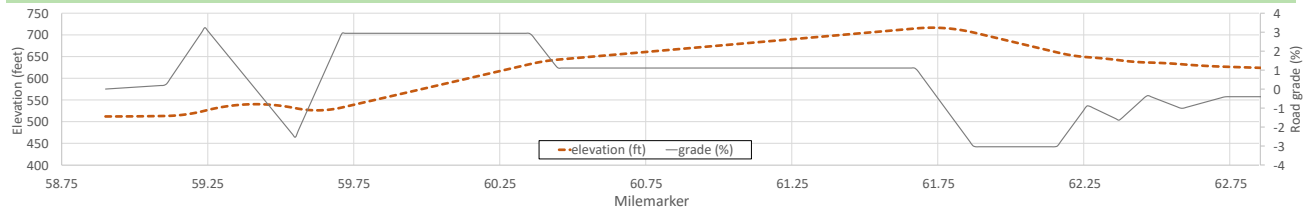
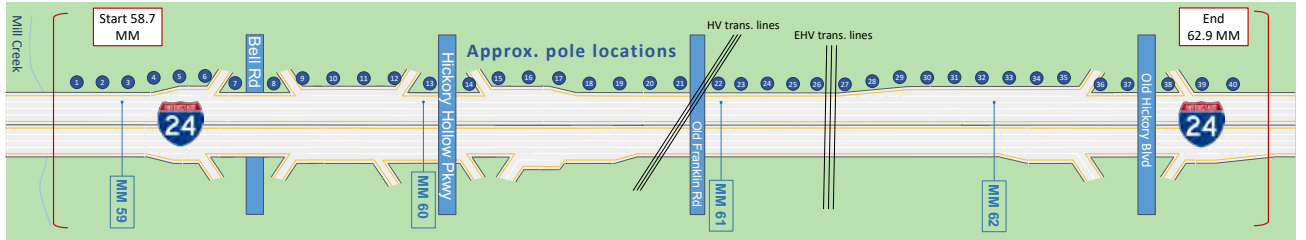
TDOT's I-24 Motion: "MRI for Traffic"

- Captures the behavior of all vehicles in the flow
- Free data available today



40 poles, spaced every 550 ft

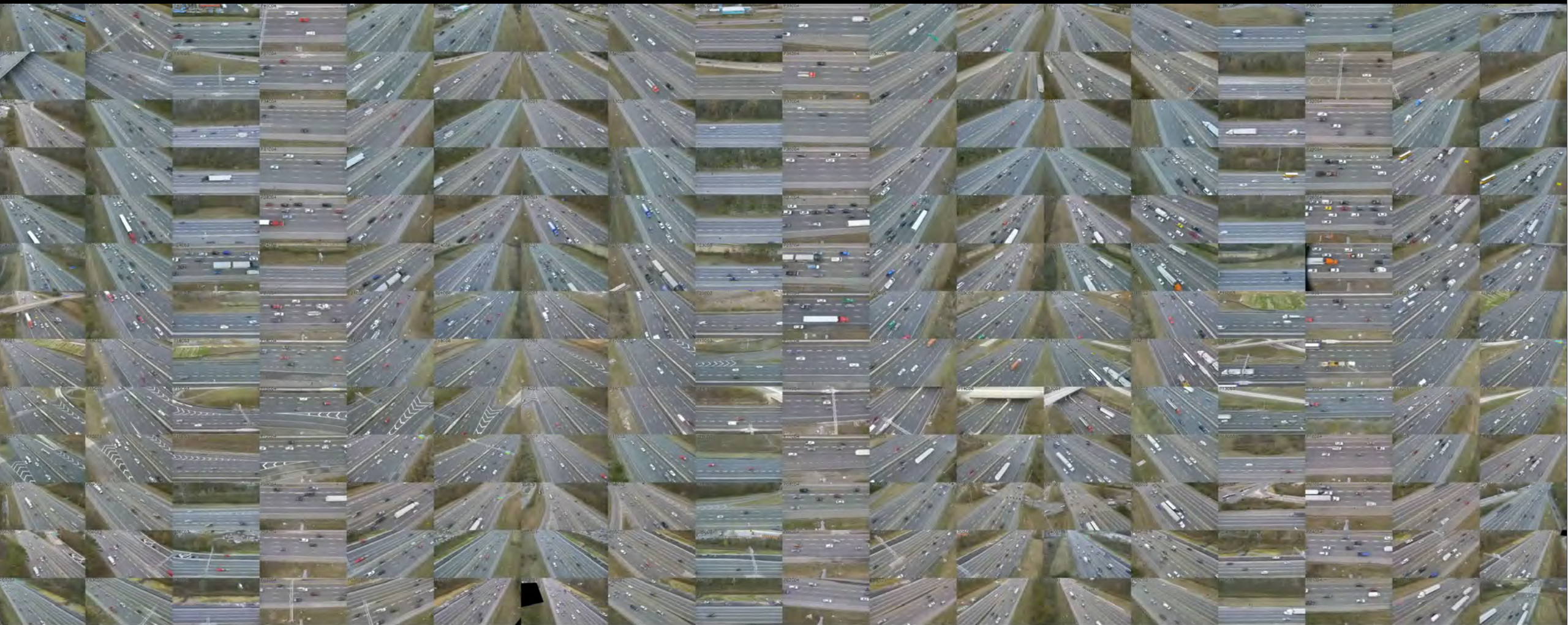






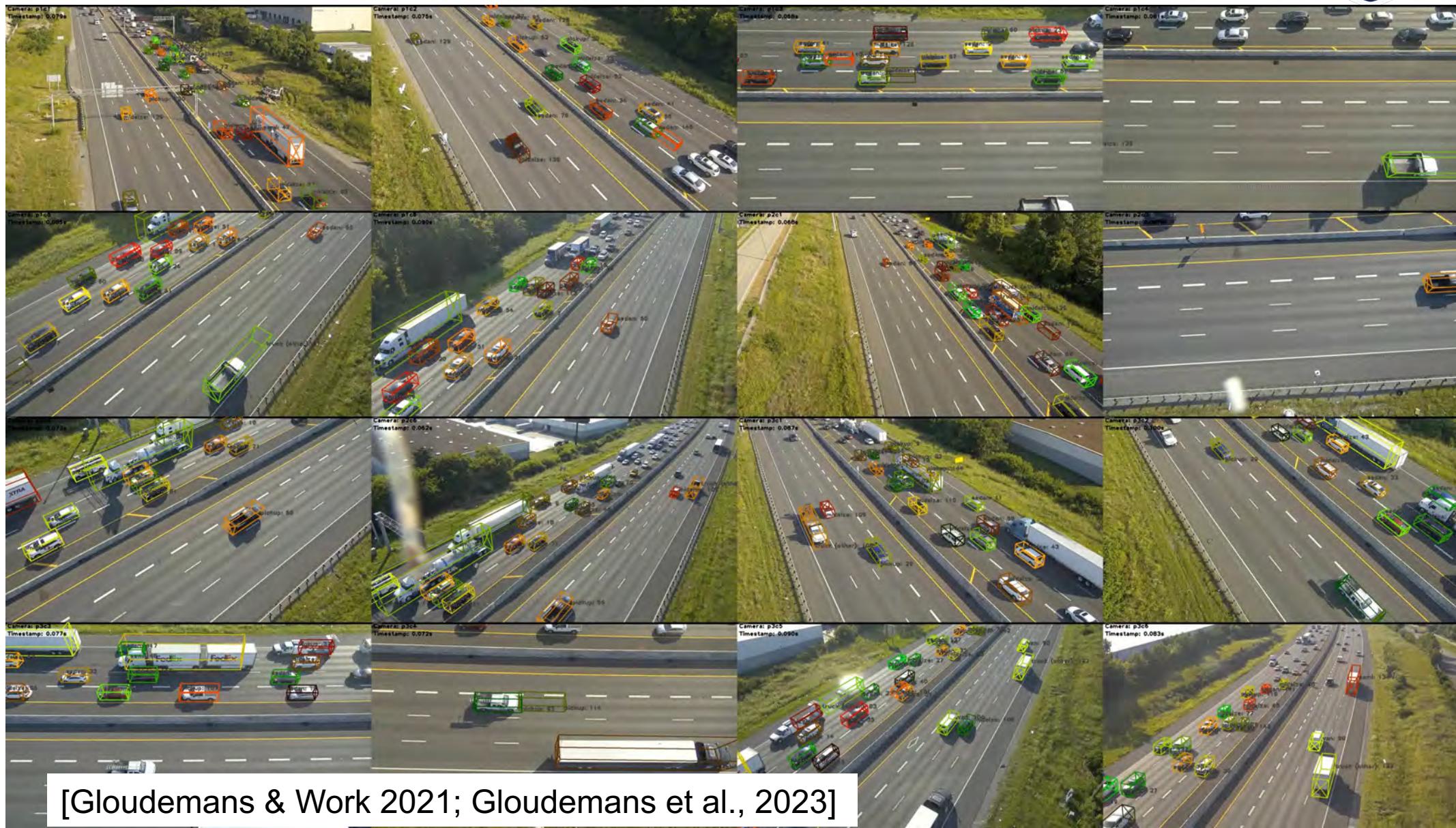
**I-24
MOTION**

New Instrument for Freeway Traffic Science



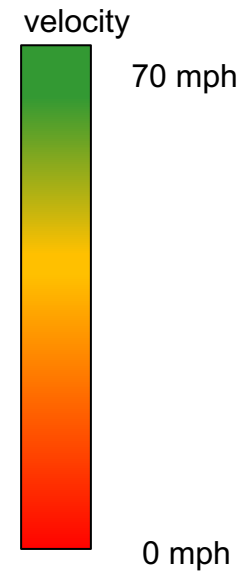
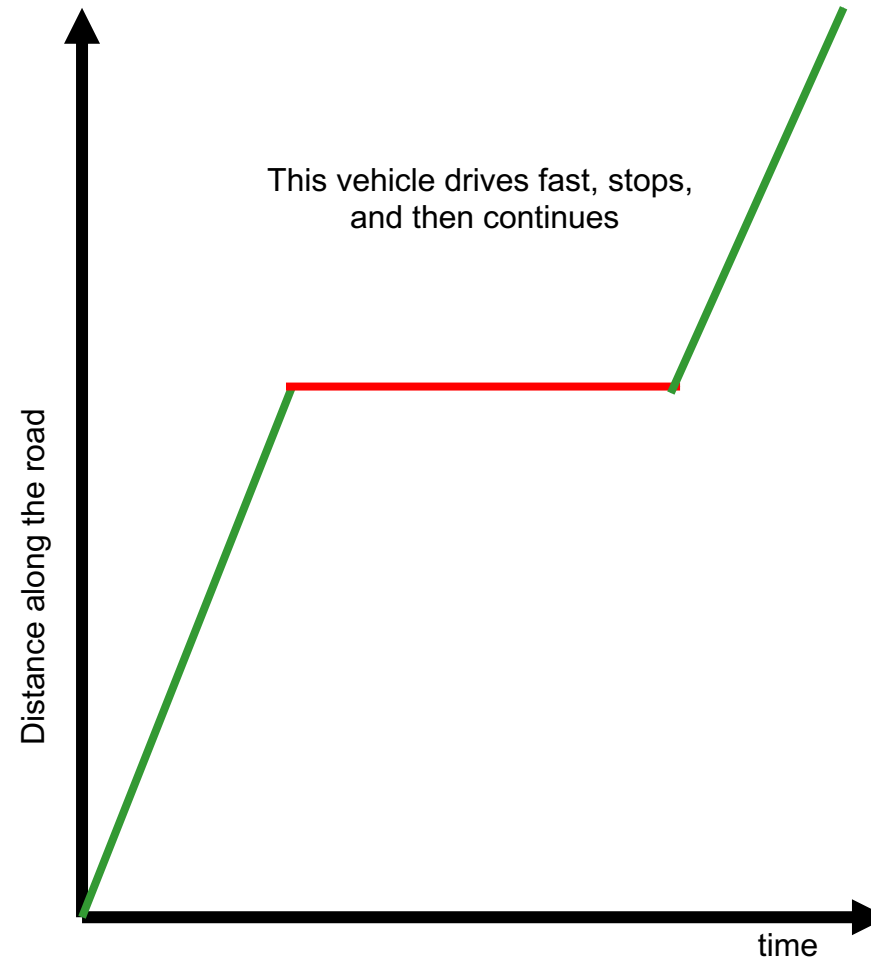
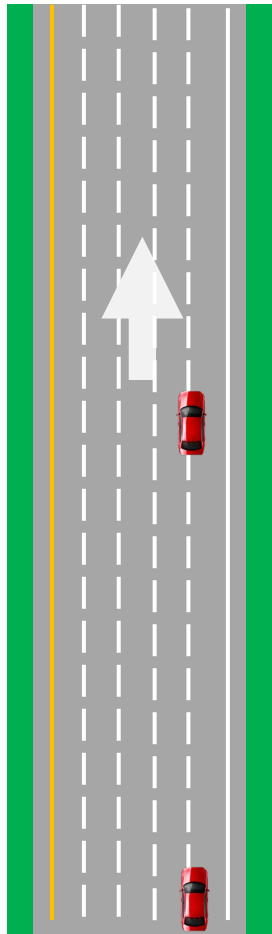
4 miles of cameras observing all vehicles

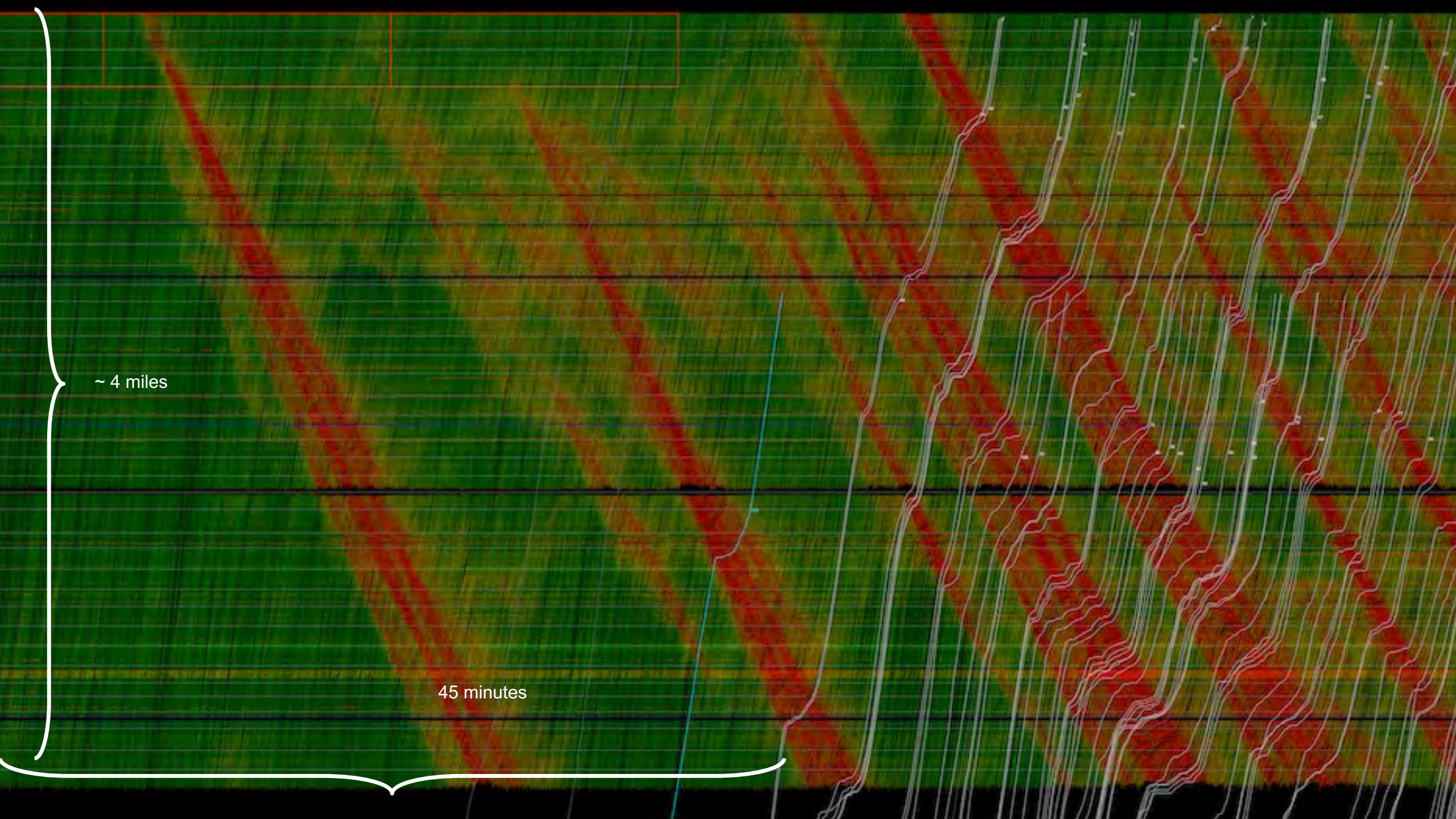
Computer vision algorithms generate trajectories



[Gloude-mans & Work 2021; Gloude-mans et al., 2023]

How to read a “traffic MRI”:

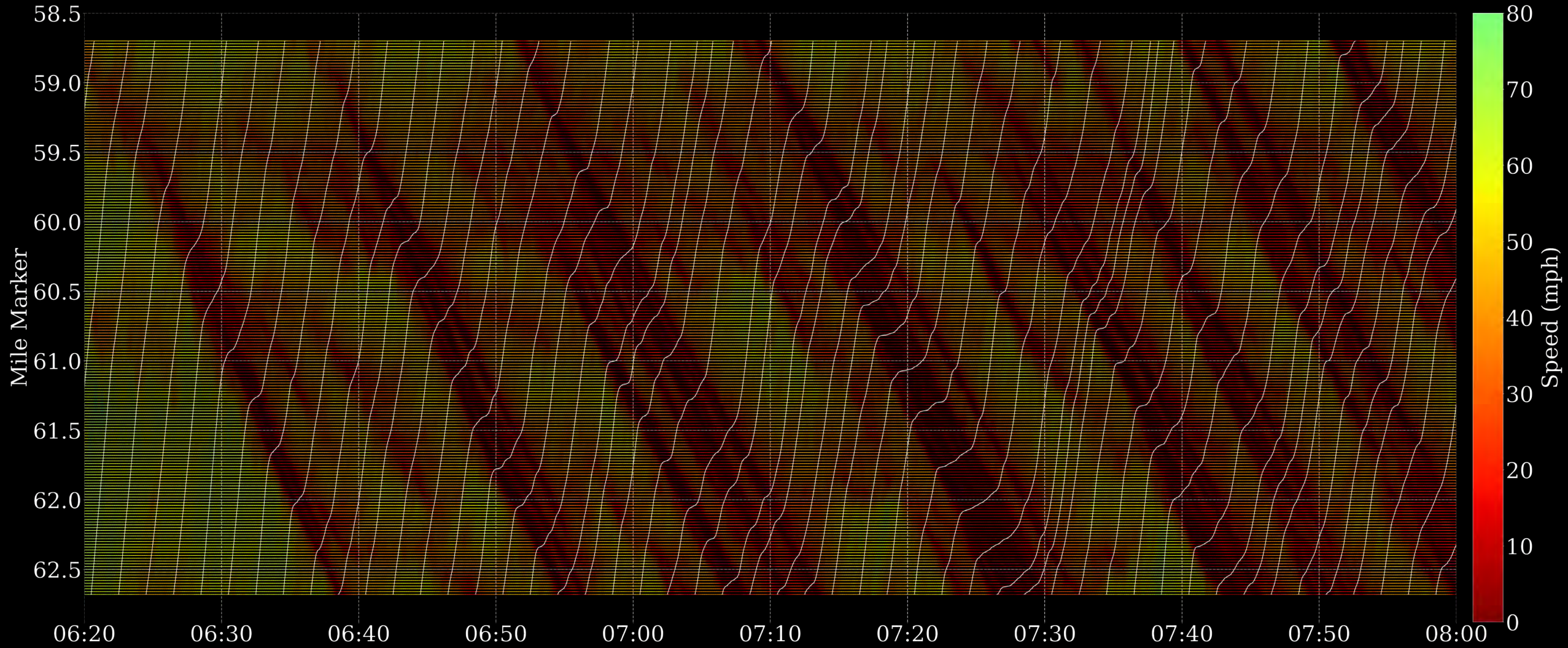




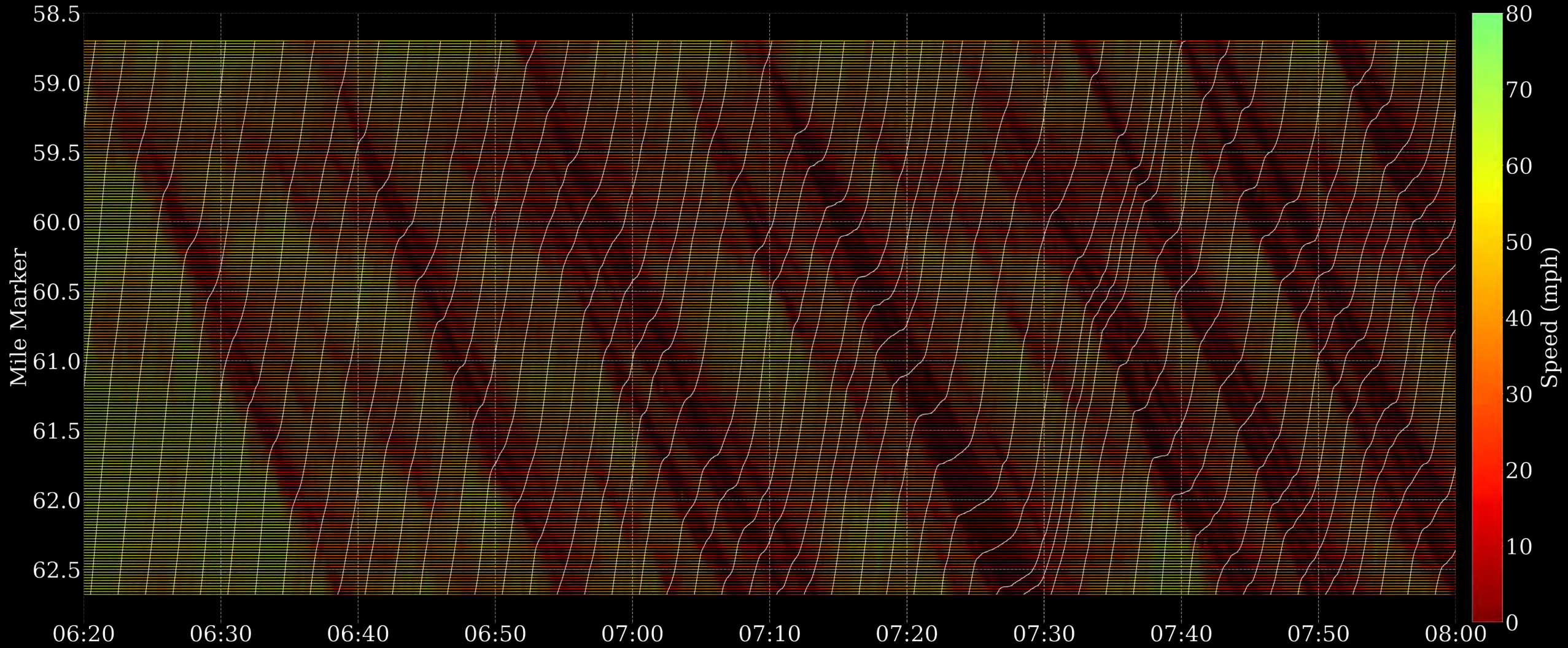
~ 4 miles

45 minutes

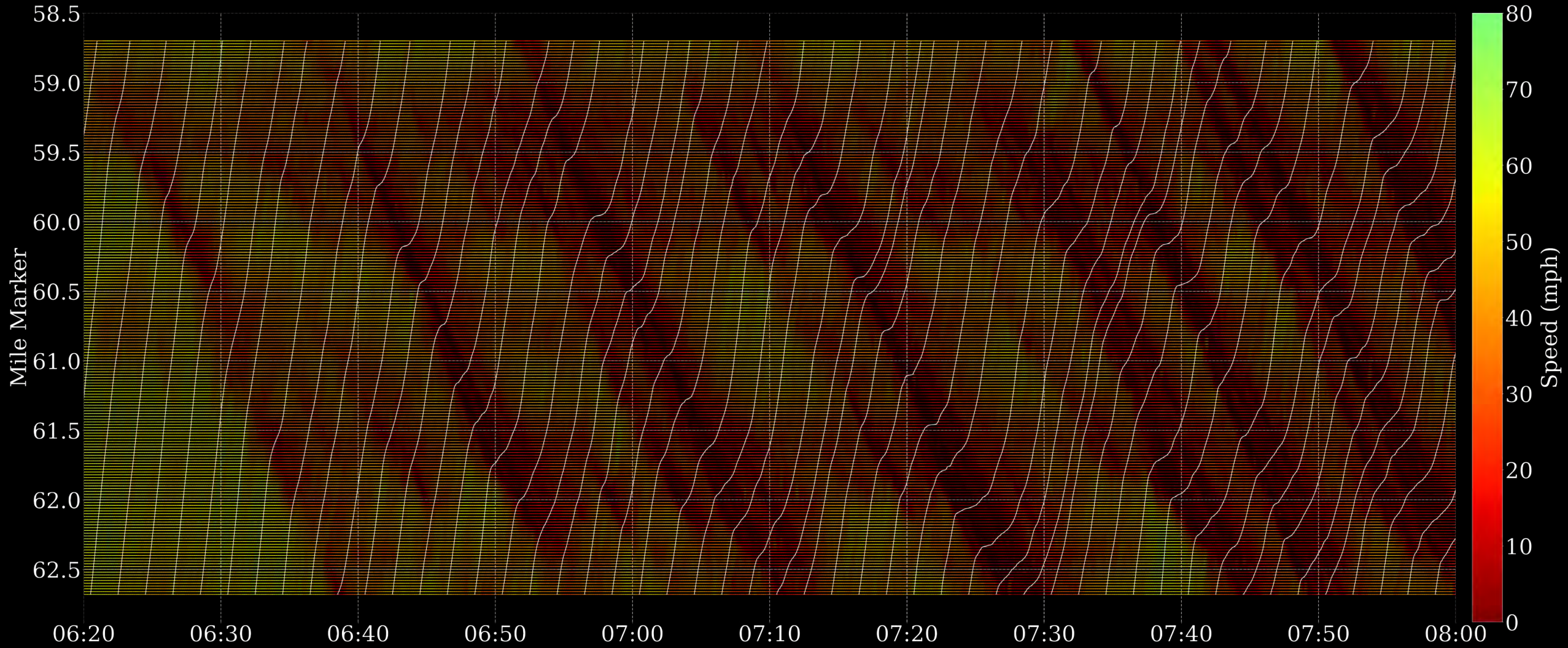
Lane 1 (HOV lane)



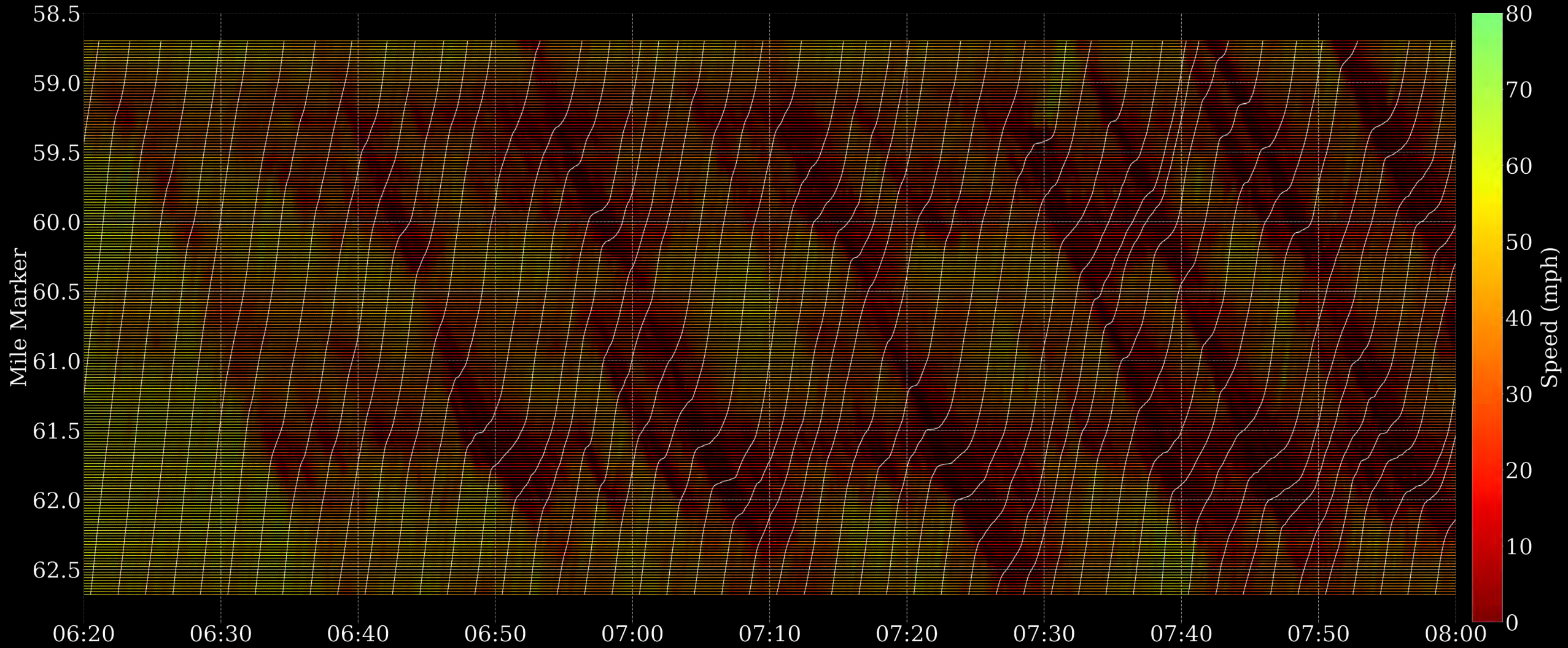
Lane 2



Lane 3



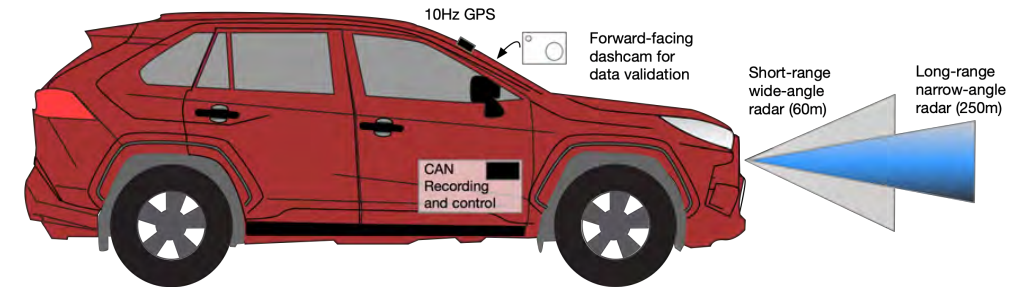
Lane 4



Complementary Capabilities



- An MRI for traffic
- Open-road freeway laboratory
- Measurement of all vehicle trajectories



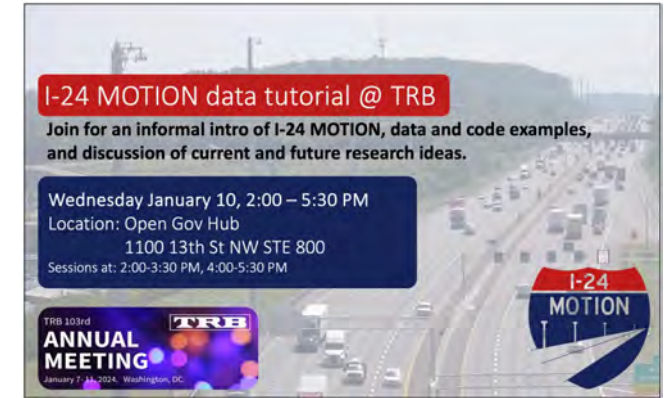
- Research vehicle testbeds
- High-frequency measurement
- Sophisticated control
- Coordinated testing

Footage from Deployment
In Morning Congestion
Westbound I-24



People are interested in the data and tools

- 80+ attendees
- Held at the 2024 Transportation Research Board Annual Meeting



What do they use the data for:



We are creating new educational experiences

First cohort of “Traffic and Autonomous Vehicles”



- First in the world course on “Traffic and Autonomous Vehicles”
- Offered Fall 2023 by Profs. Sprinkle & Work
- Project teams designed their own algorithms and ran them on our Rav4

Many thanks!!





A big research team made it possible

Institute for Software Integrated Systems research staff, students, and faculty engaged directly in the research include Will Barbour, Matthew Bunting, Gergely Zachar, Matt Nice, Riley Wagner, Caroline Janssen, Derek Gloudermans, Gracie Gumm, George Gunter, Yue Hu, Junyi Ji, Alex Richardson, Yanbing Wang, Xia Wang, Yuhang Zhang, Zhiyao Zhang, Dan Work, and Jonathan Sprinkle.

Additional participants who made the MegaVanderTest possible through operations or participation include Eric Hall, Kristy Kruse, Mary Margaret Sprinkle, Arthur Sung, Keneshia Sweet, and Shelly Wolf from Institute for Software Integrated Systems, Officer Patrick Conwell from Vanderbilt University Police Department, Rahul Bhadani, whose software written prior to joining Institute for Software Integrated Systems was critical to the project's success, and visiting researchers from Fabian Walocha and Duc Hai Le from the German Aerospace Center (DLR).

Partners at Tennessee DOT, Gresham-Smith, and Nashville DOT were critical to the success of the deployment of the I-24 MOTION Testbed.

Sustained investments include:



“CAREER: Domain-Specific Modeling Techniques for Cyber-Physical Systems” NSF CNS-1253334 (PI: Jonathan Sprinkle)

“CAREER: Modeling and Estimation Methods for Complex Traffic” NSF CMMI-1351717 (PI: Dan Work)

“CPS: Synergy: Collaborative Research: Control of Vehicular Traffic Flow via Low Density Autonomous Vehicles”, CNS-1446435, 1446690, 1446702, 1446715 (PIs: Dan Work, Benedetto Piccoli, Benjamin Seibold, Jonathan Sprinkle)

“CPS: TTP Option: Medium: Collaborative Research: Smoothing Traffic via Energy-efficient Autonomous Driving (STEAD)” NSF CNS-1837652 (PIs: Dan Work, Benedetto Piccoli, Alex Bayen, George Pappas)

“CPS: TTP Option: Medium: Coordinating Actors via Learning for Lagrangian Systems (CALLS)” NSF CNS-2135579 (PIs: Dan Work, Alex Bayen, Jonny Lee, Jonathan Sprinkle)

“Congestion Impacts Reduction via CAV-in-the-loop Lagrangian Energy Smoothing (CIRCLES)” U.S. Department of Energy’s Office of Energy Efficiency and Renewable Energy (EERE) award number CID DE-EE0008872. (PIs: Alex Bayen, Benedetto Piccoli, Benjamin Seibold, Jonathan Sprinkle, Dan Work)

I-24 MOTION, U.S. Department of Transportation and TN Department of Transportation



Resilient Highways: Experiments in Traffic Smoothing

Dan Work
Professor

Civil & Environmental Engineering
Institute for Software Integrated Systems
Vanderbilt University

Joint work with Prof. Jonathan Sprinkle & our collaborators:

I-24 MOTION: Lee Smith, Michelle Nickerson, Said El Said, Brad Freeze (TDOT); Matt D'Angelo, Meredith Cebelak (Gresham Smith); Derek Gloudemans, Yanbing Wang, Junyi Ji, Eric Hall, Gergely Zachar, Will Barbour, Craig Philip

CIRCLES: Alex Bayen, Jonny Lee, Maria Laura Delle Monache, Benedetto Piccoli, Benjamin Seibold. Additional thanks to Rahul Bhadani, Matt Bunting, Sean McQuade, Matt Nice, Riley Wagner, Regan Williams, and many other collaborators for their production of slide materials and images.

[Research Sponsors: NSF, USDOE, US DOT, Tennessee DOT, and Vanderbilt. Views are our own]

