The Role Of Transportation Infrastructure In The Future Of Connected And Automated Vehicles, 02/14/24

Donghang Li

Part I. Literature

I. Future Road Infrastructure

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II. Phantom Congestion

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Part II. Recent News

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Part III. Q&A

I. Jinhua's Questions

Question: Instead of a fixed maximum speed limit, could regulations control speed variation between vehicles to enhance safety?

Answer: Jen Duthie and Dan Work responded that speed variation is indeed a key factor in traffic instability. For example, on a highway, when one lane slows due to an exit ramp, it can cause disruption to the overall traffic flow. However, from a policy and technical point of view, this kind of regulation is more difficult to implement, especially in the case of mixed human and autonomous driving. Self-driving vehicles such as Waymo may strictly adhere to the speed limit, while nearby human-driven vehicles may choose to go faster, raising safety concerns. From the point of view of mathematical modeling, this speed regulation method can be combined with consensus algorithm to optimize the overall stability of traffic flow, but in reality, the feasibility of large-scale implementation needs to be considered.

Question: With the development of autonomous driving, humans may gradually relinquish decision-making power at different levels, from acceleration and deceleration at the lowest level, to path selection at the middle level, and even eventually relinquish high-level decisions (such as destination selection) to the machine. So what are the key issues that infrastructure operators and researchers should focus on as they evolve?

Answer: Dan Work believes that technological advances have led to a gradual shift away from low-level driving details, but this also brings new risks. For example, if some systems are manipulated maliciously, they can deliberately disrupt traffic flow, triggering artificial "phantom blockages" or path interference. Therefore, the research community not only needs to explore the potential of autonomous driving, but also needs to develop tools to detect and prevent these problems. Jen Duthie argues that even today, the question of "who is the decision maker" already exists, such as how ride-sharing platforms can transparently present costs to passengers and give them choices on dynamically priced toll roads, which is a practical dilemma. In the future, people may be willing to cede some control, but still want to regain decision-making power when needed, so a completely system-led model remains challenging in the short term.

Question: While the software industry can roll out updates every few weeks, the automotive industry only rolls out new models every 3-5 years, and infrastructure can take a decade or more to build. So how should infrastructure operators plan for long-term investment in the face of such a huge pace difference in technology turnover?

Answer: Jen Duthie believes that the public-private partnership (PPP) model can help governments manage this technological risk more flexibly. In some projects, the private sector can take on part of the technology investment with a commitment to continue updating in the future,

while the government can focus on setting overall service goals rather than specifying specific technology solutions. For example, in the transition from DSRC to C-V2X, the adaptability of the infrastructure becomes a key issue. Dan Work further pointed out that unlike rapid updates for smartphones, infrastructure must be more careful to balance technological updates with long-term durability. But he believes that technologies such as artificial intelligence, big data analytics and computer vision can empower infrastructure to be more flexible and sustainable, so as to avoid obsolescence as technology changes too quickly.

II. Audience Questions

Question: As road infrastructure becomes more "smart," will drivers' privacy be invaded?

Answer: Jen Duthie stressed that road operators generally do not collect personally identifiable information, especially in some projects where the toll system is managed by the government or a third party, rather than the operators themselves. Even in cases where user information is required, strict privacy measures are in place to ensure that the data is not misused. Dan Work further added that while infrastructure operators may not store personal data directly, different data sources (such as mobile phones, vehicles, road sensors) can inadvertently reveal user identities. Therefore, privacy protection is crucial in digital traffic management systems, and academia and industry need to work together to develop strict privacy protection mechanisms to ensure that user information is not misused or inferred.

Question: Does the highway of dynamic pricing benefit only the rich?

Answer: Jen Duthie explained that the US toll Express lanes operated by Cintra are not stand-alone toll roads, but run in parallel with the free roads, with the goal of providing users with an always-on route for urgent needs, such as rushing to the hospital or picking up and dropping off children. In addition, the express lanes are usually free to public transport vehicles and high occupancy vehicles (HOVs) to ensure that not only high-income people can enjoy this infrastructure. On the 407 ETR in Canada, which is an all-toll road, the issue is more complicated, so Cintra is also trying to introduce various policies to balance profit goals with social equity.

Question: Whether the "Phantom congestion" experiment effectively alleviates traffic congestion?

Answer: Dan Work explained that the experiment used 100 modified Nissan vehicles to test the effect of automatic cruise control on traffic flow. The results showed that energy consumption was reduced by about 10 percent, but since autonomous vehicles still have to mix with human-driven vehicles, it remains challenging to completely eliminate "phantom blockages." He further pointed out that in the current traffic environment, if only a small number of autonomous vehicles strictly follow the best driving strategy, they may be incompatible with the mainstream traffic flow, resulting in additional safety risks. Therefore, future research should focus on how to make

autonomous vehicles "seamlessly integrate" with the overall traffic flow in the case of low penetration, and gradually improve the overall road efficiency and safety.

Part IV. Summary of Memos.

I. Summary of others' reflections

The memos reflect on Jen Duthie and Dan Work's discussion on the future of transportation infrastructure in the context of connected and autonomous vehicles (CAVs). Several key themes emerge from the reflections, including the gradual transition towards higher levels of automation, the role of infrastructure in supporting this shift, and the challenges posed by increased travel demand.

One major point highlighted by multiple contributors is the mixed-traffic environment that will persist for the foreseeable future. Many emphasize the need for infrastructure planning that accommodates both human-driven and autonomous vehicles, as interactions between the two can be unpredictable. Additionally, several memos discuss the expected increase in travel demand due to automation, with factors like deadheading, longer-distance trips, and increased mobility for individuals who currently cannot drive. This raises concerns that automation might not alleviate congestion but instead exacerbate it, necessitating adaptive traffic management strategies.

Another key focus is on "phantom traffic jams," which Dan Work's research identifies as being caused by small variations in human driving behavior. Some memos discuss the potential of adaptive cruise control and AI-driven traffic management systems to mitigate these inefficiencies. However, there is also recognition that real-world implementation is complex, requiring high penetration rates of automated vehicles and careful integration with existing infrastructure.

Several reflections also explore the shift in decision-making from humans to algorithms, questioning whether individuals will gradually relinquish control over routing and even destination selection. Some express concern over the implications of this shift for personal agency, while others view it as a natural extension of existing technological trends. Equity and privacy concerns are also raised, particularly regarding digital road pricing, surveillance risks, and whether toll-based managed lanes disproportionately benefit wealthier travelers.

Finally, the mismatch between infrastructure development timelines and technological advancements is another recurring theme. While software updates and vehicle innovations occur rapidly, infrastructure projects take decades, making it difficult to align investments with future mobility needs. Some memos propose more modular and adaptable infrastructure designs, while others emphasize the need for regulatory and policy frameworks that can keep pace with technological change.

Overall, the memos highlight the complexities of integrating CAVs into existing transportation systems, balancing innovation with public interest, and ensuring that advancements in automation contribute to a more efficient, equitable, and adaptable mobility future.

II. My reflection

In today's mobility forum lecture, my most profound reflection was on the mismatch between infrastructure, technological innovation, and policy, as well as the shift in decision-making power within automated transportation systems.

First, the pace of infrastructure development lags significantly behind technological advancements. This issue is particularly evident in the transportation industry. As mentioned during the conference, software updates may occur every two weeks, automotive products are replaced every two to three years, while major infrastructure updates often take a decade or even longer. When private companies such as Cintra invest in highways or other transportation facilities, they must anticipate technological changes over the next twenty years, yet the speed of technological iteration far exceeds the lifecycle of these long-term projects. This mismatch not only exposes infrastructure investments to significant technological risks but also leads to inefficient use of public resources. At the same time, the government's conservative approach to infrastructure development further slows down the adaptation to new technologies. In this context, we need to explore more flexible infrastructure investment models, such as incorporating more modular designs, enabling facilities to adapt more easily to technological updates during operation rather than being constrained by existing hardware and regulations.

Another critical issue for reflection is how automated transportation systems impact human decision-making power. During the conference, Jinhua made an interesting analogy—when we purchase a self-driving car, we inherently relinquish control over micro-level decisions, such as acceleration and braking, while possibly retaining the right to choose routes. However, will future intelligent transportation systems gradually strip us of even route selection or destination choices? For instance, if the system detects congestion on a particular road, it may mandate vehicles to take an alternative route. In extreme cases, such as emergency evacuations, it might even enforce carpooling or reassign destinations. While this trend enhances overall system efficiency, it also raises ethical and privacy concerns. Should the decision-making power in automated systems be entrusted to individuals, governments, or private companies? Are people willing to surrender their mobility choices to algorithms beyond their daily commutes? These are critical questions worth deeper consideration.

This discussion made me realize that the future development of transportation infrastructure requires more than just technological breakthroughs—it also demands synchronized adaptation in policy, business models, and social culture. Otherwise, even if the technology matures, the

complexities of the real world may still hinder the realization of the vision for automated transportation.

Part V. Other Information

Other audience's questions:

1. Weather Conditions for AVs
    - What are the Operational Design Domain (ODD) specifications regarding weather for Waymo?
2. Privacy vs. Surveillance
    - Is "protecting the privacy of drivers/passengers" a goal of roadway operators, or is roadway infrastructure going to become an extension of the surveillance state?
    - Specifically, how does this relate to individuals crossing state lines for healthcare access?
3. Real-Time Speed Regulation
    - Are you anticipating that roadway management will change road speeds in real-time?
    - Won't this be very difficult to safely manage with human and autonomous vehicle operators?
4. Digital Infrastructure for AVs
    - Do you foresee installed hardware in roadways assisting AV sensors to maintain speed limits or follow traffic rules?
    - Should infrastructure-to-vehicle data include lane guidance, regulatory information, and cooperative operating strategies?
5. Cost-Sharing Models
    - Any thoughts about cost-sharing models for infrastructure-enhanced systems (digital/others)?
    - How should funding be managed, especially when DOT budgets are tight?
6. Equity in Tolling and Pricing
    - To what extent does pricing (tolling) consider equity?
    - How do policymakers balance profit-making and social benefits in infrastructure operations?
    - Is congestion pricing equitable, given that congestion itself is not distributed equally?
7. Driver Education and Behavior
    - Should we reintroduce driver education in schools to improve driving behavior?
    - Would improving driver behavior be more effective than automation in reducing congestion?
8. Freight vs. Passenger Traffic Separation
    - What are the infrastructure and operational considerations behind separating freight truck traffic from auto traffic within the same right-of-way?
9. Speed Limit Enforcement

- We have laws for speed limits, but do we need to have the courage to enforce them?
- Could automated speed monitoring systems significantly reduce violations?

10. Feedback and Incentives for Drivers
    - Can we implement feedback systems to educate drivers on the impact of their speed choices (e.g., driving at 40 mph increases congestion and fatalities)?
    - Could incentives be provided to avoid traffic jams?
11. Private-Public Partnerships in AV Infrastructure
    - Any ideas or research about integrating the Private-Public Partnership (PPP) model into the Autonomous Driving (AD) business?
12. Autonomous Vehicle Lanes
    - How about having autonomous vehicles on their own roadway, separate from human-driven vehicles?
13. Failure Modes in Digital Infrastructure
    - How can we account for failure modes of digital infrastructure?
    - Could digital twins help test new updates before real-world implementation?
14. Infrastructure vs. Technological Obsolescence
    - How do we address the varying obsolescence rates of electronic technology vs. highways and other infrastructure systems?
15. Cybersecurity, Privacy, and Safety in Traffic Management
    - Beyond congestion and traffic management, what are the implications for driving safety, cybersecurity, and user privacy?

The Role of Transportation Infrastructure in the Future of Connected & Automated Vehicles

Presentation to MIT Mobility Forum

February 14, 2025

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For a world on the move

Ferrovial is a leading global infrastructure company transforming highways, airports and energy infrastructure across the U.S. and around the world.

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$27B	15+	24K+	80%
market cap	countries	global workforce	equity value in North America*

407 ETR Express Toll Route | TEXPRESS | I-77 EXPRESS

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Ferrovial's distinctive integrated model supports the entire lifecycle of a project—from conceptualization to design, funding, construction and operation of essential infrastructure

HIGHWAYS

Provides traffic congestion relief solutions to communities as their populations grow

AIRPORTS

Facilitates air transport growth improving the passenger experience

ENERGY

Develops projects that support the energy transition

CONSTRUCTION

Provides end-to-end technical, engineering, and production capabilities to deliver complex projects

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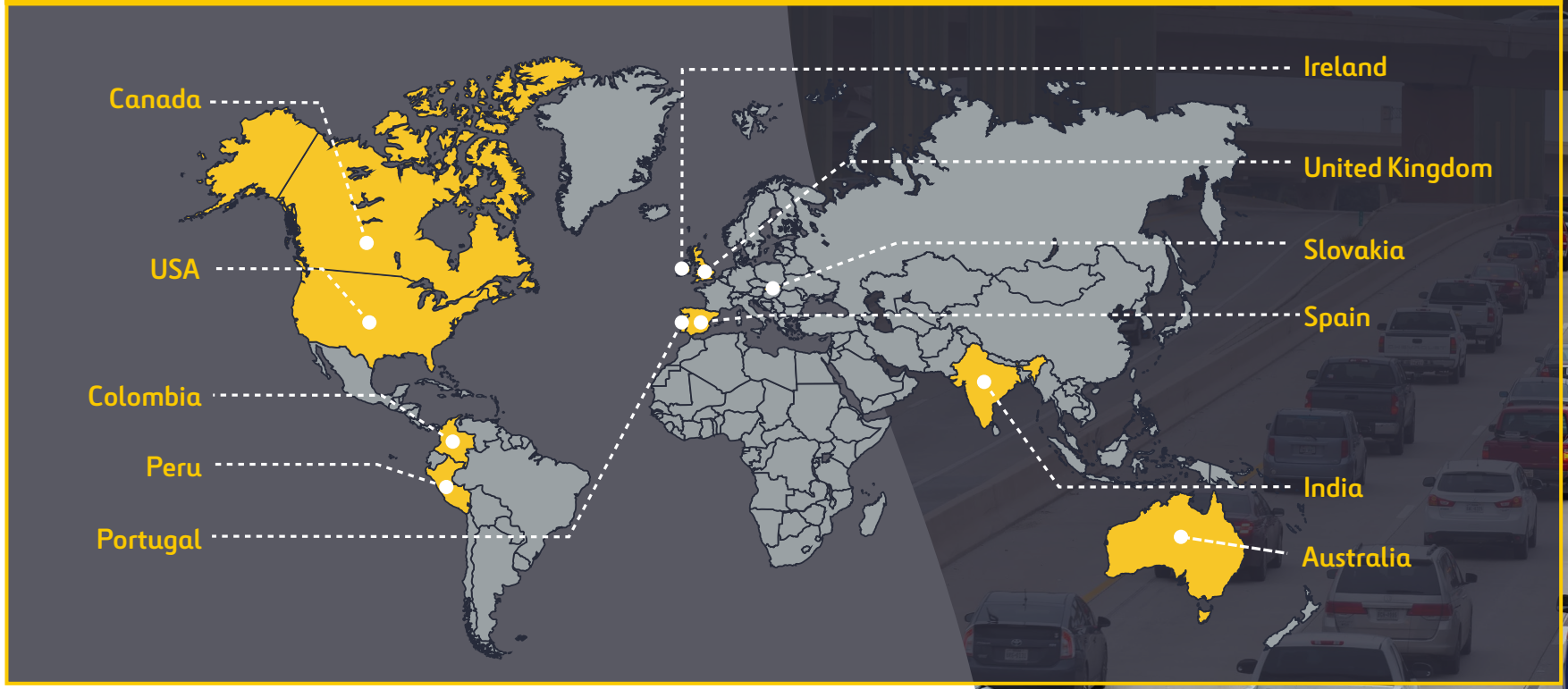
11 Countries with Assets



+50

Years in Infrastructure Development

159

Miles of Managed Lanes North America

Our Digital Business

NextMove makes innovative digital solutions that power the future of mobility for a world on the move.

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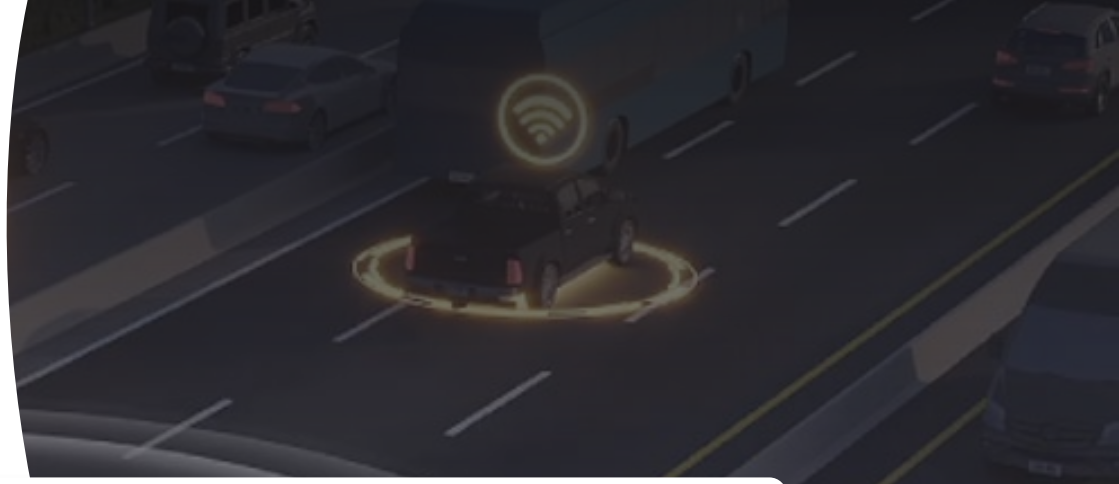
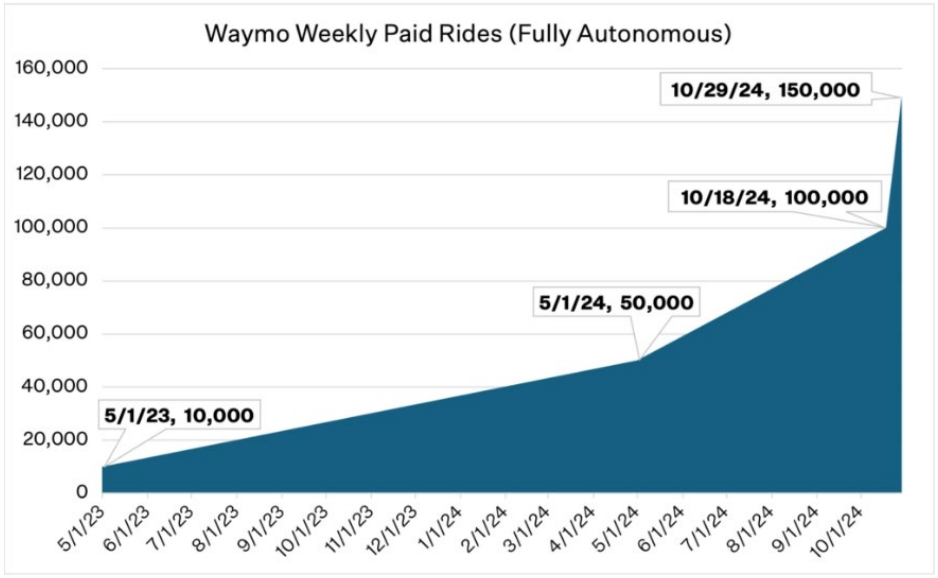
Future of Roadway Travel

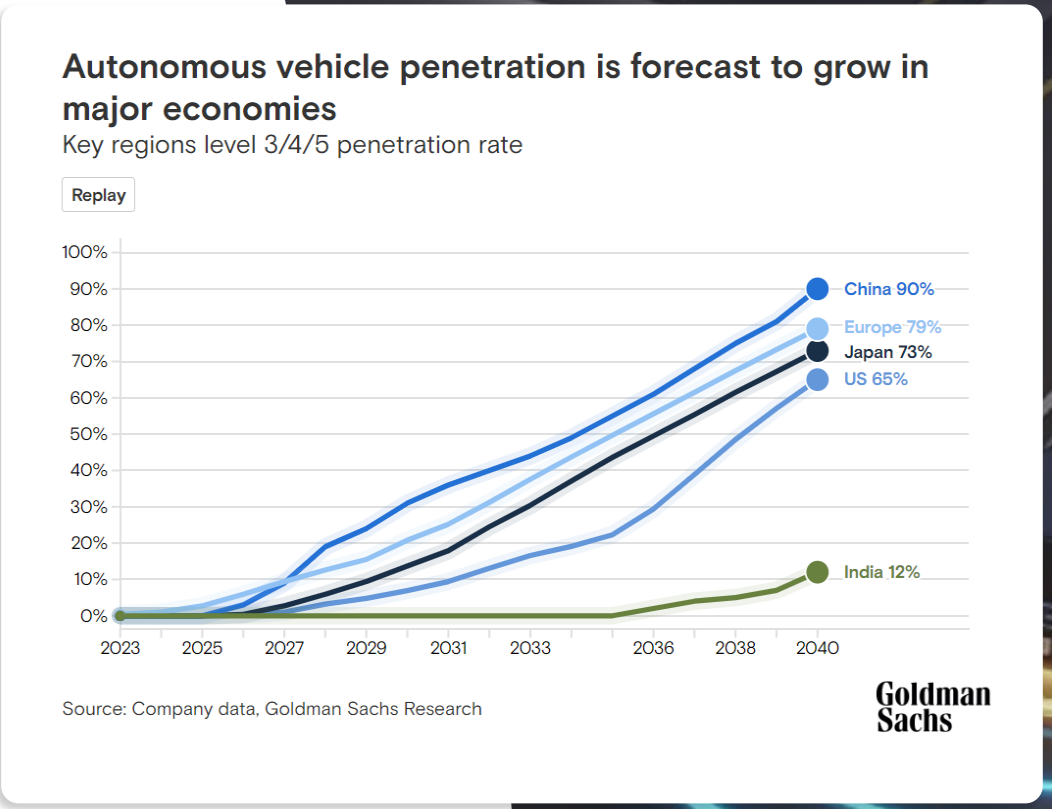


CHANGES EXPECTED:

- Levels of autonomy



Sources: WSJ, Alphabet Q3 2024 Earnings Call; as of October 29, 2024.



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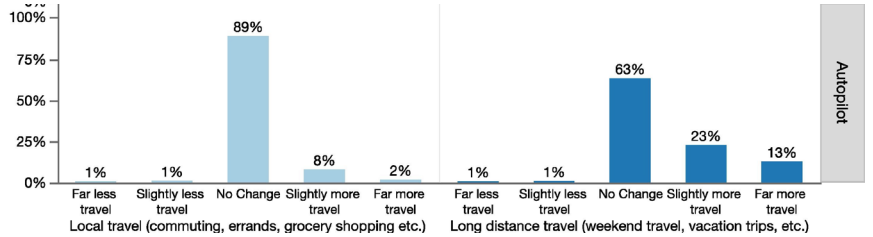
Future of Roadway Travel

CHANGES EXPECTED:

- Levels of autonomy
- Amount of travel

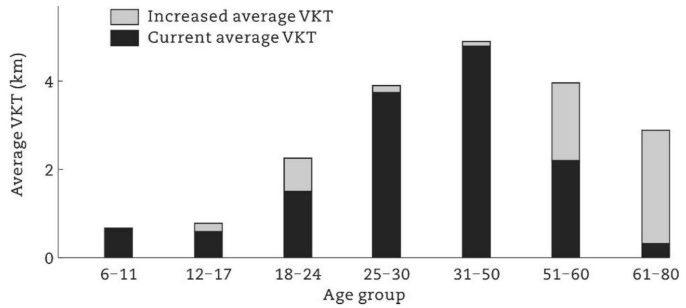
Estimating the Travel Demand Impacts of Semi Automated Vehicles (Hardman et al., 2022)

- Increasing vehicle automation (focus on L2) is expected to increase long-distance travel (for 36% of respondents)



Potential Effects of Automated Driving on Vehicle Travel Demand: A Comparison of Three Case Cities in China (Dai et al., 2024)

- VKT increases expected for each age group, with majority of increases in the younger and elderly age ranges



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Future of Roadway Travel

CHANGES EXPECTED:

- Levels of autonomy
- Amount of travel
- The decision maker

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Future of Roadway Travel

CHANGES EXPECTED:

- Levels of autonomy
- Amount of travel
- The decision maker
- Payment methods

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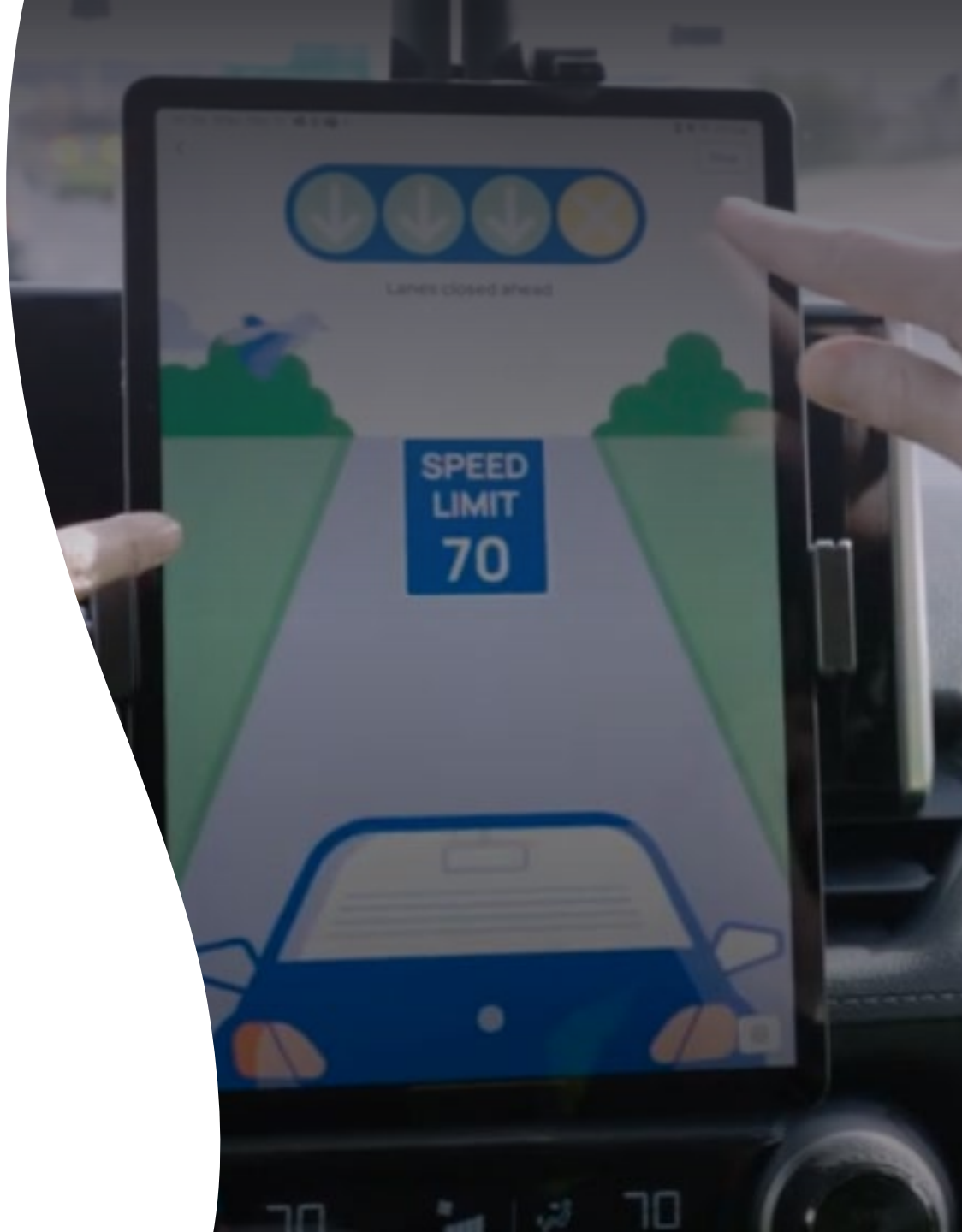
Future of Roadway Operations

- A safe and efficient system remains the goal
- Complementing vehicle capabilities
  - Beyond line of sight
  - Trusted information on road closures, incidents, and other non-recurrent events
- Infrastructure is digital as well as physical
- Safe and secure two-way communication with users
- Autonomous transit operations



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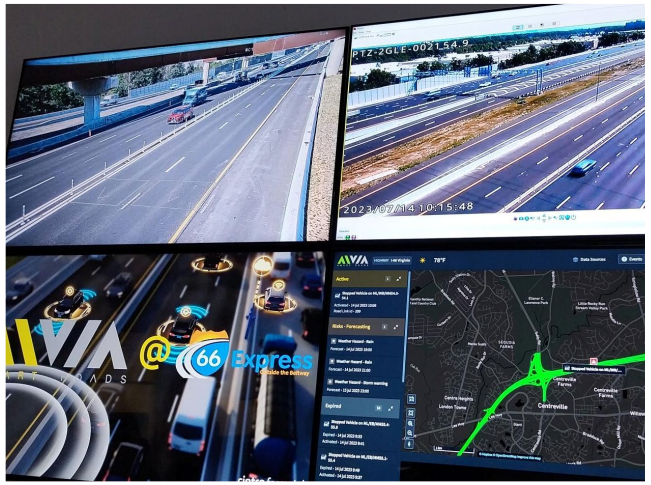
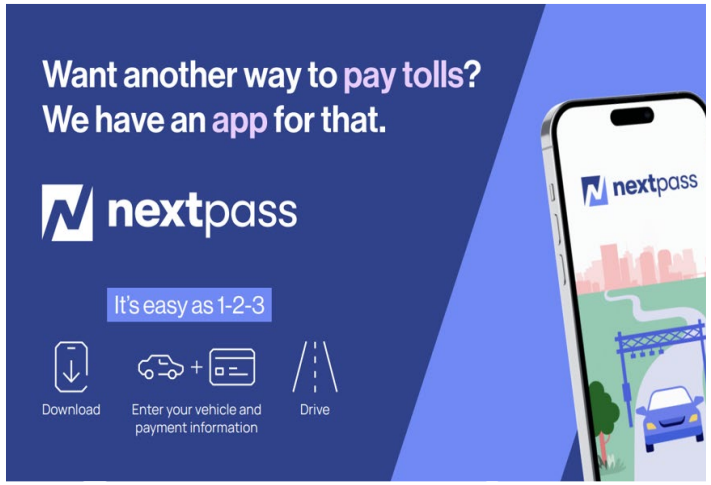
Preparing for the Future





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Thank you

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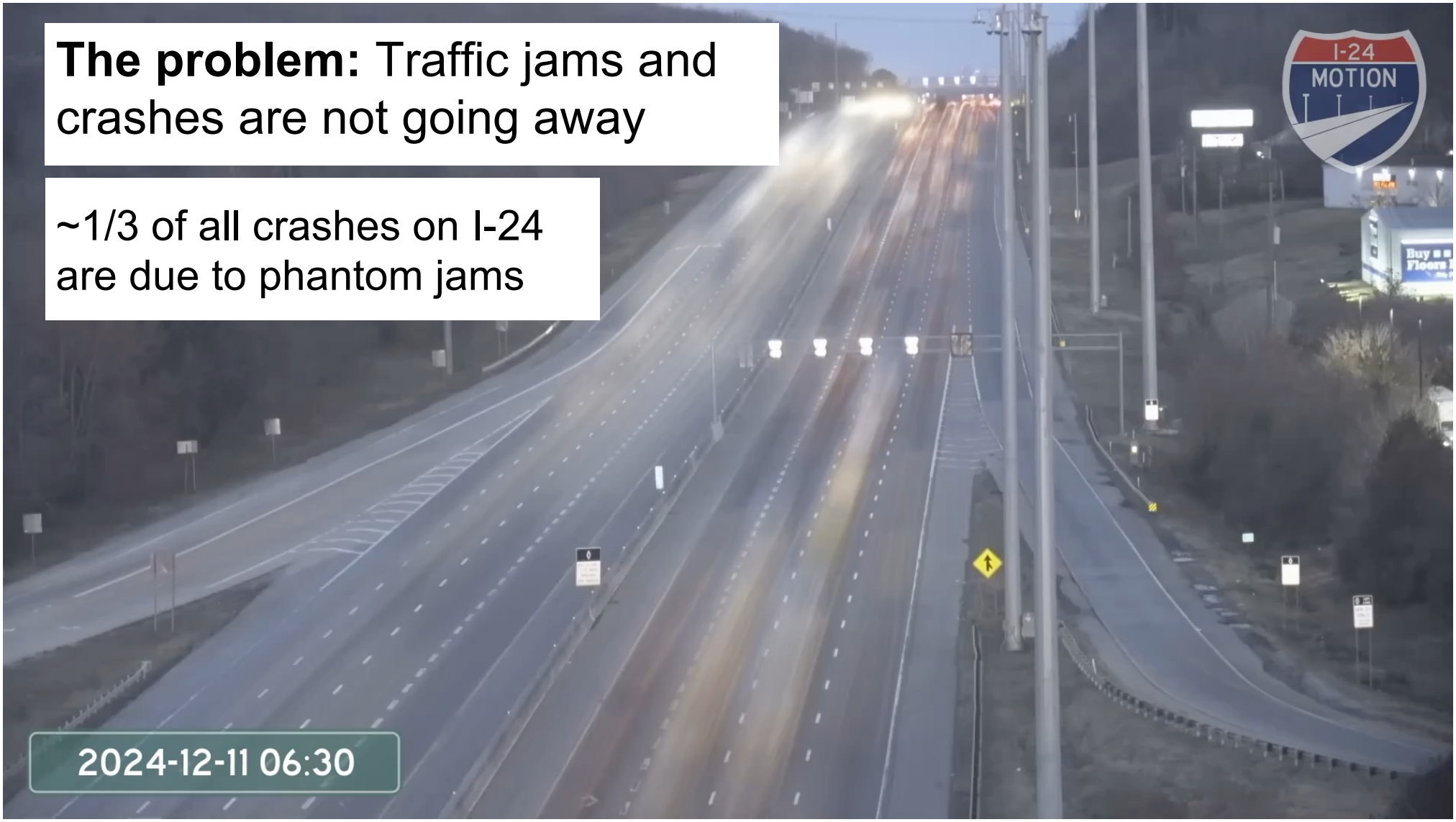
I-24 MOTION: an instrument for understanding AVs on traffic management

Junyi Ji, Yuhang Zhang, Zhiyao Zhang, George Gunter, Matt Nice, Derek Gloudemans, Gergely Zachár, Yanbing Wang, Matt Bunting, Will Barbour, Marcos Quiñones-Grueiro, Gautam Biswas, Jonathan Sprinkle, and Dan Work

Institute for Software Integrated Systems
Vanderbilt University

Joint work with A. Bayen (UC Berkeley), M.L. Delle Monache (Berkeley), Jonny Lee (UC Berkeley), B. Piccioli (Rutgers Camden) ,B. Seibold (Temple)

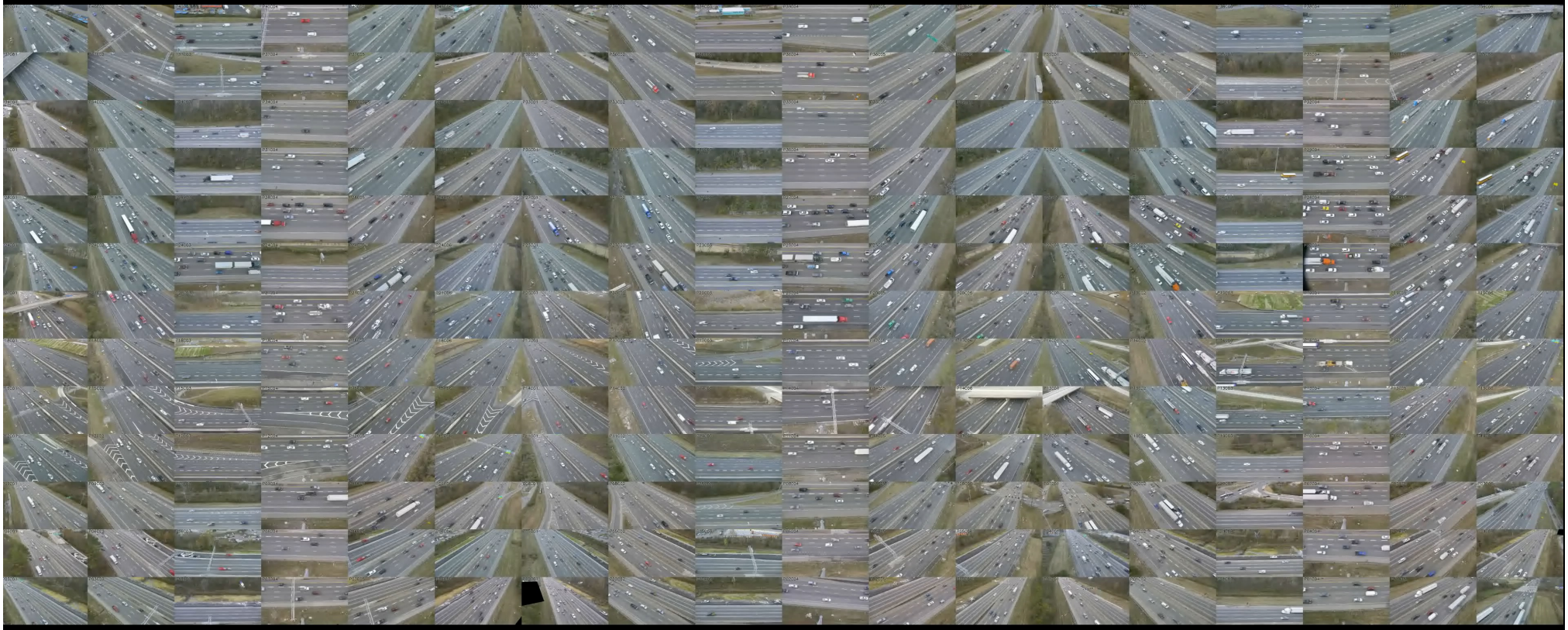
[Research Sponsored by National Science Foundation Cyber Physical Systems program, Tennessee Department of Transportation, US Department of Transportation, US Department of Energy; views are my own]


The problem: Traffic jams and crashes are not going away
~1/3 of all crashes on I-24 are due to phantom jams
I-24
MOTION
2024-12-11 06:30

TDOT Department of Transportation

I-24 MOTION

A massive phantom jam detector



[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.]

Solution 1: teach everyone to be a better driver

Solution 1: teach everyone to be a better driver

Solution 2: design smarter cars that help everyone drive better


5244
STOP
STOP


ENTRANCE
45+ researchers
5 universities, TDOT and 3 OEMs
CAMDEN
TEMPLE UNIVERSITY
THE UNIVERSITY OF ARIZONA
VANDERBILT UNIVERSITY
TN TDOT Department of Transportation
GM
NISSAN

Nice, Matthew W., George Gunter, Junyi Ji, Yuhang Zhang, Matthew Bunting, Will Barbour, Jonathan Sprinkle, and Daniel B. Work. "A middle way to traffic enlightenment." In *2024 ACM/IEEE 15th International Conference on Cyber-Physical Systems (ICCPS)*, pp. 147-156. IEEE, 2024.

The Vandy team