Connected and Automated Vehicles: Modeling and Management Needs

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Vehicular automation, in conjunction with connectivity, is proving to be disruptive and transformative

- After more than a century, the human is relinquishing driving control
- Machines (vehicles): control and artificial intelligence (learning)

Vehicular capabilities, driven by technology, are advancing at a far greater pace than society’s ability to handle them

- Gaps (human, built environment, management, models/procedures)
- Consequences (emergent)
- Transition (getting there from here)
Challenges arising from CAVs

- Standards: clarity, uniformity, policy, ethics, legal
- Technology: flux, acceptability, adoption, long-term
- System evolution: emergent outcomes, phenomena
- Transition: mixed traffic, infra. design, regulations
- Potential for obsolescence: how to hedge?
- Decision-making: planning, investment, recourse
- Traffic/system modeling and management needs
Why: modeling & management needs?

Academia → Government → Infrastructure → Human → Vehicle → Industry → SOCIETY
Why: modeling & management needs?

- It is about more than just the vehicle
- How humans interface needs to be well-understood
- Infrastructure design
- Regulatory, legal, policy/ethical, security, standards
Impacts of CAVs

Safety
- Fewer road accidents
- Eliminate human error

Positive

Mobility
- Enhanced mobility for low-mobility population
- Lesser “wasted” time in travel

Positive

Emergent phenomena
- Ghost ridership, car sharing, ride hailing
- Data management and security

Unknown
Impacts of CAVs

Industry
- Disrupts freight, mobility services, etc.
- Could create new jobs

Real estate market
- Urban sprawl
- Redesigning land use

Environment
- Energy-efficient driving
- Vehicle-miles traveled may increase

Models need to be able to capture CAV impacts
Example: Level of automation

Human

LEVEL 0
No Active Assistance System

LEVEL 1
Longitudinal or Transverse Guide

LEVEL 2
Traffic Control

LEVEL 3
Awareness for Take Over

LEVEL 4
No Driver Intervention

LEVEL 5
No Driver

Machine

Hands On Eyes On

Hands On Eyes On

Hands Temp Off Eyes Temp Off

Hands Off Eyes Off

Hands Off Mind Off

Hands Off Driver Off

Source: iq.intel.com
Example: America is aging

By 2030, the U.S. population aged 50 or over will increase to 132 million. In this time, the number of adults aged 65-74 will nearly double from 21.7 million in 2010 to 38.6 million in 2030.

132 million
In the next 20 years, the population aged 50+ will increase from 109 million to 132 million.

1 in 5 people will be 65 and over in 2030.

1 in 8 people will be 75 and over in 2040.

Source: www.jchs.harvard.edu
Example: Aging and travel

61% of older adults limit their driving to certain hours of the day, and 21% say they frequently or occasionally miss out on activities they like to do, because of driving limitations.

www.jchs.harvard.edu  www.aarpfoundation.org

Source: www.jchs.harvard.edu
What: modeling & management needs?

Individually in flux, and interactions on top of that!
What: modeling & management needs?

- Transportation characteristics
  - Demand-side aspects
  - Supply-side aspects

- System management objective
  - Planning
  - Operations

- Analysis and implementation tools
  - Analytical models/procedures/processes
  - Simulation models/software
  - Driving simulators
  - Virtual/augmented reality approaches
  - Real-world testing facilities
Demand-side aspects

- Vehicle ownership
- New modes & adoption
- Mobility as a service
- Transition period

Travel Mode

In the Vehicle
- Value of time
- In-vehicle activities
- Human-machine interactions

Modeling for CAVs: Demand-side

Lifestyle Choices
- Locational decisions
- Activities
- Activity scheduling
- Travel decisions (role of demographics)

Travel Behavior
- Mode choice
- Departure time choice
- Route choice
- Parking choice
- Role of technology
Supply-side aspects

Driver/Traveler Behavior
- Role of human
- Role of information
- Technology uptake

Traffic Flow
- Traffic measures
- Vehicular interactions
- Platooning
- Mixed traffic
- Ghost ridership

Traffic Management
- User objective
- Role of technology
- Innovations in solutions
- Cyber-physical systems

Modeling for CAVs: Supply-side

Network Design
- Signal control (V2X)
- Traffic operations
- Public transit
- Roadway design
- Parking system
Concluding comments

- Existing models need to be updated/modified/discarded to account for changes due to CAVs
- New models to leverage new technological capabilities, and capture emergent interactions
- Modeling for CAVs emphasizes integration of advanced technologies
- Modeling challenges in the transition period
- Modeling needs to factor social and interaction/integration aspects
- Data will play a more important role
- Cooperative/synergistic applications will be more promising
Thank you!

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Role of human

- **New phenomena**
  - Driving decisions/actions will be replaced by autonomous control systems
  - Routing decisions/actions will be dynamically intervened by autonomous control systems

- **Current models can do**
  - Departure time choice; route choice; mode choice; value of travel time; value of travel time reliability

- **Questions need to be addressed**
  - Changes to value of travel time and its reliability (vehicle as an extension of work place or for leisure)
  - Routing/rerouting under CAVs
  - Combination of travelers’ preferences and autonomous system control
Role of information

- **New phenomena**
  - Real-time information can be automatically processed and analyzed by CAVs

- **Current models can do**
  - Travel time estimation; travel time reliability estimation; dynamic shortest path; V2V information propagation; V2I communications

- **Questions need to be addressed**
  - Information provision strategies for CAVs
  - Information filtering/customization
  - Malicious information prevention
  - Privacy protection
  - Information integration with traveler preferences
Technology uptake

- **New phenomena**
  - Transition period and transience will exist

- **Current models can do**
  - Lifecycle analysis

- **Questions need to be addressed**
  - How travelers’ behaviors change gradually
  - Modeling traffic flow evolution toward a purely autonomous driving environment
Current traffic flow theory may not be applicable for CAVs due to homogeneity in driving behavior

- CAVs can move in platoons at a uniform speed
- Highway capacity is more flexible and controllable
- Queue formation and dissipation mechanism may change
Volume, speed and density

- **Current models can do**
  - Relation of traffic volume with respect to speed and density \( q = v \cdot k \)
  - Macroscopic Fundamental Diagram
  - Volume, density, and speed changes under inclement weather conditions
  - Uncertainty in the traffic flows

- **Questions need to be addressed**
  - Changes in the relationships between volume, speed and density under CAVs
  - Uncertainty reduction
  - Uniform headways

New phenomena
- CAVs can communicate with each other and react to information more efficiently
- Different mobility pattern without human intervention

Current models can do
- Homogeneous and heterogeneous traffic wave (kinematic wave theory)

Questions need to be addressed
- Traffic wave characteristics due to V2V and V2I communications
- Traffic wave speeds can increase significantly
Mixed traffic

- **New phenomena**
  - CAVs behave more homogeneously in platoons to improve system performance
  - CAVs can communicate with each other and infrastructure

- **Current models can do**
  - Heterogeneous traffic flow models (focus more on mixture of cars and trucks)

- **Questions need to be addressed**
  - Modeling platoon streams for CAVs
  - Car-following model for mixed traffic with autonomous and human-operated vehicles
  - “Car-following models” for multi-class CAV traffic
New phenomena
- CAVs can communicate with signal control systems and automatically determine optimal speeds
- CAVs can form platoons when approaching intersection
- CAV flows may be managed through signal control

Current models can do
- Signal timing plans; adaptive traffic signal controls; signal coordination; signal preemption

Questions need to be addressed
- Realize network-wide signal coordination for CAVs
- Provide signal preemption to CAV platoons
- Manage purely autonomous vehicles at signalized intersections
Highway design

- **New phenomena**
  - CAVs move more efficiently than human-driven vehicles
  - Special design to facilitate the mobility of CAVs

- **Questions need to be addressed**
  - Highway design for mixed traffic with autonomous and human-driven vehicles
  - Highway design for purely autonomous vehicles
Parking system

- **New phenomena**
  - A CAV can park itself
  - Parking distance can be extended
  - Parking space can be used more efficiently (on-demand)

- **Current models can do**
  - Parking facility design; parking demands and supply analysis; park-and-ride planning and operations; parking pricing strategies

- **Questions need to be addressed**
  - Facility design to facilitate auto-parking
  - Shared park-and-ride
New phenomena

- Human-operated taxicab can be replaced by driverless ones
- Public transit ridership may increase due to reduced car ownership

Current models can do

- Public transit infrastructure system modeling and optimization
- Integrated public transportation planning
- Route optimization and dispatching planning for taxicab
- Optimal timetables for transit systems

Questions need to be addressed

- Transit demand analysis
- Pricing strategies for CAV taxis, ride-sharing/ride-hailing services
Freight facility

- **New phenomena**
  - Connected and autonomous trucks can travel more efficiently
  - Routes can be optimized and updated in real-time
  - Connected and autonomous trucks can form platoons

- **Questions need to be addressed**
  - Location planning for freight facility
  - Joint optimization problems of freight operations and network design
New phenomena

- User decisions will be more influenced by system level objectives

Current models can do

- User equilibrium/system optimum traffic assignment
- Activity based traffic assignment

Questions need to be addressed

- UE/SO traffic assignment with new cost function
- UE/SO traffic assignment for mixed traffic with autonomous and human-operated vehicles
- UE/SO traffic assignment for multi-class CAVs
**Deterministic/Stochastic**

- **New phenomena**
  - Vehicles can be controlled more easily by centralized system
  - Traffic condition “perceptions” will be more accurate

- **Current models can do**
  - Deterministic/stochastic traffic assignment

- **Questions need to be addressed**
  - Notion of stochasticity may have a different perspective; not primarily driven by driver perceptions/actions
  - Stochastic traffic assignment for purely autonomous vehicles
New phenomena
- CAVs can receive real-time information and dynamically adjust decisions

Current models can do
- Static/dynamic traffic assignment

Questions need to be addressed
- Static/dynamic traffic assignment for mixed traffic with autonomous and human-operated vehicles
- Static/dynamic traffic assignment for CAVs with full cooperation and real-time traffic information
Response to incidents

- **New phenomena**
  - CAVs can receive traffic information more quickly
  - CAVs can move cooperatively

- **Current models can do**
  - Emergency evacuation routing
  - Rerouting under non-recurrent traffic congestion

- **Questions need to be addressed**
  - Traffic assignment models under incident scenarios with cooperative vehicle movement
Intersection design

- **New phenomena**
  - CAVs can move at higher speeds when approaching intersections
  - CAVs can talk to each other and the infrastructure

- **Current models can do**
  - Clover-leaf design; roundabout; intersection capacity modeling; safety analysis

- **Questions need to be addressed**
  - Signal-free intersection design to facilitate CAV movement
Highway operations

- **New phenomena**
  - CAV platoons can travel more efficiently
  - Interactions between human-driven vehicles and autonomous vehicles need to be factored
  - Cooperative operations are possible

- **Current models can do**
  - Congestion tolling and tradable-credit tolling strategies; ramp metering; managed lanes; contraflow lanes

- **Questions need to be addressed**
  - Using existing highway operations to encourage CAV ride-sharing
  - Demand management strategies for purely autonomous vehicles