Cyber-Physical Systems Development for Connected and Autonomous Vehicles

Ronnie Chowdhury, Ph.D., P.E., F. ASCE

Eugene Douglas Mays Professor of Transportation Director, USDOT Center for Connected Multimodal Mobility Director, USDOT Beyond Traffic Innovation Center
I thought this car could pilot itself. It could until it started texting.
Cyber-Physical Systems (CPS) for Connected and Autonomous Vehicles (CAVs)

Cyber Space

Physical Sensing

Networks

Actuation

Real Space

Pedestrian
Connected Vehicle
Autonomous Vehicle
Smart Road
CPS Architecture for CAVs

**System Node** (Regional Traffic Management Center)
- CAV Applications (Regional Level)
- Traffic Management Center

**Fixed Edge** (Roadside Equipment (RSE))
- CAV Applications (Local Level)
- DSRC Lower Edge Node
- LTE Lower Edge Node

**Mobile Edge** (Connected and Autonomous Vehicles)
- CAV Safety Applications

**Internet Gateway**
- LTE Wireless Link
- DSRC wireless link

**Telco Infrastructure**
- LTE Wireless Link
- LTE Wireless Link
Current CV Deployment using Advanced Network Technology

Clemson University Campus Deployment

- VPN Service
- LTE Coverage
- LTE Base Station
- Roadside DSRC Unit
- WiFi Access Point
Next SC-CVT Testbed Deployment using Advanced Network Technology

I-85 Deployment

- LTE Coverage
- LTE Base Station
- SCDOT CCTV Location
- Roadside DSRC Unit
Inevitable Future with CAVs

**September 2016: NHTSA released self-driving car guidelines**
Require a 15-point safety inspection for driverless cars

**December 2016: NHTSA proposed a new national policy**
Requires all manufacturers to include V2V in all new light-weight vehicles

**March 2017: California DMV proposed rules for self-driving car**
Allow testing that does not require the presence of a driver in the car
NHTSA’s 15-point Safety Inspection for Driverless Cars

- Data Sharing
- Privacy
- System Safety
- Digital Security
- Human-Machine Interface
- Crashworthiness
- Consumer Education
- Certification
- Post-Crash Behavior
- Laws and Practices
- Ethical Considerations
- Operational Design
- Detection and Response
- Fallback
- Validation
CPS Design Considerations for CAVs

- Communication
- Cyber Security
- Data Analytics
- Failure Risk Assessment
- Human Factors
- Privacy
- Institutional Issues
- Legacy Systems
- Applications
Applications

- Safety
- Mobility
- Environmental
- Support

The Connected Vehicle Reference Implementation Architecture is based on a set of Applications that have been defined by various connected vehicle programs. The source for the application descriptions ranges from Concepts of Operations (ConOps), Requirements Specifications, or existing Standards and Architectures.

There are four types of Connected Vehicle Applications: Environmental, Mobility, Safety, and Support. Each type is comprised of groups of applications. Click on an Application name in the table below to see and description of the application, its source references, and the subset of the Connected Vehicle Reference Implementation Architecture that pertains to that application, including sub-tabs for each view (enterprise, functional, physical, and communications).

<table>
<thead>
<tr>
<th>Type</th>
<th>Group</th>
<th>Application Name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Connected Eco-Driving</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dynamic Eco-Routing</td>
</tr>
</tbody>
</table>
Applications

Challenges

- Application-specific robust computing, communication and networking strategy

- Public-private partnership in the deployment of CPS infrastructure

Clemson University Campus Deployment - Queue Warning
# Wireless Communication

### Dedicated Short Range Communication (DSRC)
- DSRC uses the IEEE 802.11p standard in the 5.9 GHz band

### Wireless Fidelity (WiFi)
- WiFi uses the IEEE 802.11 standards in the 2.4 GHz / 5 GHz band

### Long-Term Evolution (LTE)
- LTE uses 3GPP standards with a wide range of bands (from 700 MHz to 2600 MHz in US)

## Challenges
- Different latency requirements
- Unpredictable network latency
- High bandwidth requirement
Heterogeneous Wireless Network

Using DSRC

DSRC
RSU

Using LTE

LTE
Base

Accident
Cybersecurity: Human Vs Machine

People’s Choice Awards Nominee
FAVORITE NEW TV DRAMA

Source: Bull, Season 1, Episode 10: E.J.
Cybersecurity

In Vehicle Cybersecurity

Vehicle-to-Infrastructure Cybersecurity

Vehicle-level Security of Distributed Cyber-Physical Systems

Security Protection for V2I and V2V Network and Infrastructure
Challenges

- Secure network with confidentiality, integrity and availability
- Privacy during cyber attack
- Consideration of high mobility and dynamic topology

Types of Cybersecurity Attacks

- Denial of Service
- Message Alteration
- Eavesdropping
- Impersonation
- Fake Message
- Fake Vehicle
Data Analytics – CAV Operations

- Server / Cloud
- Roadside Unit
- Data Infrastructure
- Machine Learning
- Object Detection
- Trajectory Planning
- Path Planning
Data Analytics – Data Distribution

Simulation of the Real World

Data Sources
- Palmetto Cluster
  - Clemson University

Message Brokers
- Holocron Cluster
  - Clemson University

Data Users
- Palmetto Cluster
  - Clemson University

Message Broker

Roadside/Roadway Equipment
- Consumer
- Producer

News and Weather
- Consumer
- Producer

Human Drivers/Traffic Operators
- Consumer
- Producer

Mobile Devices
- Consumer
- Producer

Vehicles
- Consumer
- Producer

Centers
- Consumer
- Producer
### Risk Factors for CAVs

<table>
<thead>
<tr>
<th>Communication System</th>
<th>Vehicle-passenger interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware System</td>
<td>Road Condition</td>
</tr>
<tr>
<td>Non-autonomous Vehicles Crashes</td>
<td>Construction zones</td>
</tr>
<tr>
<td>Software System</td>
<td>Cyclists</td>
</tr>
<tr>
<td>Weather</td>
<td>Pedestrians</td>
</tr>
</tbody>
</table>

### Challenges

- Identify risks of CAVs in mixed traffic streams
- Develop countermeasures to minimize risks
Adoption of CAV technology could be hindered if end users are unsure about the comfort of this technology and feel insecure.

Challenges

- User preferences/acceptance in different driving conditions
- Engaging and disengaging in different roadway traffic events
No clear property regime for ownership and control of data

Policy questions concerning data use and related legal issues need to be addressed

Privacy concerning CAV data is an issue that “could derail the business”
Institutional Issues

Who regulates it?

Liability issues with autonomous vehicles?

Ethical issues?
Embracing Legacy Transportation Infrastructures
## Embracing Legacy Transportation Infrastructures

### An Example Scenario of Legacy Transportation System and CAVs Integration

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Existing infrastructure-CAVs interface strategies/technical issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost-effective roll-out plans (both short-term and long-term) for CAV in coordination with legacy and new CPS infrastructure</td>
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<tr>
<td>Skilled workforce for efficiently managing the environment where CAV and legacy components will co-exist</td>
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Smart cities are wide-scale CPS, which include CAVs for smart mobility.
Wide-Scale CPS: Smart City Challenges

- Integration of cyber-physical systems from different sectors
- Funding for large scale CPS deployments
- Ubiquitous distribution of privileges for all system users
Adoption Timeline

- **2013**: NHTSA Notice of Regulatory Intent
- **2014**: NHTSA issues draft proposed rulemaking
- **2014/2015**: Final proposed rule making
- **2018/2019**: Launch of first vehicles with V2V/V2I capability
- **2025**: Sufficient built-in and after-market penetration to support self-driving applications
South Carolina Enabler:
Clemson University International Center for Automotive Research (CU-ICAR)

• $250 million initial investment
• 250 acres advanced-technology research campus
• Premier automotive research, innovation and educational enterprise
• Only graduate Department of Automotive Engineering in the US

Research Areas

- Advanced Powertrains
- Vehicular Electronics
- Manufacturing & Materials
- Vehicle-to-vehicle Infrastructure
- Vehicle Performance
- Human Factors/HMI
- Systems Integration
Fostering Innovative Ideas in Multimodal Transportation to Solve National and Regional Problems
CUBTIC will be a driving force behind the creation of a southern innovation hub focused on transportation technology innovations and entrepreneurship.
Clemson University Beyond Traffic Innovation Center (CUBTIC) will foster growth by leveraging the efforts of public, private and community partnerships.
“The best way to predict the future is to create it”

- Abraham Lincoln

Contact Information:
Ronnie Chowdhury
mac@clemson.edu
(864) 656-3313