Vehicle and Highway/Roadway Automation with VII

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Outlines

• Vehicle Automation
• Highway/Roadway Automation
• Microscopic Simulation of Mixed Traffic with CAVs
Vehicle Automation

- Vehicle Internal System Automation
- Driver Assistance System (DAS)
- Progressive Automation
- Full Automation for Operation
- Challenges for Vehicle Automation
- Rolls of V2I in Vehicle Automation
- Fuel Saving for Truck CACC/Platooning
- Factors Affecting Vehicle Energy Consumption
Vehicle Internal System Automation

- **Onboard sensors**
  - Wheel speed, acceleration/deceleration, gyro, GPS, road grade (tilting), brake pressure, ...

- **Onboard data bus:**
  - Passenger cars: CAN Bus
  - Trucks: J1857 → J1939 Bus

- **Remote sensors:**
  - Video camera, Doppler radar, lidar, ...

- **Control actuators**
Vehicle Internal System Automation

- Engine:
  - Higher Level: Speed control and torque control
  - Lower Level:
    - Engine control – fueling timing
    - Sparking timing
    - Transmission control
    - Integrated control of engine and transmission
    - Jake brake control (truck)
- Transmission: Gearbox ➔ E-Gearbox ➔ fully automatic transmission
- Braking: power braking ➔ E-braking ➔ braking by wire
- Steering; power steering ➔ automatic steering control module ➔ steering by wire
Passive Driver Assistance System – with Warning
Active Driver Assistance System – with Control

- Vehicle stability control (active rollover prevention)
- ABS
- Lane keeping & lane changing
- CC (Cruise Control), ACC (Adaptive Cruise Control)
- Automatic parking assistance (Parallel Parking – Lexius)
- Emergency braking
- Collision avoidance
- Collision avoidance with situation awareness (detection + comm)
- Coordinated Onramp Merging Assistance with comm.
- Coordinated Lane Changing Assistance with comm.
- Coordinated Emergency braking Assistance with comm.
Progressive Automation

• Partial Automation = Driver Assistance System
  – CC – Cruise Control: speed control; driver distance control
  – ACC - Adaptive Cruise Control: speed and distance control
  – Both of them need driver steering
Progressive Automation

• Platooning
  – Constant distance gap, maintain string stability in following
• CACC – cooperative Adaptive Cruise Control
  – Constant Time Gap: higher speed with longer following distance
  – Mimic driver behavior, maintain string stability in following
  – Coordinated emergency braking
• Fully Automated Vehicle
  – Longitudinal Control
  – Lateral Control
• Autonomous vs. Connected Automated Vehicle (CAV)
  – Autonomous: Only using sensor detection for control
  – CAV: sensor + communication
Progressive Automation – PATH Automated Vehicles
Progressive Automation – PATH CAV Milestones

1997: 8 fully automated Buick Platooning demo 6m following 60mph on I-15

2000: 3-car coordinated automated vehicle merging

2003: 2-Truck Platooning at 3m distance

2009: 3-Truck Platooning with 4m on SR722 Nevada at 55mph
Progressive Automation – PATH CAV Milestones

• 2015 - 2017: 3-Volvo Class-8 fully loaded truck CACC
  – on Transport Canada Test 4m

LA Demo I-110

Transport Canada Test Track, Montreal

On Highway 4 EB

On I-80 EB
Progressive Automation – **PATH CAV Milestones**

2013: 4 - passenger Infiniti CACC driving with public traffic

2015: Implemented CACC on 5 Cadillac of FHWA Saxton Lab
Progressive Automation – PATH CAV Milestones

• 2017: Test Track & Scenarios:

- 4m CACC following
- Speed variation with 18m D-Gap
- Cut-in CACC string with 35m D-Gap
- Manually driven SUV leading 3-truck CACC with 56m separation & 12m between trucks
- Long combination vehicle testing

Transport Canada’s Motor Vehicle Test Centre, Blainville, Québec
Generic CACC Design for Vehicle with Different Powertrains

- **V2V network**
- **High-level control layer**
  - Reference trajectory
  - Vehicle state
- **Low-level control layer**
  - Actuators (torque)
  - Proprioceptive sensors
- **Target perception**
Generic CACC Design for Vehicle with Different Powertrains - Tests

- CACC system tested in Crows Landing tracks
- Scenarios tested:
  - Speed steps with different rates
  - Smooth speed steps
  - Multisine profile for string stability study
  - Cutting in vehicle
  - Emergency braking
Generic CACC Design for Vehicle with Different Powertrains - Tests

Speed steps of $a=\pm 1.5 \text{ m/s}^2$
Challenges for Vehicle Automation

- Reliability of road and target detection/perception
  - Space
  - Time
- Interaction with others in mixed traffic
  - Complicated environment: road + traffic + other objects
  - Driver behavior differences
  - Vehicle control performance differences
- Roadway design: roadside detection & wireless communication
- Fault detection and management
- Institutional issues
  - Policies and regulation
  - Driver trust and acceptance
Challenges for Vehicle Automation

Tesla AutoPiolet

Waymore

Uber
Challenges for Vehicle Automation – Where are We?

**SOCIETY OF AUTOMOTIVE ENGINEERS (SAE) AUTOMATION LEVELS**

<table>
<thead>
<tr>
<th>Level</th>
<th>Automation Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>Zero autonomy; the driver performs all driving tasks.</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>Vehicle is controlled by the driver, but some driving assist features may be included in the vehicle design.</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>Vehicle has combined automated functions, like acceleration and steering, but the driver must remain engaged with the driving task and monitor the environment at all times.</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>Driver is a necessity, but is not required to monitor the environment. The driver must be ready to take control of the vehicle at all times with notice.</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>The vehicle is capable of performing all driving functions under certain conditions. The driver may have the option to control the vehicle.</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>The vehicle is capable of performing all driving functions under all conditions. The driver may have the option to control the vehicle.</td>
</tr>
</tbody>
</table>

*We are still here*
Roles of VII in Vehicle Automation

• VII:
  – V2V: DSRC - Dedicated Short Range Communication
  – I2V: Vehicle to/from Infrastructure
  – I2I: Infrastructure to Infrastructure (data system, ATM)

• DSRC – local situation awareness
  – for vehicle guidance:
    • Longitudinally following
    • Lateral: lane keeping and lane changing
  – 10+ Hz and 300 ~ 500m range
  – Dynamic assignment of Vehicle ID
  – Following IEEE Standard and SAE

• DSRC vs 5G, which is better for V2V?
  – Small packet ~ 200 bytes, reliable, local, cyber security, …
Roles of V2I in Vehicle Automation

• Cooperative Driving
  – Changing driver behavior
  – Coordinated merging
  – Coordinated braking for collision avoidance and impact mitigation
  – Coordinated following (CACC & platooning) with shorter distance
    • Reducing fuel consumption due to aerodynamic drag reduction
    • Increasing traffic capacity
    • Collision avoidance (both lateral and longitudinal)
Roles of VII in Vehicle Automation

• Active Safety
  – Location
  – Speed
  – Lane ID if GPS is available
  – Throttle peddle deflection
  – Brake peddle deflection
  – Steering angle and rate
  – Fault mode
  – …
Fuel Saving for Truck CACC/Platooning

Magnitude of each effect is dependent on separation distance!
...what happens for a 3-vehicle platoon?
Fuel Saving for Truck CACC/Platooning

- Truck 2 has highest savings at short D-Gap
- Truck 3 savings decrease at short D-Gap
- Truck 1 has savings at short D-Gap
Fuel Saving for Truck CACC/Platooning

- SUV leading 3-truck CACC
- Average fuel savings of 3-truck CACC
- Average fuel savings of 2-truck CACC, same D-Gap
- 3-truck CACC with cut-in
- 1 truck following SUV

Fuel consumption: measured vs. estimated from J-Bus fuel rate data.
Fuel Saving for Truck CACC/Platooning

- SUV leading 3-truck CACC
- Average fuel savings of 3-truck CACC
- Average fuel savings of 2-truck CACC, same D-Gap
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Graph showing fuel savings as a function of time gap and vehicle separation distance.
Factors Affecting Vehicle Energy Consumption

- Vehicle energy savings in real world traffic mainly affected by factors at three levels: (a) meso/macroscopic traffic patterns; (b) local vehicle following behavior; and (c) vehicle level: control & powertrain/drivetrain characteristics.
- Local vehicle following behavior affect aerodynamic drag and speed.
- Progressive market penetration of CAVs and Active Traffic Management (ATM) changes the traffic pattern significantly.
- Field test of CAVs impact (for different market penetration) on energy savings is cost prohibitive.
- Needs a reasonably accurate models to simulate fuel consumption.
Factors Affecting Vehicle Energy Consumption

- Main factors affecting fuel consumption at local traffic and vehicle levels:
  - Mass
  - Speed
  - Road grade
  - Acceleration/deceleration
  - Following distance in traffic
  - Position in CACC string/platoon
  - Vehicle geometry and shape (streamlined or not)
  - Control (automatic or manual) performance
  - Powertrain and drivetrain characteristics
Highway and Roadway Automation

- Traffic Monitoring and Measurement
- Network Traffic Measurement and Control: PeMS
- Roles of V2V & V2I in Highway/Roadway Automation
- Active Traffic Management (ATM)
- Integrated Traffic Signal Control with CV and CAVs
- Challenges for Highway/Roadway Automation
- Towards Fully Automated Highway/Roadway System
Traffic Monitoring and Measurement

• **Ground Sensors**
  – Inductive loops (single, dual)
  – Roadside-vehicle wireless transponder
  – Video camera
  – Microwave/Laser/Infrared/radar
  – WIM
  – Air tubes
  – …

• **Probe Vehicle or Connected Vehicles (CV)**
  – Cellphone or modem (wireless comm.) + GPS + speed etc
  – Driver report
Traffic Monitoring and Measurement - PeMS
Traffic Monitoring and Measurement

• Traffic State Parameter Estimation:
  – Distance/time aggregate traffic parameters
    • Occupancy, Distance mean speed, Flow, Density
    • Link travel time
  – Onramp demand
  – Turning ratio
  – Onramp/off-ramp queue length
  – Time delay
  – Vehicle re-identification ➔ ODs
  – Issues: Detector fault, communication fault, …
Active Traffic Management (ATM)

- Freeway:
  - Coordinated Ramp Metering (CRM)
  - Variable Speed Limit/Advisory (VSL/VSA)
  - Lane Management
  - Coordinated Onramp Merge
  - Incident/accident management

- Arterial Intersections
  - Active Traffic Signal Control (ATSC)
  - Coordinated Traffic Signal Control along an arterial corridor

- Network Level
  - Coordination of all sub-control
  Systems for overall system optimization
Active Traffic Management: CRM & VSA

• Freeway Coordinated RM
  – SR99 NB, Sacramento, CA:
    VMT increased by 5.39%,
    VHT decreased by 1.64%,
    \( Q = \frac{\text{VMT}}{\text{VHT}} \) increased by 7.25%.

• Freeway VSA field test (2018)
  – SR 78 EB, San Diego, CA:
    • VMT increased by 2.72% on average.
    • VHT decreased by 6.28% on average.
    • \( Q \) increased by 8.71% on average.
Active Traffic Management: Experiences

- Coordination of Freeway Ramp Metering and Arterial Traffic Signals (ongoing)
  - I680 & Capitol, San Jose, CA: Coordination of all sub-control systems overall optimization
Integrated Traffic Signal Control with CAVs

- Intersection Active Traffic Signal Control
- Trajectory planning for CAVs: used as the set-speed for CACC
- Real-time simulation
  - Synchronized with traffic controller and the signal
  - To generate virtual traffic for signal activation
  - Repeatable test scenarios
- Physical CACC vehicles with V2I connection with 2070 controller
- Energy consumption measurement
  - Repeat 50~100 laps for each designed scenario
  - Gauge of actual fuel filled on each vehicle
  - On-vehicle fuel rate recorded if available from CAN Bus
  - Real-time simulation energy consumption of all traffic based on models
Integrated Traffic Signal Control with CAVs

Intersection at RFS

Traffic Signal
Loop Detector

CACC cars with optimal speed trajectories

Traffic controller

Aimsun real-time simulation

Physical CACC cars & traffic signals
Integrated Traffic Signal Control with CAVs
Roles of V2V & V2I in Highway/Roadway Automation
Roles of V2V & V2I in Highway/Roadway Automation

- Function: Real-time message passing
  - Reduce the Need to Sensors
  - Reduce time Delay
  - Better traffic state parameter estimation by fusion of CV data and road detector data

- Application
  - Traffic Monitoring and ATM
  - Integrated Intersection Traffic signal control and Safety

- Examples
  - Situation awareness for collision avoidance
  - Downstream congestion warning → shockwave reduction
  - VSL/VSA passed to vehicle for driver to follow
  - VSL/VSA used in CAV as set-speed for control
Roles of V2V & V2I in Highway/Roadway Automation

• Limit of CV Data
  – CV data alone cannot measure flow nor density unless market penetration level is 100%

• Road sensor
  – Still necessary for freeway
  – Very important for intersection traffic and all target detection
    • For better safety
    • For integrated traffic signal control
Roles of V2V & V2I in Highway/Roadway Automation

• Roadside and intersection sensor (radar + video camera)
  – Help in the situation vehicle sensor cannot see
• Dynamic road map broadcasting situation awareness ➔ collision avoidance
  – Road and lane geometry
  – Nearby all movement traffic
  – All vehicle position
  – Any moving object position including pedestrian
• Integrated traffic signal control
  – Driver warning initially
  – ADAS
  – CAV control eventually
Roles of V2V & V2I in Highway/Roadway Automation

• Function:
  – Providing richer info ➔ Better perception for complicated traffic situation
  – Reduced vehicle onboard sensors ➔ reduced energy use
  – Reducing time Delay & improved highway capacity

• Application
  – Cooperative Driving: CACC & platooning
  – Situation awareness for collision avoidance:
    • Using DSRC passed other vehicle info
    • Using wireless passed roadside sensor information

• V2V & V2I is the only and eventual solution of automated vehicle deployment in urban area and in complicated traffic situation

• Autonomous vehicle must become connected with VII
Challenges for Highway/Roadway Automation

- Capacity estimation for non-recurrent bottleneck
- Demand uncertainties
- Large scale system problem
- Integration of freeway and arterials
  - Open system - difficult to isolate
  - Limit onramp storage: e.g. US-101 near San Francisco
- Non-homogeneity of driver behavior
- User equilibrium approach for routing will no improve traffic
- Only system-wide optimal coordination (dynamic system equilibrium) can improve traffic in a meso and macroscopic level
Towards Fully Automated Highway/Roadway System

• V2V and V2I Communication system
• Automated vehicles technologies
  – Sensor technologies
  – Individual vehicle control and Cooperative Control
• Infrastructure systems
  – Sensor, communication
  – traffic control devices
• Institutional issues and driver acceptance
• Potential benefit
  – increased highway/roadway capacity, mobility and safety
  – reduced travel time, energy consumption, and emission
• Mixed traffic will last for long time with progressive market penetration of CAVs
Simulation of Mixed Traffic with CV and CAVs

- Traffic Flow GEH criteria

<table>
<thead>
<tr>
<th>Detector Location (post-mile)</th>
<th>Target</th>
<th>Cases</th>
<th>Cases Met</th>
<th>% Met</th>
<th>Target Met?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td>GEH &lt; 5 for &gt; 85% of k</td>
<td>504</td>
<td>464</td>
<td>92.06%</td>
<td>Yes</td>
</tr>
</tbody>
</table>

- Speed Contours Comparison:

Comparison of contour plots of (a) field observed and (b) simulated speeds (mph).

Ref: X. Y. Li, Simulation Meeting, Washington D.C., 2017
Simulation of Mixed Traffic with CV and CAVs

- Modeling dynamic interactions with other vehicle for microscopic traffic simulation: to build simple vehicle following model to replace complicated feedback control system based on test data

![Diagram of CC/ACC/CACC Driving and Manually Driving processes]
Simulation of Mixed Traffic with CV and CAVs

• Impact on Capacity

Impact on capacity of different level of CACC penetration vs. onramp demand

- MOVES model for estimating the fuel saving
- Plot shows the normalized fuel rate in gallon per vehicle per meter
- Energy consumption drops with CACC% increases
- Connectivity and coordination are important

• Impact on Energy Saving
Simulation of Mixed Traffic with CV and CAVs

• Theory: calculated capacity
• Simulation_Ideal: simulated capacity for no lane changes and no randomness in drivers’ behaviors
• Simulation: simulated capacity
Simulation of Mixed Traffic with CV and CAVs

- VTT decreases and speed increases with the CACC market penetration.
- No significant change between 0% and 20% CACC case.
1997 Demo, I-15 HOV Lane San Diego

Automated Vehicle Merging, 2001
Transport Canada Test Track (2017)
Truck Platoon (Nevada SR722, 2009)

Truck CACC on I-580 & Hwy4, 2017
Links of Some PATH Demos and Vehicle Tests

- PATH 1997 Automated Vehicle Platoon Demo on I-15 San Diego
  https://www.youtube.com/watch?v=h7tO-4FoKCo&t=67s
- 3 Connected Fully Automated Vehicle (CAV, Level 4) Merging (2000):
  https://www.youtube.com/watch?v=CLKty9u-2z8
- 3-Truck CACC fuel econ test at Transport Canada Test Track, Montreal, including 4m following:
  https://www.youtube.com/watch?v=DNLLycxlees
- 3-Truck CACC demo in Washing DC Sept 13-15 2017:
  https://www.fhwa.dot.gov/research/truck_platooning/ (FHWA Website)
  https://youtu.be/7lyZ62S4U5E (video)
- 3-Truck CACC on Highway 4 and Interstate 80, in 2016:
  https://www.youtube.com/watch?v=IIIRSNb6rJnI
- 3-Truck CACC Demo with Public Traffic on Interstate Highway I-110 in LA, 2017:
  https://youtu.be/FPdBmlVFKIQ
- 2-truck platooning test at 55mph with 3m in Crows Landing NASA airport, 2003:
  https://www.youtube.com/watch?v=E3eEwz9W5E
Links of Some PATH Demos and Vehicle Tests

- 3-truck platoon with 4m constant gap at 55mph on SR722 Nevada in 2009:
  - https://www.youtube.com/watch?v=hxXanXBVy7o

- 5-Cadillac SUV CACC (Level 1) implementation 2015:
  - https://www.youtube.com/watch?v=A0o4utksX9M

- Truck Driver Assistance 2005:
  - https://www.youtube.com/watch?v=2tiFrmPybg0

- Cooperative Intersection Collision Avoidance System (CICAS) (2005):
  - https://www.youtube.com/watch?v=RgqeGj8_wI
Thank You!