Yisheng Lv, Editor

# AI+CASE Lab: Advanced Interdisciplinary Research and Education Lab for Connected, Autonomous, Shared, and Green Transportation Systems

**EDITOR'S NOTE**

Please send your proposal on profiling research activities of your or other intelligent transportation systems research groups and labs for the "ITS Research Labs" column to Yisheng Lv at yisheng.lv@ ia.ac.cn.

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## Mission

The University of Florida strives to be the internationally recognized leader among research universities creating new knowledge and technologies, performing research with impact, spawning new economic opportunities, and educating the next generation of leaders. The mission of the Advanced Interdisciplinary Research and Education Lab for Connected, Autonomous, Shared, and Green Transportation Systems (AI+CASE Lab) at the Civil and Coastal Engineering Department is to develop interdisciplinary research and training which produces 1) comprehensive and advanced artificial intelligence (AI)-empowered operations, research, and innovative data analytics methods for essential transportation problems raised by emerging technologies, such as connected vehicles, autonomous vehicles, connected and autonomous vehicles (CAVs), electric vehicles (EVs), mobility on demand, and mobile charging on

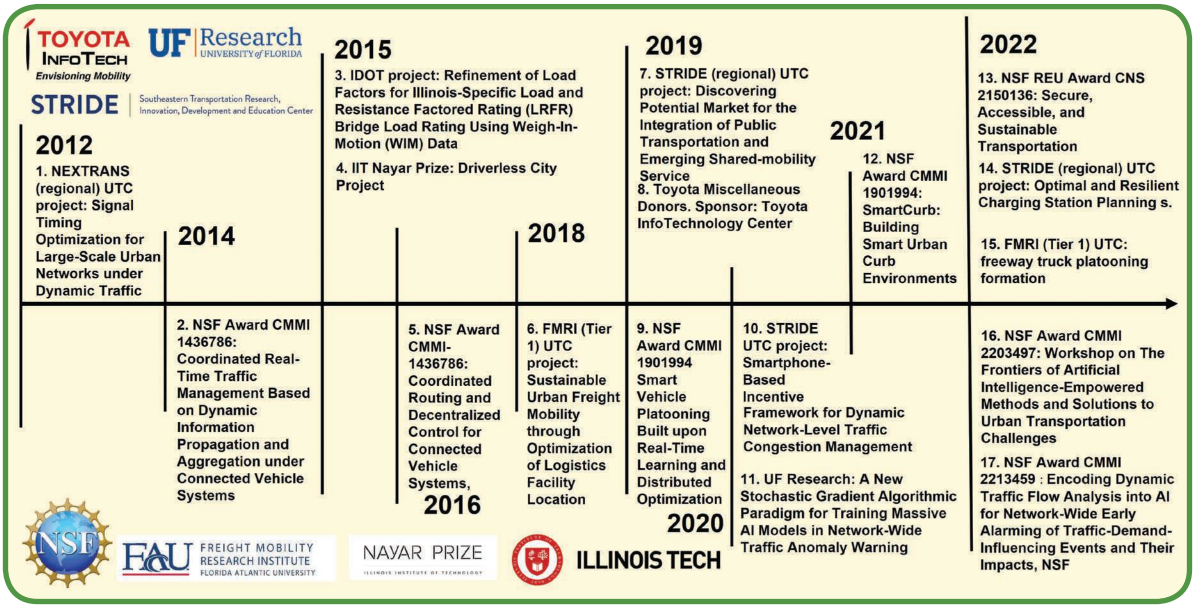


**FIG 1** The timeline of major lab projects and accomplishments. IDOT: Illinois DOT; STRIDE: Southeastern Transportation Research, Innovation, Development and Education; UF: University of Florida; IIT: Illinois Institute of Technology; FMRI: Freight Mobility Research Institute; REU: Research Experiences for Undergraduates; CNS: Computer and Network Systems.

demand (CoD), and 2) rigorous analyses of mathematical properties of the models and solutions (optimality, algorithm convergence, resilience analysis, control feasibility, stability analysis, etc.) for improving traffic safety, efficiency, sustainability, and resilience. This is accomplished through the research programs presented below.

## Research Programs: Monument and Future Directions

To date, the AI+CASE Lab has been dedicated to investigating innovative solutions for the research programs related to CAV platooning, on-demand mobile charging service, coordinated routing mechanisms (CRMs), transportation domain knowledge-based AI applications, and the vehicle-to-vehicle communication (V2V) network. The lab's studies have been sponsored by the U.S. National Science Foundation (NSF), Department of Transportation (DOT) University Transportation Centers (UTCs), state DOTs, Toyota, and university research funding (Figure 1). Many Ph.D. and master's students and visiting scholars have been involved in the lab's research activities and produced considerable outcomes (Figure 2).

### *Develop Platoon-Centered Control (PCC) for CAV Platooning*

CAV technology can provide great opportunities to address urban and highway traffic issues. CAV platooning has been considered one of the most important techniques to coordinate CAV driving to improve safety, relieve traffic congestion, and reduce energy consumption. Specifically, CAV platooning groups and drives a fleet of CAVs together through cooperative acceleration and longitudinal speed control. While existing research is based on controlling individual vehicles using adaptive cruise control and cooperative adaptive cruise control techniques, the AI+CASE Lab has designed an innovative PCC approach for CAV platooning.

The PCC approach considers the platoon as a system and uses control technology to coordinate individual CAVs' maneuvers toward a better platoon-wide system performance. An interesting challenge with the PCC approach is that it often gives rise to complicated, large-scale optimal control or optimization problems that require extensive computation. To successfully implement the PCC approaches, beginning with the NSF Civil, Mechanical and Manufacturing Innovation (CMMI) 1436786 and 1901994 awards, the team has been dedicated to developing a comprehensive framework, shown in Figure 3, that integrates control theory, optimization theory, distributed algorithms, and machine learning (ML) approaches to address various driving scenarios (Figure 4) such as car following [1], [2], lane change [3], merging and splitting [4], eco-intersection

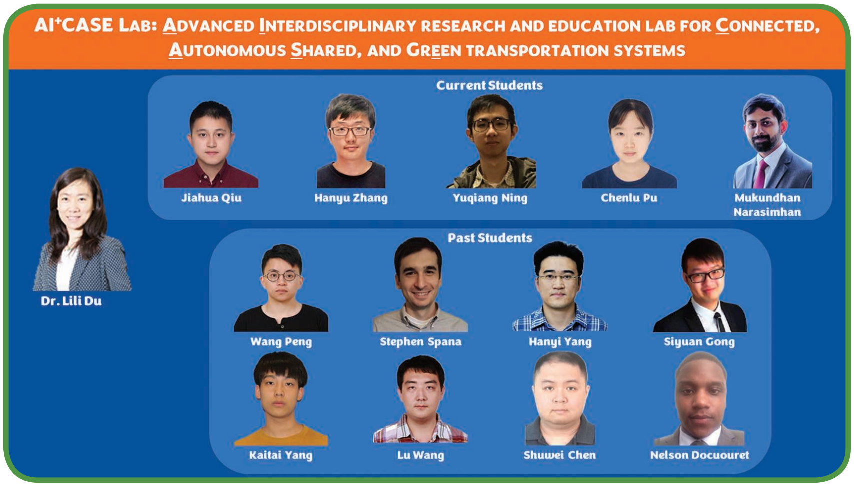


**FIG 2** The members of the AI+CASE Lab.

## QUICK FACTS

Lab name: Advanced Interdisciplinary Research and Education Lab for Connected, Autonomous, Shared, and Green Transportation Systems (AI+CASE Lab)

Affiliation: University of Florida

Website: https://faculty.eng.ufl.edu/lilidu/

Research focus: innovative ideas and solutions for connected, autonomous, shared, and green transportation systems

Director: Dr. Lili Du

Dr. Lili Du is an associate professor at the University of Florida. She received her Ph.D. degree in decision sciences and engineering systems from Rensselaer Polytechnic Institute in 2008.

Dr. Du's research integrates operations research, control theories, and artificial intelligence methods into transportation system analysis and network modeling, with current focuses on connected and autonomous vehicles and electric vehicles, mobility on demand, charging on demand, smart curbs, network resilience, and traffic prediction. Dr. Du is a recipient of the NSF CAREER award in 2016. She is the founding chair of the Transportation Research Board ADB30-5 Subcommittee on Emerging Technologies in Network Modeling and the ASCE-T&DI Artificial Intelligence in Transportation Committee.

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> CAV platooning has been considered one of the most important techniques to coordinate CAV driving to improve safety, relieve traffic congestion, and reduce energy consumption.

passing [5], [6], and broader interactions between PCC and other road infrastructure.

### *Mobile Charging On-Demand (CoD) Service*

Mobile charging is an emerging technology that combines CAV technology and mobile V2V (wireless or cable-connected) charging (V2VC) or automated battery-swapping technology to provide CoD services for eliminating lengthy charging delays or detours, alleviating EV "range anxiety," and promoting the mass adoption of EVs. Specifically, it uses electric vans [Figure 5(a)] or battery-swapping services [Figure 5(b)] as mobile chargers or swappers for on-demand roadside charging. Started from NSF award 1818526 and the Southeastern Transportation Research, Innovation, Development and Education (STRIDE) UTC project [the STRIDE Center is the 2016 USDOT Region 4 (Southeast) UTC], the AI+CASE Lab develops innovative and viable solutions to mobile CoD services, leveraging these emerging charging technologies. Specifically, by publishing multiple research papers since 2019 (e.g., [7]), the AI+CASE Lab contributed the methodologies to enable 1) large-scale CoD via on-the-move charging [Figure 5(c)] or mobile battery swapping [Figure 5(d)] while balancing service

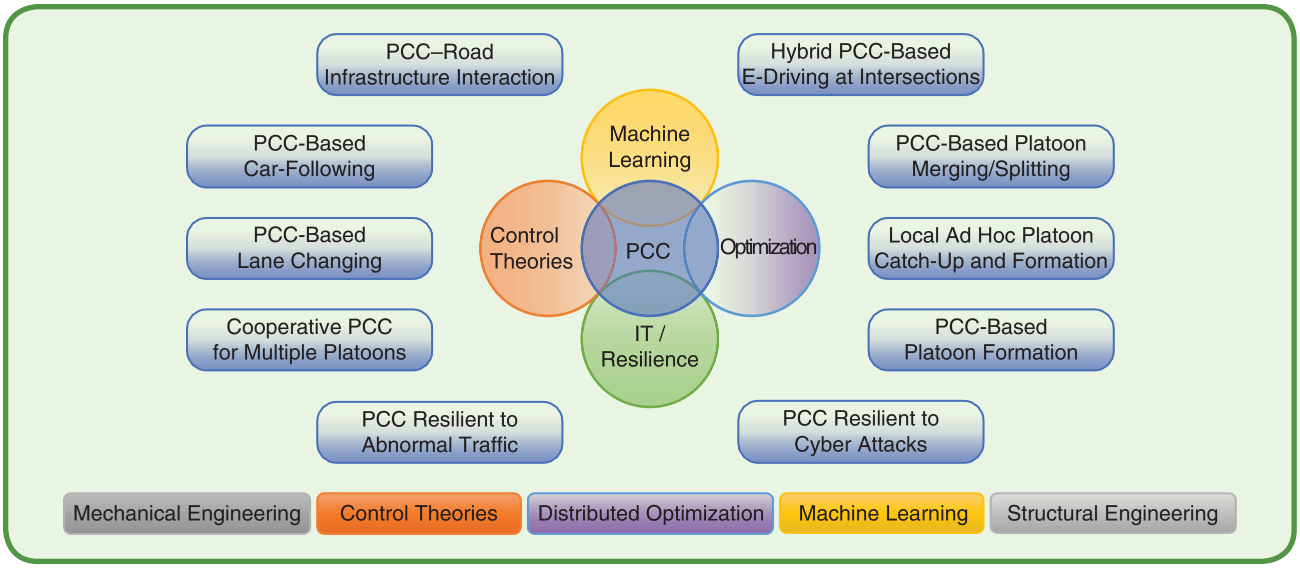


**FIG 3** The methodologies for PCC.

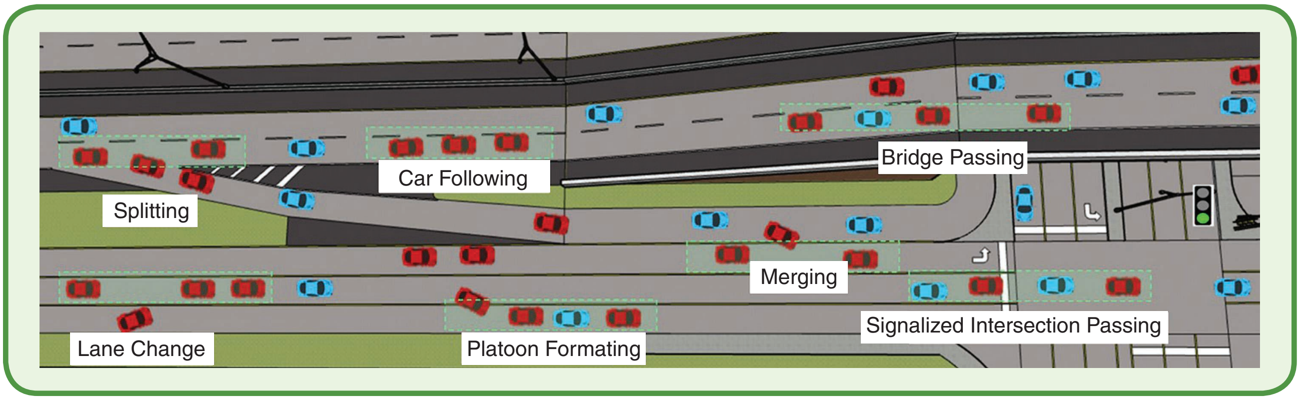


**FIG 4** PCC in different driving scenarios.

efficiency and traffic overhead, 2) pairing electric vans and demand on a road for safe and efficient on-the-move V2VC charging [Figure 5(e)], and 3) a resilient and optimal charging station plan [Figure 5(f)].

### *CRMs for Connected Vehicle Systems*

With the rapid developments in wireless communication, mobile computing, and GPS technologies, connected vehicles have the potential to revolutionize transportation by increasing safety, reducing congestion, and improving the system's efficiency and sustainability. One key research area in the AI+CASE Lab is to realize this potential by developing effective CRMs for connected vehicle systems [Figure 6(a)], in which vehicles communicate with each other and/or to a central planner to jointly decide their route choices. Sponsored by the NSF CAREER award, the AI+CASE Lab utilizes game theory, ML, optimizations, and distributed computations to develop new methods and algorithms to coordinate and/or manipulate the movement of connected vehicles in highly dynamic and uncertain environments, shown in Figure 6(b). The innovation and contribution of our methodologies are demonstrated from the following aspects:

1) modeling, i.e., proposing snapshot equilibrium routing mechanisms based on atomic game theories to

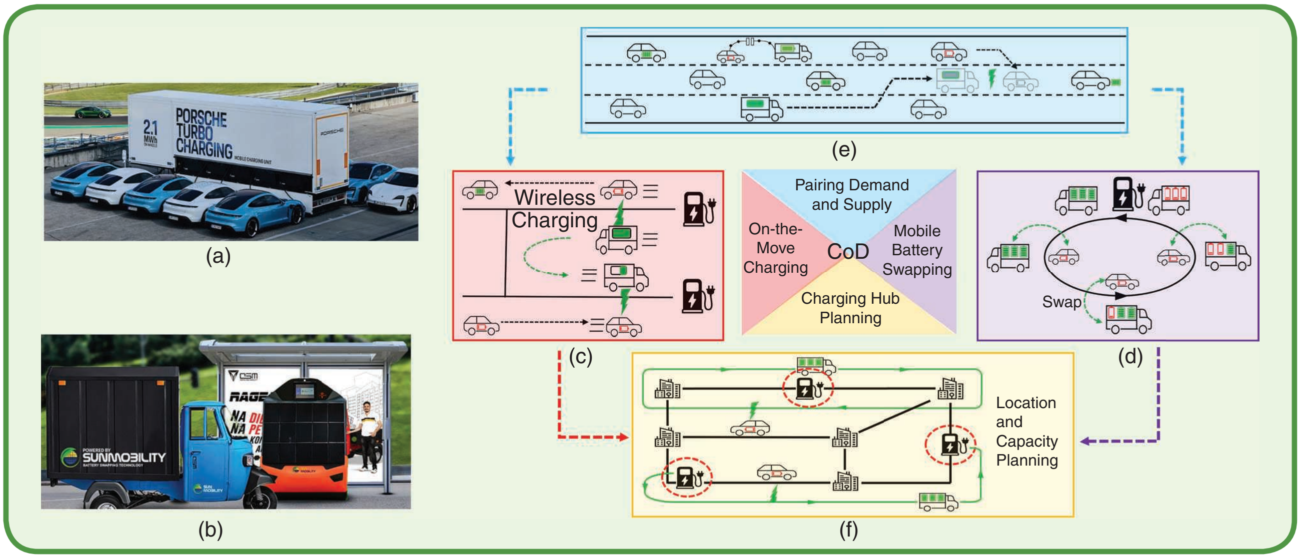


**FIG 5** Mobile charging as service. (a) Mobile cable-connected V2VC [7]. (b) Mobile battery swapping [8]. (c) and (d) The dispatching, routing, and rebalancing of electric vans. (e) Pairing electric van and demand on a road. (f) Resilient and optimal charging station planning.

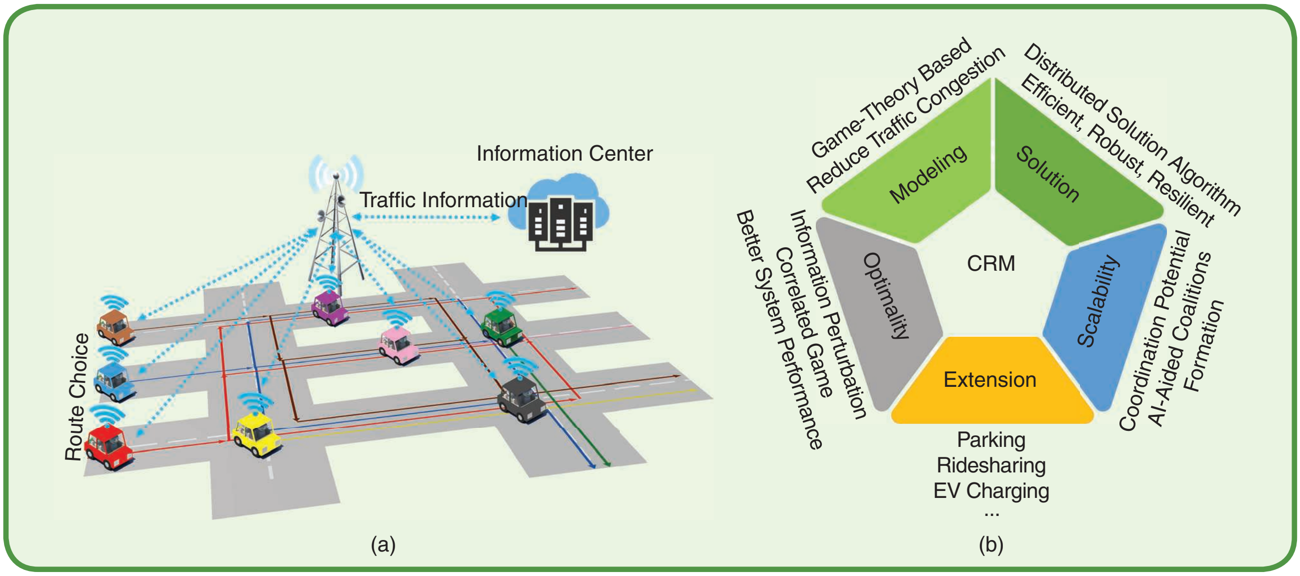


**FIG 6** (a) CRMs. (b) Research development for CRMs.

> V2V communication via dedicated short-range communications provides real-time information for traffic prediction and management, but we need tools to trace information availability.

mitigate traffic congestion without violating travelers' self-interests [10, 11]
2) solution, i.e., developing efficient and robust distributed solution algorithms [10] to solve large-scale game models in real time for online navigation services and handle unstable wireless communications commonly encountered in real-world applications [13]
3) optimality, i.e., designing information perturbations and information incentives [15], [16] and utilizing game theories to push snapshot equilibrium routing decisions toward system optimal while satisfying travelers' selfish nature without using externalities such as regulations and tolls
4) scalability, i.e., developing routing coordination potential theories and applying AI to form routing coordination coalitions that could solve the scalability issue of implementing CRMs in big cities with a large scale of travelers [16], [17]
5) extension, i.e., applying the coordination strategy to improve the system's efficiency in other transportation scenarios such as parking [12], ridesharing [17], EV charging, etc.

### *Transportation Domain Knowledge-Based AI Applications*

AI and data acquisition technologies have been broadly applied for planning and managing transportation networks in recent decades. However, we still face the challenge of identifying appropriate application scenarios of AI in transportation and developing effective solutions. Seizing this opportunity, the AI+CASE Lab works on integrating AI and transportation domain knowledge to explore latent features of the transportation system and develop physics-informed, interpretable, and robust solutions to address traffic problems (Figure 7). Supported by NSF and DOT UTC projects, the aggregated effort of our lab made the following significant contributions:

1) Our lab developed transportation domain knowledge-based data-driven/AI approaches (e.g., deep learning [18], [19] and reinforcement learning [20]) for traffic speed, shockwave, traffic events, and traffic network performance detection and prediction. The proposed approaches leverage traffic flow theory and AI technologies to capture traffic dynamics in real time.

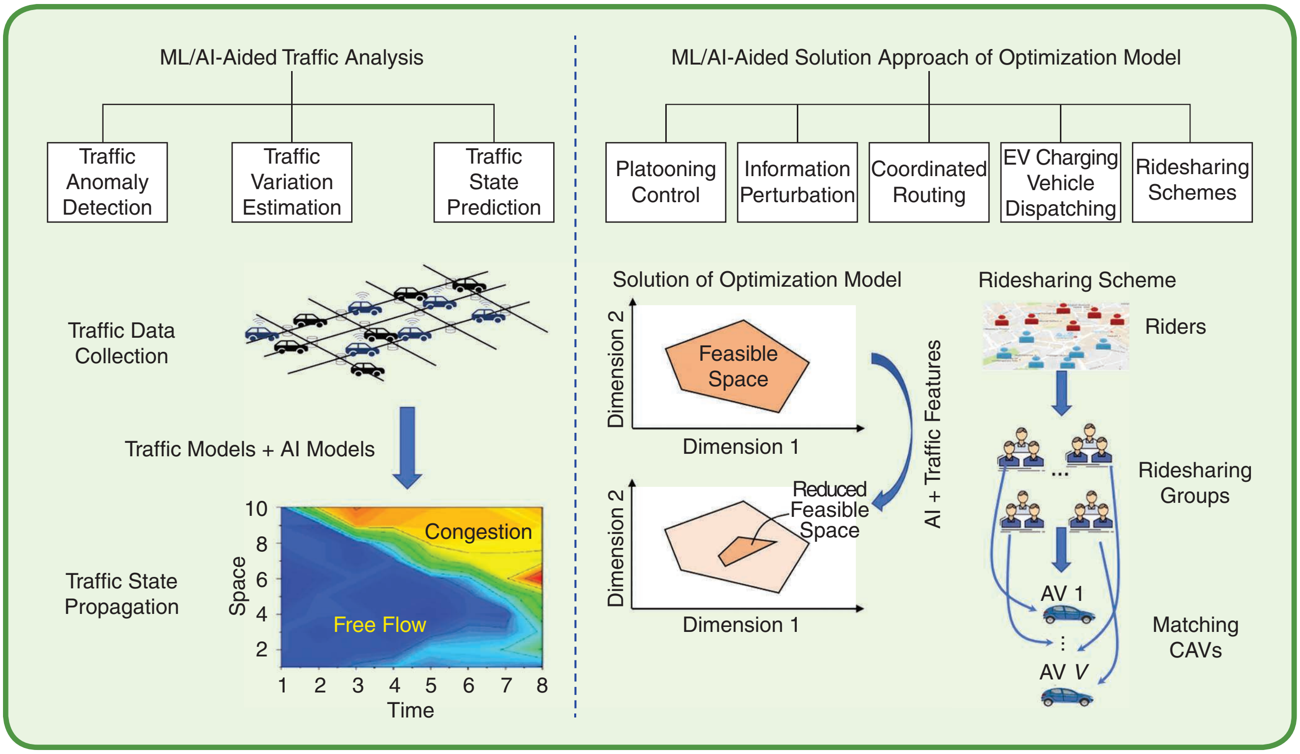


**FIG 7** The framework of transportation domain knowledge-based AI applications.

2) Our lab integrated the domain knowledge and ML/AI approaches (Gaussian process regression [15], community learning [17], clustering [7], and regression [3]) into large-scale optimization modeling and solution approaches to address CAV control and operation problems. The proposed approaches can efficiently solve the optimization model online by reducing the solution space, which is achieved by capturing the traffic features through AI technologies.

### *Modeling Information Flow Dynamics Upon Traffic Flow Dynamics*

V2V communication via dedicated short-range communications provides real-time information for traffic prediction and management, but we need tools to trace information availability. Starting from NSF award CMMI-1817346, we developed a mathematical simulation framework (Figure 8) to trace V2V information propagation dynamics built upon traffic flow dynamics. Through multiple journal papers, we made contributions as follows:

1) developed mathematical formulations [22], [23], [24], [25] to characterize the connectivity, broadcast capacity, and interference of V2V communications in a traffic flow on road segment
2) invented novel mathematical techniques to capture information propagation delay on a long stretch of road, considering intermittent transmission resulting from traffic flow dynamics [22], and developed the information and traffic flow coupled cell transmission model (IT-CTM) to trace V2V information spreading dynamics on a road segment [21]
3) modeled V2V information dissemination dynamics at an arterial or ramp intersection [IFNM-a(r)], integrated IFNM-a(r) and IT-CTM to trace information dissemination across a road network, and predicted information propagation

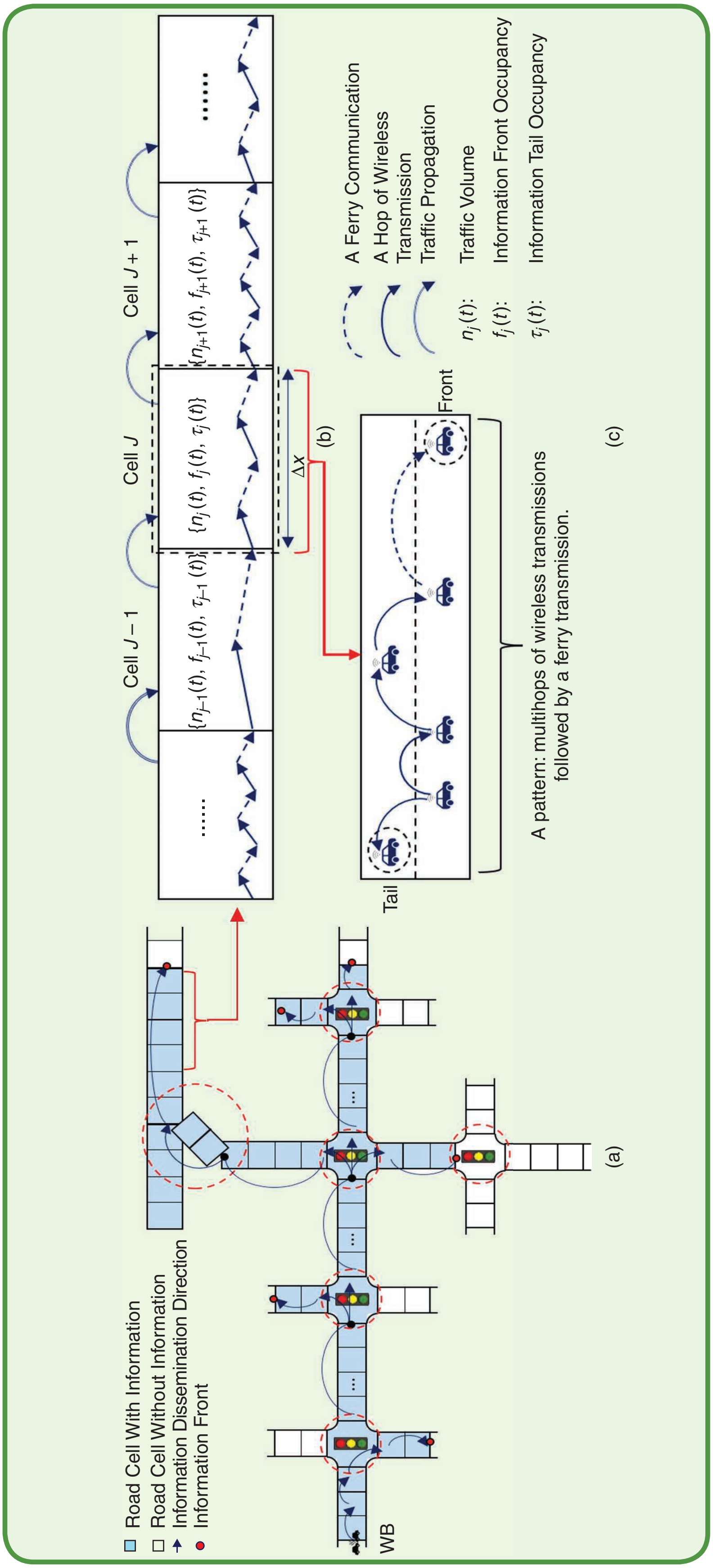


**FIG 8** (a) Information wavefront spreading over roadway network. (b) The information and traffic flow coupled cell transmission model (IT-CTM) on a road segment. (c) Intermittent information propagation in a cell. WB: westbound.

dynamics to capture traffic congestion and events [18], [19].

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# ERRATA

In the article "A New Cellular Vehicle-to-Everything Application: Daytime Visibility Detection and Prewarning on Expressways" [1], (10) contained errors. The correct equation is

$$D = 2R \cdot \arcsin\left(\sqrt{\sin^2\left(\frac{\Delta Lat}{2}\right) + \cos(Lat_1)\cdot\cos(Lat_2)\cdot\sin^2\left(\frac{\Delta Lon}{2}\right)}\right). \quad (10)$$


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[1] C. Zhang, F. Li, J. Ou, P. Xie, and W. Sheng, "A new cellular vehicle-to-everything application: Daytime visibility detection and prewarning on expressways," *IEEE Intell. Transp. Syst. Mag.*, early access, Jun. 22, 2022, doi: 10.1109/MITS.2022.3181988.


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