Road Vehicle Automation: Challenges and Opportunities

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Outline

- **Diverse types of vehicle automation, with very different capabilities**
- **Potential transportation impacts of each type of automation**
- **Timing for automation market introduction and growth**
- **Example unresolved questions**
- **Near-term opportunities**

Diversity of Vehicle Automation

- **Automated driving systems classified according to:**
  - **Levels of automation (division of roles between humans and system)**
  - **Operational Design Domain (ODD)**
  - **Architecture (autonomous/unconnected vs. connected)**

Operational Design Domain (ODD)

- **The specific conditions under which a given driving automation system is designed to function, including, ...**
  - Roadway type
  - Traffic conditions and speed range
  - Geographic location (boundaries)
  - Weather and lighting conditions
  - Availability of necessary supporting infrastructure features
  - Condition of pavement markings and signage
  - (and more…)

Levels of Automation
(SAE J3016 - http://standards.sae.org/j3016_201609/)

Driving automation systems **are categorized into levels based on:**

1. **Whether the driving automation system performs *either* longitudinal *or* lateral vehicle motion control**
2. **Whether the driving automation system performs *both* the longitudinal and lateral vehicle motion control simultaneously.**
3. **Whether the driving automation system *also* performs *object and event detection and response*.**
4. **Whether the driving automation system *also* performs *fallback* (recovery from failures).**
5. **Whether the driving automation system is limited by an ODD.**

Example Systems at Each Automation Level

Level	Example Systems	Driver Roles
1	Adaptive Cruise Control OR Lane Keeping Assistance	Must drive other function and monitor driving environment
2	Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist (Mercedes, Tesla, Infiniti, Volvo…) Parking with external supervision	Must monitor driving environment (system nags driver to try to ensure it)
3	Traffic Jam Pilot	May read a book, text, or web surf, but be prepared to intervene when needed
4	Highway driving pilot Closed campus “driverless” shuttle “Driverless” valet parking in garage	May sleep, and system can revert to minimum risk condition if needed
5	Ubiquitous automated taxi Ubiquitous car-share repositioning	No drivers needed

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No Automation and Driver Assistance (Levels 0, 1)

- **Primary safety advancements likely at these levels, adding machine vigilance to driver vigilance**
  - **Safety warnings based on ranging sensors**
  - **Automation of one function facilitating driver focus on other functions**
- **Driving comfort and convenience from assistance systems (ACC)**
- **Traffic, energy, environmental benefits depend on cooperation**
- **Widely available on cars and trucks now**

Partial Automation (Level 2) Impacts

- **Probably only on limited-access highways**
- **Somewhat increased driving comfort and convenience (but driver still needs to be actively engaged)**
- **Possible safety increase, depending on effectiveness of driver engagement**
  - **Safety concerns if driver tunes out**
- **(*only* if cooperative) Increases in energy efficiency and traffic throughput**
- **When? Now (Mercedes, Tesla, Infiniti, Volvo…)**

Intentional Mis-Uses of Level 2 Systems

Mercedes S-Class

Infiniti Q50

Conditional Automation (Level 3) Impacts

- **Driving comfort and convenience increase**
  - **Driver can do other things while driving, so disutility of travel time is reduced**
  - **Limited by requirement to be able to re-take control of vehicle in a few seconds when alerted**
- **Safety uncertain, depending on ability to re-take control in emergency conditions**
- **(*only* if cooperative) Increases in efficiency and traffic throughput**
- **When? Audi planning first product introduction this year.**

High Automation (Level 4) Impacts – General-purpose light duty vehicles

- **Only usable in some places (limited access highways, maybe only in managed lanes)**
- **Large gain in driving comfort and convenience on available parts of trip (driver can sleep)**
  - **Significantly reduced value of time**
- **Safety improvement, based on automatic transition to minimal risk condition**
- **(*only* if cooperative) Significant increases in energy efficiency and traffic throughput from close-coupled platooning**
- **When? Starting 2020 – 2025?**

High Automation (Level 4) Impacts – Special applications

- **Buses on separate transitways**
  - Narrow right of way – easier to fit in corridors
  - Rail-like quality of service at lower cost
- **Heavy trucks on dedicated truck lanes**
  - (cooperative) Platooning for energy and emission savings, higher capacity
- **Automated (driverless) valet parking**
  - More compact parking garages
- **Driverless shuttles within campuses or pedestrian zones**
  - Facilitating new urban designs
- **When? Could be just a few years away**

Vehicle-Infrastructure Protection for L4 Shuttle Vehicle – La Rochelle, France

Full Automation (Level 5) Impacts

- **Electronic taxi service for mobility-challenged travelers (young, old, impaired)**
- **Shared vehicle fleet repositioning (driverless)**
- **Driverless urban goods pickup and delivery**
- **Full "electronic chauffeur" service**

- **Ultimate comfort and convenience**
  - **Travel time won't discourage longer trips**
- ***(if cooperative)* Large energy efficiency and road capacity gains**
- **When? Many decades… (Ubiquitous operation without driver is a huge technical challenge)**

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Heavy Truck Automation - Platooning

- **Likely early adopters of CAV technology based on strong return on investment**
  - **Energy cost savings as initial motivation for long-haul trucking (L1, L2 automation)**
  - **Changes in driving responsibilities (L3, L4)**
- **Significantly reducing traffic impacts of trucks**
- **Dedicated truck lanes could facilitate higher levels of automation by simplifying driving environment and enhancing safety (L4)**
- **Potential losses of truck driving jobs - decades away**
  - **Non-driving responsibilities of drivers**
  - **Safety assurance challenges for automation**

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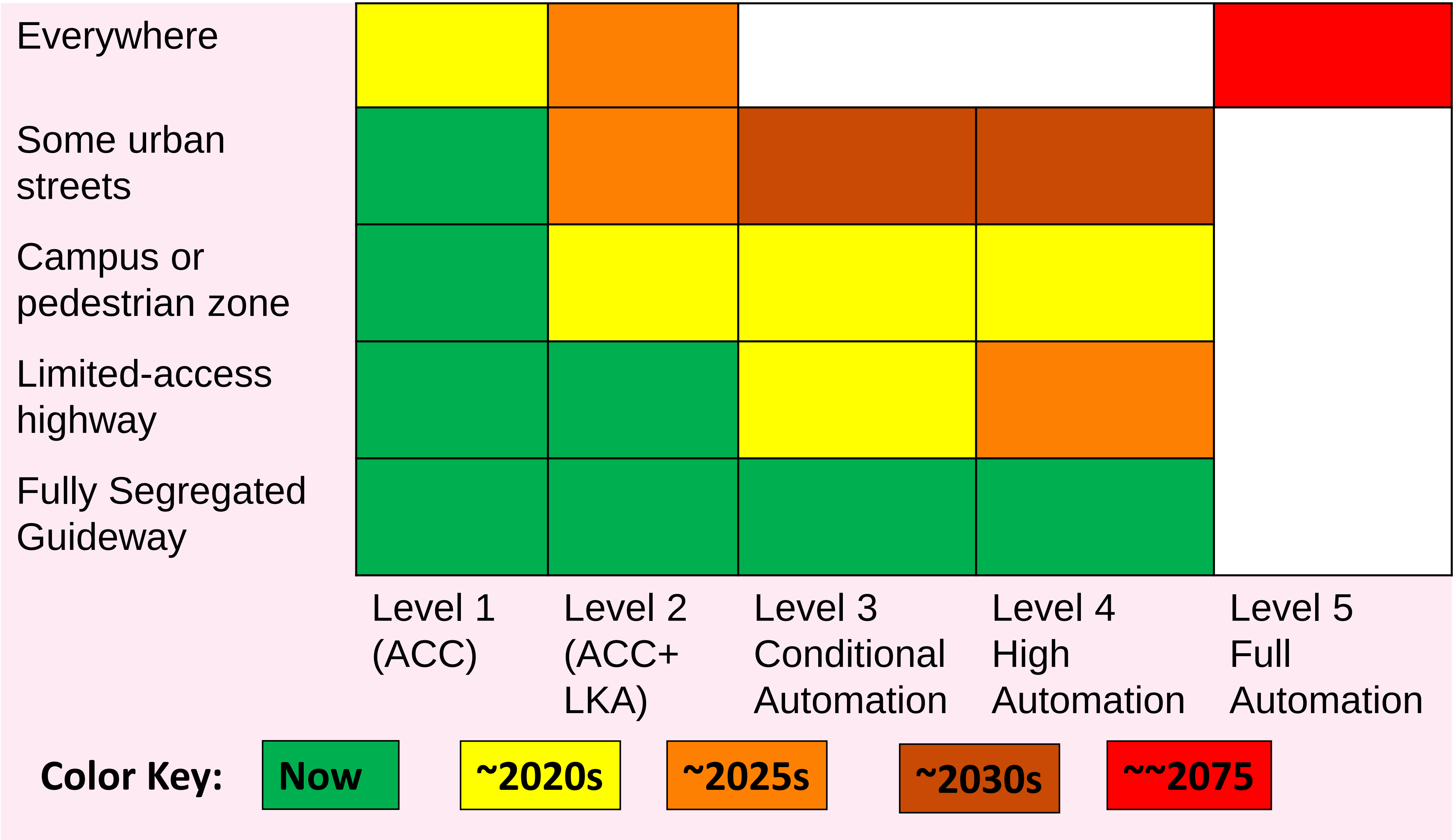
Personal Estimates of Market Introductions
** based on technological feasibility **



+ add decades to turn over vehicle fleet!

Fundamental Safety Challenge

- **Current traffic safety sets a very high bar:**
  - **3.4 M vehicle <u>hours</u> between fatal crashes (390 years of non-stop 24/7 driving)**
  - **61,400 vehicle <u>hours</u> between injury crashes (7 years of non-stop 24/7 driving)**
- **Automated systems must be no less safe than this (and probably safer to gain public acceptance)**
  - **How to design an automated vehicle to be this safe?**
  - **How to demonstrate that this level of safety has been achieved?**

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Traffic Safety Challenges for High and Full Automation

- **Extreme external conditions arising without advance warning (failure of another vehicle, dropped load, lightning,…)**
- **NEW CRASHES caused by automation:**
  - **Strange circumstances the system designer could not anticipate**
  - **Software bugs not exercised in testing**
  - **Undiagnosed faults in the vehicle**
  - **Catastrophic failures of vital vehicle systems (loss of electrical power…)**
- **Driver not available to provide fallback**

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Why this is a super-hard problem

- Software intensive system (no technology available to verify or validate its safety under its full range of operating conditions)
- Electro-mechanical elements don't benefit from Moore's Law improvements
  - Cannot afford extensive hardware redundancy for protection from failures
- Harsh and unpredictable hazard environment
- Non-professional vehicle owners and operators cannot ensure proper maintenance and training

Much Harder than Commercial Aircraft Autopilot Automation

Measure of Difficulty – Orders of Magnitude	Factor
Number of targets each vehicle needs to track (~10)	1
Number of vehicles the region needs to monitor (~10^6)	4
Accuracy of range measurements needed to each target (~10 cm)	3
Accuracy of speed difference measurements needed to each target (~1 m/s)	1
Time available to respond to an emergency while cruising (~0.1 s)	2
Acceptable cost to equip each vehicle (~$3000)	3
Annual production volume of automation systems (~10^6)	- 4
Sum total of orders of magnitude	**10**

Main Unresolved Questions (1/2)

- How safe is "safe enough"?
- How can an AV be reliably determined to meet any specific target safety level?
- What roles should national and regional/state governments play in determining whether a specific AV is "safe enough" for public use?
- Should AVs be required to inhibit abuse and misuse by users?
- How long will it take to achieve the fundamental technological breakthroughs needed for higher levels of automation?

Main Unresolved Questions (2/2)

- **How much support and cooperation do AVs need from roadway infrastructure and other vehicles?**
- **What should the public sector role be in providing infrastructure support?**
- **Are new public-private business models needed for higher levels of automation?**
- **How will shared–ride AVs change public transport services and VMT, energy and environmental impacts? What are the relative contributions of:**
  - **Automation?**
  - **Shared occupancy of vehicles?**
  - **Electric propulsion?**

Opportunities for Early Wins (1/2)

- **Deploy wireless communication infrastructure to support I2V/V2I cooperation at intersections, freeway interchanges**
  - **Collision warnings to enhance safety (L0)**
  - **Speed harmonization, eco-driving speed profiles and cooperative ACC to enhance traffic flow and efficiency (L1)**
- **Encourage use of managed lanes as testbeds and early deployment sites for connected automation systems (starting with L1 cooperative adaptive cruise control)**
  - **Significant traffic flow improvements as market penetration grows in those lanes**

Opportunities for Early Wins (2/2)

- **Heavy truck CACC and platooning to cluster trucks in high-volume corridors (L1, then L2, eventually L4)**
  - **Reduce traffic congestion impacts**
  - **Save significant energy**
- **Low-speed automated shuttle vehicles for niche applications (L4)**
  - **Closed campuses (university or industrial)**
  - **Retirement and resort communities**
  - **Commercial activity centers**
  - **Pedestrian malls or zones**
  - **Feeder services to line-haul transit**

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