Using Artificial Intelligence to Improve Connected and Autonomous Vehicle Operations in Mixed Traffic

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CCAT RESEARCH ACTIVITIES

- Enabling technologies
- Policy and planning
- Human factors
- Infrastructure design & management
- Modeling & Implementation
- Operations & Controls

All CCAT consortium members

- University of Michigan
- Purdue University
- University of Illinois
- University of Akron
- Washtenaw Community College
### Transportation Problems

<table>
<thead>
<tr>
<th>National impact</th>
<th>Impact for normal commuter</th>
<th>Safety issue</th>
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<tbody>
<tr>
<td>• $179 billion lost in traffic delays &amp; fuel costs</td>
<td>• $1080 extra annual cost due to traffic delay per commuter</td>
<td>USA:</td>
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<tr>
<td>• $74.5 billion lost in trucking industry</td>
<td>• 54 hours lost to traffic delay per commuter</td>
<td>• 40,000+ traffic related fatalities</td>
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<td>• 1.2 billion in lost hours of truck productivity</td>
<td></td>
<td>• 2 million+ injuries</td>
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<td>• 56 billion lbs of additional CO$_2$ emissions</td>
<td></td>
<td>Global:</td>
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<tr>
<td>• 3.3 billion gallons of wasted fuel</td>
<td></td>
<td>• 1 million+ fatalities</td>
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</table>

**Source:** Texas A&M; ATRI; FHWA
Connected vehicles can “talk” to each other and to infrastructures, smartphones, and other devices via V2V or V2I communication.

Drivers would receive notifications and alerts of dangerous situations, such as someone about to run a red light as they’re nearing an intersection or an oncoming car, out of sight beyond a curve, swerving into their lane to avoid an object on the road.

Source: U.S. DOT
Autonomous Vehicle (AV)

- Autonomous vehicle technology aims to precisely operate the vehicle without human involvement using AI/control systems.

Source: Lyft
Cooperative driving automation (CDA) enables connected and autonomous vehicles (CAVs) to “work together” and “work with roadway infrastructure”.

CDA has the potential to advance transportation efficiency, facilitate freight movement, increase productivity, and reduce the need for roadway facilities, therefore, saving billions of dollars.

Source: U.S. DOT
Two types of AI

**Imitation learning**

AI learns and imitates

*Human driving*

*Autonomous driving*

**Reinforcement learning**

*Driving Simulator*

*Deep Reinforcement Learning Agent*

*Action*

*States*

*Reward*

*Source: BBG*

*Source: youtube*
Research examples

• Developing innovative AI for multi-agent systems
• Mitigating highway congestion in mixed traffic streams using CAVs
• Collision avoidance framework for CAVs under crash imminent situations
• A few other work...
Example 1

Developing innovative AI for multi-agent systems
Innovative AI for multi-agent systems

- Cooperative sensing and control

- Challenges
  - Highly dynamic mixed traffic environment
  - Dynamic-number-agent problem (DNAP)
  - Complex interactions among agents (vehicles), combinatorial action space
Innovative AI for multi-agent systems

- Graphic representation
  - Each vehicle represents a node in the graph
  - Local links (CAV to surrounding HDVs)
    Information passing from HDVs to CAVs
  - Global links (CAVs to CAVs)
    Information sharing between CAVs

- Centralized control framework
  - Graphic Convolutional Network (GCN)
    Local and global information fusion
  - Deep Q Network (DQN)
    Centralized decision controller, dynamic number agents
Innovative AI for multi-agent systems

• Graphic Convolutional Q network (GCQ)

Information fusion on high dimensional node embeddings

Control output decisions for all existing CAVs in the network
Innovative AI for multi-agent systems
Example 2

Mitigating highway congestion in mixed traffic streams using CAVs
Mitigating highway congestion in mixed traffic streams using CAVs

• Highway congestion

Source: YouTube
Mitigating highway congestion in mixed traffic streams using CAVs

• Active Traffic Management (ATM)
  • Speed Harmonization (SH)
  • Variable Speed Limits (VSL)
  • Ramp Meters

• Wide range of applications
  • Improve safety and flow conditions (Lu and Shladover, 2014)
  • Address weather and visibility related flow breakdown (Filipovska and Mahmassani, 2019)

• However, traditional ATM often requires human driver compliance to be effective
Mitigating highway congestion in mixed traffic streams using CAVs

- Use of Connected Autonomous Vehicles (CAVs) to perform ATM strategies without requiring human driver compliance
- Non-bottleneck related (stop-and-go waves)

Image: Traffic Jam without Bottleneck

Experimental evidence for the physical mechanism of forming a jam

Yuki Sugiyama, Minoru Fukui, Macoto Kikuchi, Katsuya Hasebe, Akihiro Nakayama, Katsuhiro Nishinari, Shin-ichi Tadaki and Satoshi Yukawa

Movie 1
Mitigating highway congestion in mixed traffic streams using CAVs

- Bottleneck related

Rule-based Controller

RL-based Controller (GCQ)

[Graphs and charts showing comparisons between rule-based and RL-based controllers, including heat maps and bar charts.]

Variable Speed Limits
Example 3

Collision avoidance framework for CAVs under crash imminent situations
Collision avoidance framework for CAVs under crash imminent situations

- Human errors in driving
95% of crashes are related directly or indirectly to human error (NHTSA, 2016)

Various causes of human error

- Overconfidence: 88% of drivers perceive themselves as “good” or “excellent”
- Distractions: phone, music, infotainment system
- Driving under the influence
- Fatigue
- Slow reaction times

Key Question: How can we reduce the number of traffic accidents?

Eliminate or reduce human error by **self-driving cars.**
Collisions in the Era of Mixed Traffic

Two perspectives regarding crashes involving AVs

**Perspective 1:** AV at fault

Perspective 1 receives much attention, particularly by the technology developers and manufacturers.

- Karla and Paddock, 2016
- Koopman and Wagner, 2017
- Kim et al., 2019
- Ko et al., 2015
- Chen et al., 2013
- Naranjo et al., 2008
- Wang et al., 2019
- Babu et al., 2018

**Perspective 2:** Potential of using AV to avoid crash is not utilized

Perspective 2 is not emphasized enough.
Collision avoidance framework for CAVs under crash imminent situations
Success rates of crash avoidance maneuvers

• When the bumper to bumper distance is smaller than 7m:
  - Success rates are quite low (<0.4) for deceleration only cases.
  - Success rates are significantly improved (>0.6) for deceleration + lane-changing cases.
A few other work...

- Deployment in controlled small-scale environment
  Amazon AWS DeepRacer
A few other work...

- Human factors
  - Electroencephalography (EEG)
  - Eye tracker
  - VR headset

Brain electrical activity data
Psychophysiological analysis
Eye tracking data

Immersion
First-person view in Carla simulation
References:


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