Resilient traffic systems

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, Cam Morris, Xiaoyang Jia, Matt D'Angelo, Christina Florez, Meredith Cebelak (Gresham Smith); Derek Gloudemans, Yanbing Wang, Junyi Ji, Eric Hall, Gergely Zachár, Will Barbour, Craig Philip
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[Research Sponsors: NSF, USDOE, US DOT, Tennessee DOT, and Vanderbilt. Views are my own]

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How can we leverage data we already collect to measure resilience?

- 2-10K taxis
- ~170M trips/yr
- 200+ GB data
- Only two GPS points
  - Start of trip
  - End of trip
- Travel time
- Total distance traveled

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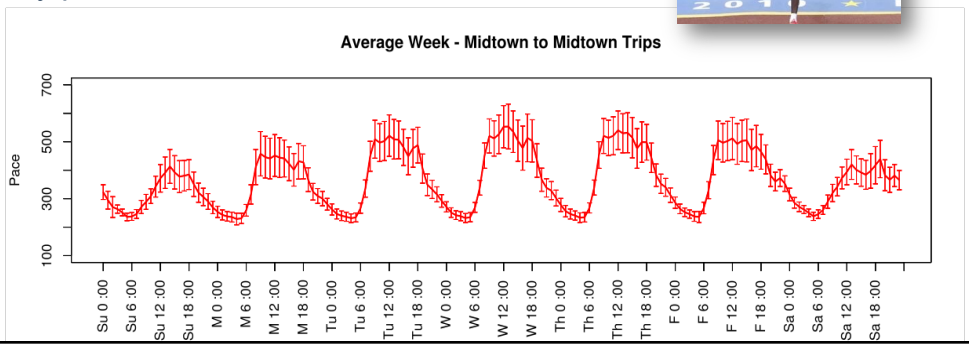
Compute origin destination paces

- Pace = travel time / distance (normalizes against distance)
- Average pace = 4.6 minutes / mile
  - Varies over time and distance
- Compute hourly OD paces, assume traffic is weekly periodic:



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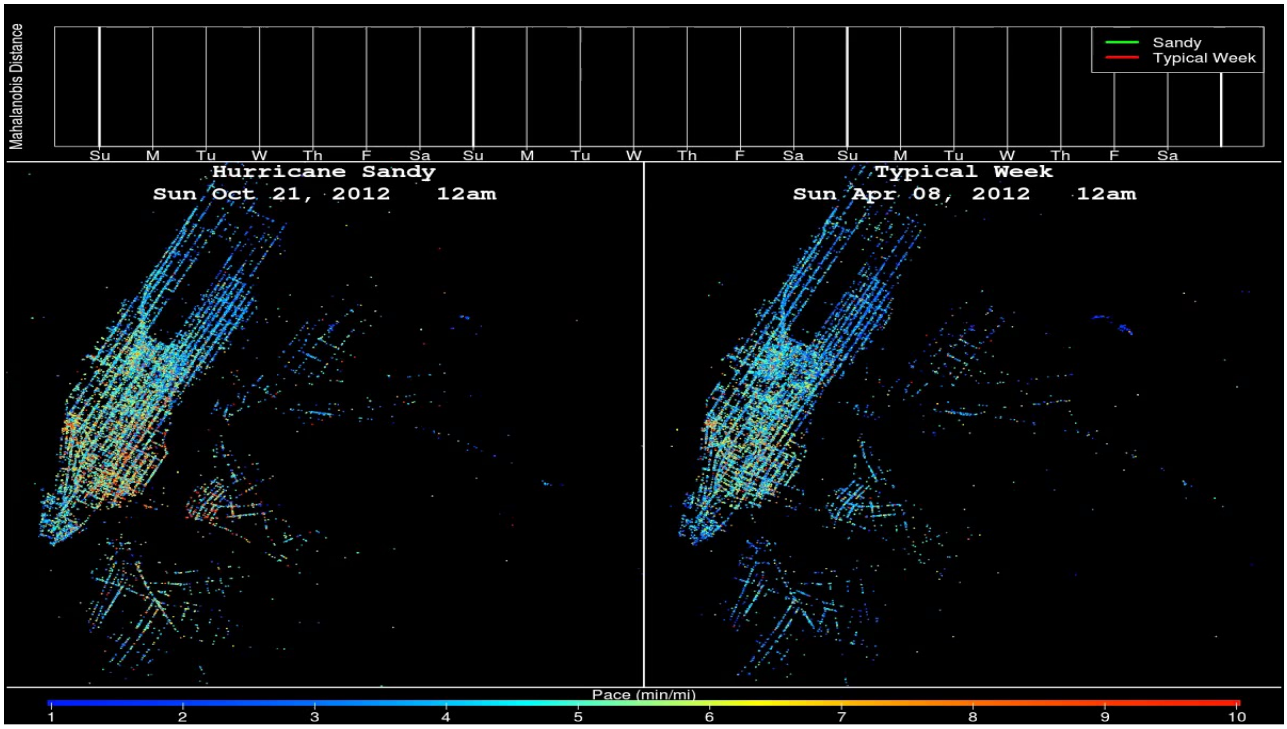

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Step 5: Worst events in New York City

Event	Start Time	Duration (Hours)	Max Pace Dev (Min/Mi)	Min Pace Dev (Min / Mi)	Worst Trip
Hurricane Sandy	2012-10-28 21:00	134	2.26	-1.54	M->E
Snowpocalypse	2010-12-26 13:00	109	4.24	0.33	L->U
Blizzard	2011-01-31 10:00	47	2.01	0.34	U->E
Hurricane Irene	2011-08-27 13:00	43	0.65	-1.65	M->U
Blizzard	2010-02-10 06:00	32	0.65	-1.03	E->U
Blizzard	2013-02-08 06:00	27	1.53	-0.59	U->U
unknown	2013-10-12 14:00	22	1.09	0.35	E->M
NYE	2012-12-31 15:00	20	1.41	-2.62	M->M

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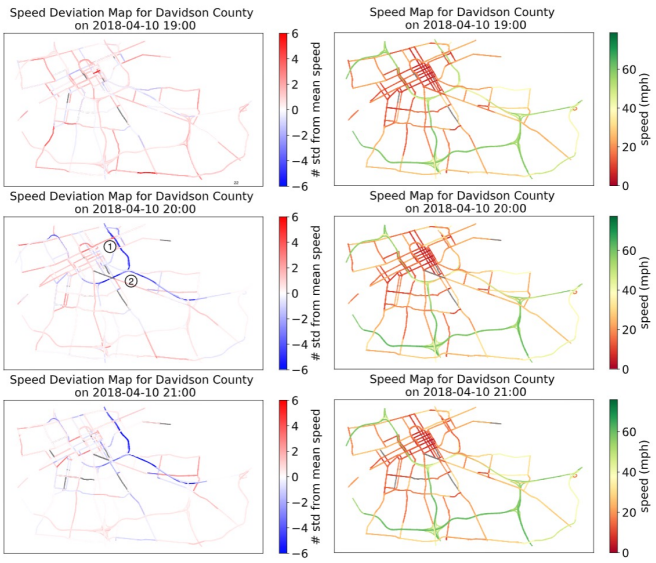
Nashville example w/ HERE data

Input:

- Traffic speed data of downtown Nashville from HERE, between Jan 1 to Apr 29, 2018.
- Observation ratio 80%, 556 road segments for 17 weeks, hourly resolution.

Result:

- Detected events like major car crashes, the marathon, and road closures.
- Example: detected maintenance lane closures in two major Interstate highways (① Interstate 24, ② Interstate 40).



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Zooming into freeways
[video courtesy TDOT]

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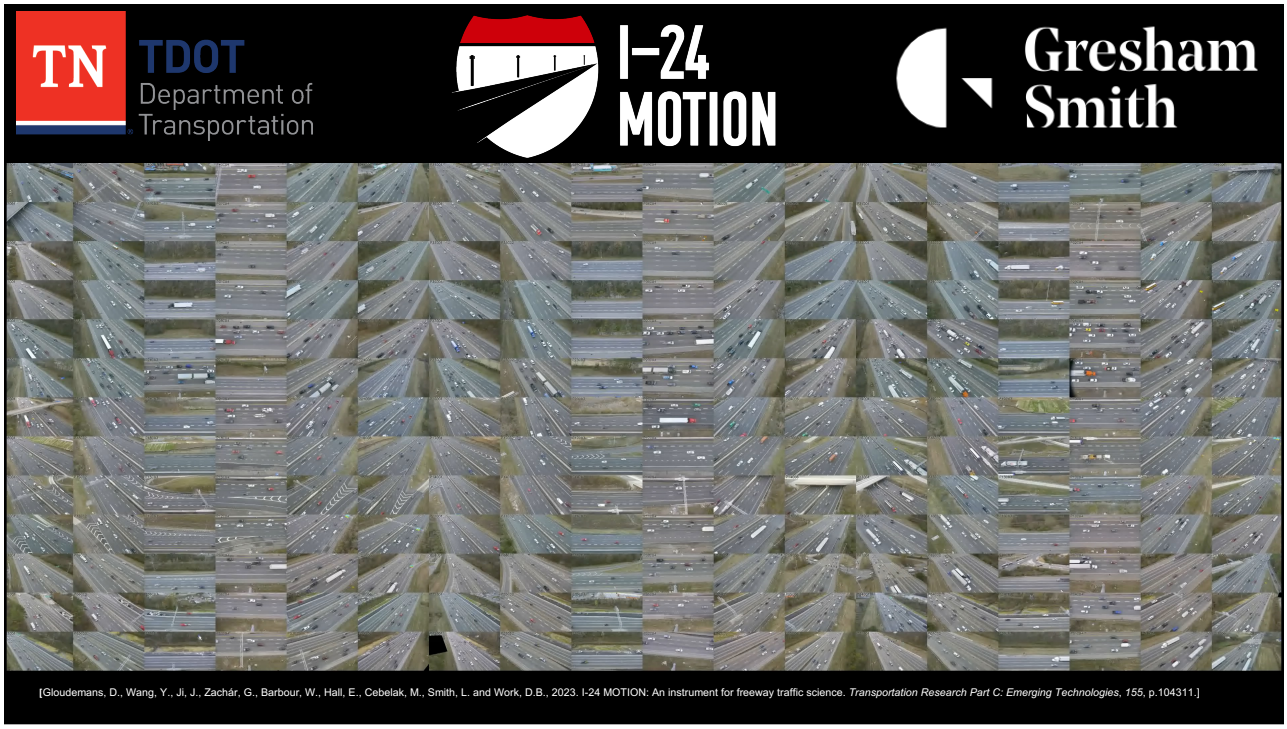
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Department of Transportation
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Gresham Smith
[Gloudemans, D., Wang, Y., Ji, J., Zachár, G., Barbour, W., Hall, E., Cebelak, M., Smith, L. and Work, D.B., 2023. I-24 MOTION: An instrument for freeway traffic science. Transportation Research Part C: Emerging Technologies, 155, p.104311.]

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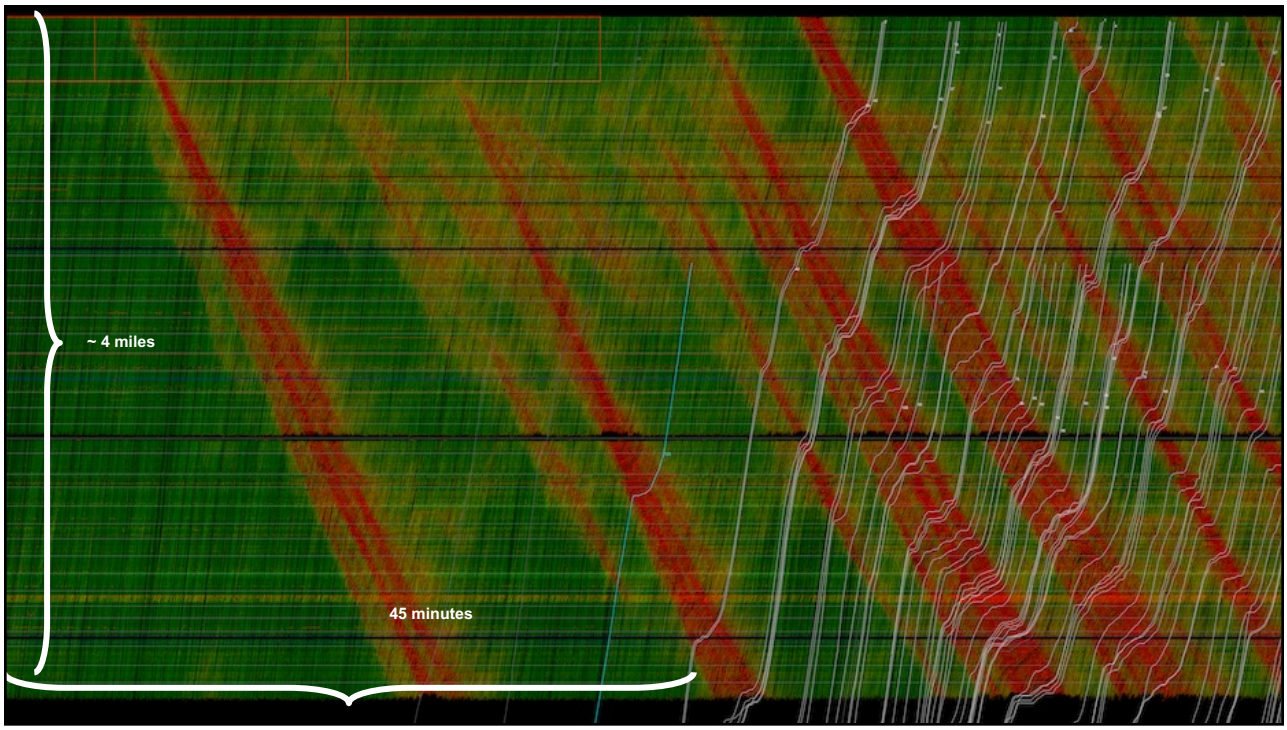

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~95% of the days we look at have phantom jams

5/13	5/14	5/15	5/16	5/17
5/20	5/21	5/22	5/23	5/24
5/27	5/28	5/29	5/30	5/31
6/3	6/4	6/5	6/6	6/7
6/10	6/11	6/12	6/13	6/14
6/17	6/18	6/19	6/20	6/21
6/24	6/25	6/26	6/27	6/28
7/1	7/2	7/3	7/4	7/5
7/8	7/9	7/10	7/11	7/12
7/15	7/16	7/17	7/18	

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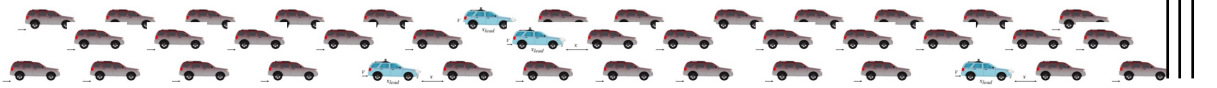
CIRCLES Project funded by U.S. DOE and NSF

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

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



PIs: Alex Bayen, Maria Laura Delle Monache
Jonny Lee, Benni Seibold, Benedetto Piccoli,
Jonathan Sprinkle, Dan Work

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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

[Lee et al., 2023; Nice et al., 2023, under review]

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The largest open-road field test of wave-smoothing ACC in history

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Another approach – Variable Speed limit (VSL) control

- Post legally enforceable speed limits
- Ask 150,000 drivers per day follow them

TN TDOT Department of Transportation ARCADIS Stantec SwRI Southwest Research Institute 24 smart CORRIDOR

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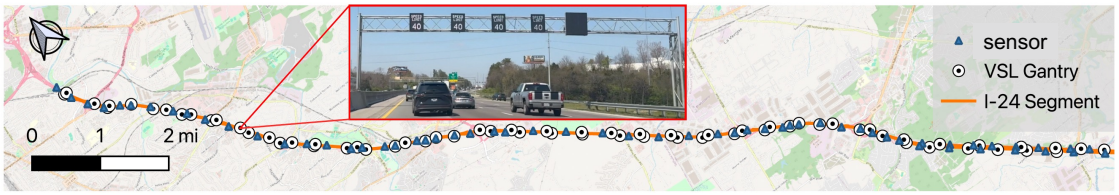
Multi-Agent Reinforcement Learning VSL Design



- **Agents.** One per gantry. For scalability, all agents are homogeneous
- **State space:** Downstream speed & occupancy, upstream speed and occupancy, downstream gantry's speed limit.
- **Action space:** Valid speed limits (with action masking to enforce step-down constraints)
- **Reward:** A weighted balance of performance goals
  - **Safety:** post a valid slowdown profile near the congestion tail
  - **Mobility:** Post higher speeds when traffic allows
  - **Adaptability:** Penalize large deviations between measured speeds and posted speed limits

[design details in Y. Zhang, M. Quiñones-Grueiro, Z. Zhang, Y. Wang, W. Barbour, G. Biswas, D. Work, 2023; more experimental details on Wednesday here at IEEE ITSC!]

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Since deployment on March 8, 2024:

- **The Multi-agent reinforcement learning (MARL) VSL has made more than 38,500,000 decisions**
- **More than 30,000,000 trips on the corridor with MARL VSL running**

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