Why Automated Vehicles Need to be Connected Vehicles

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Outline

- **Historical development of automated driving**
- **Reasons for automated driving (benefits)**
- **Definitions of automation concepts and terms**
- **Why V2X (wireless) cooperation is needed**
- **Technical challenges**
- **What to do next?**

History of Automated Driving (pre-Google)

- **1939 – General Motors "Futurama" exhibit**
- **1949 – RCA technical explorations begin**
- **1950s – GM/RCA collaborative research**
- **1950s – GM "Firebird II" concept car**
- **1964 – GM "Futurama II" exhibit**
- **1964-80 – Research by Fenton at OSU**
- **1986 – California PATH program started**
- **1994-98 – National AHS Consortium**
- **2003 – PATH automated bus and truck demos**
- *(2004 - 2007 – DARPA Challenges)*

General Motors 1939 Futurama

General Motors' Futurama
1939 New York World's Fair

GM Firebird II Publicity Video

1954-55

GM Technology in 1960

General Motors 1964 Futurama II

Robert Fenton's OSU Research

Automatically Controlled
1965 Plymouth at
Transportation Research Center of Ohio
The Ohio State University (OSU)
1977

Pioneering Automated Driving in Japan
(courtesy of Prof. Tsugawa, formerly at MITI)

1960s

1970s – Vision Guidance

Inductive Cable and A Pair of Pickups

Intelligent Vehicle

Pioneering Automated Driving in Germany
(1988 - courtesy Prof. Ernst Dickmanns, UniBWM)

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Automation Can Be a Tool for Solving Transportation Problems

- **Alleviating congestion**
  - **Increase capacity of roadway infrastructure**
  - **Improve traffic flow dynamics**

- **Reducing energy use and emissions**
  - **Aerodynamic "drafting"**
  - **Improve traffic flow dynamics**

- **Improving safety**
  - **Reduce and mitigate crashes**

…BUT the vehicles need to be connected

Alleviating Congestion

- **Typical U.S. highway capacity is 2200 vehicles/hr/lane (or 750 trucks/hr/lane)**
  - Governed by drivers' car following and lane changing gap acceptance needs
  - Vehicles occupy only 5% of road surface at maximum capacity
- **Stop and go disturbances (shock waves) result from drivers' response delays**
- **V2V Cooperative automation provides shorter gaps, faster responses, and more consistency**
- **I2V Cooperation maximizes bottleneck capacity by setting most appropriate target speed**

→ **Significantly higher throughput per lane**
→ **Smooth out transient disturbances**

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Reducing Energy and Emissions

- **At highway speeds, half of energy is used to overcome aerodynamic drag**
  - **Close-formation automated platoons can save 10% to 20% of total energy use**

- **Accelerate/decelerate cycles waste energy and produce excess emissions**
  - **Automation can eliminate stop-and-go disturbances, producing smoother and cleaner driving cycles**

- **BUT, this only happens with V2V cooperation**

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Improving Safety

- **95% of crashes in the U.S. are caused by driver behavior (perception, judgment, response, inattention) and environment (low visibility or road surface friction)**
- **Automation avoids driver behavior problems**
- **Appropriate sensors and communications are not vulnerable to weather problems**
  - **Automation systems can detect and compensate for poor road surface friction**
- **BUT, current traffic safety sets a high bar:**
  - **3 M vehicle <u>hours</u> between fatal crashes**
  - **65,000 vehicle <u>hours</u> between injury crashes**

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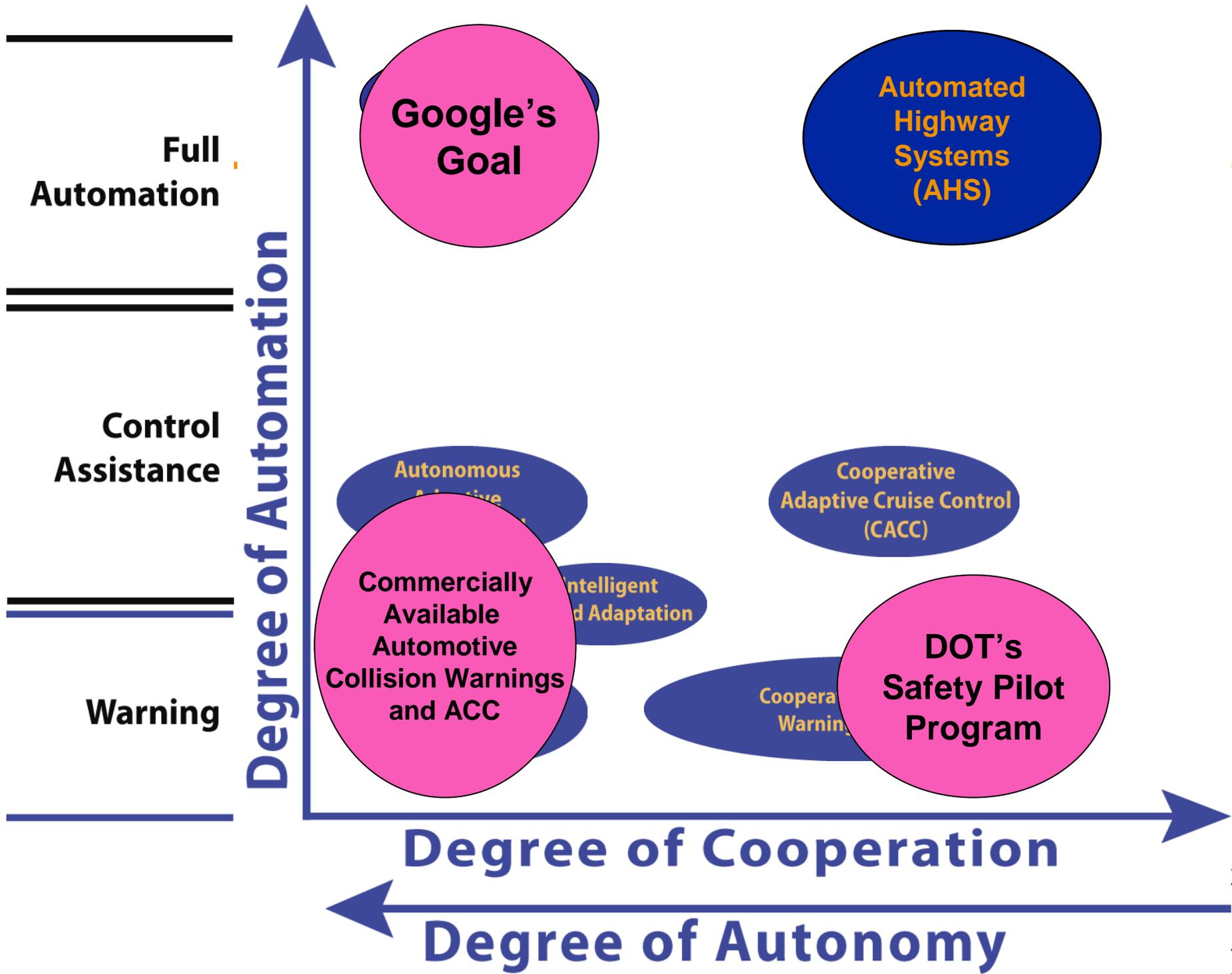# Definitions (per Oxford English Dictionary)

- **autonomy:**
  1. *(of a state, institution, etc.)* the right of <u>self-government</u>, of making its own laws and administering its own affairs
  2. *(biological)* (a) the condition of being controlled only by its own laws, and not subject to any higher one; (b) organic <u>independence</u>
  3. a <u>self-governing</u> community.

  autonomous:
  1. of or pertaining to an autonomy
  2. possessed of autonomy, <u>self governing, independent</u>
  3. *(biological)* (a) conforming to its own laws only, and not subject to higher ones; (b) independent, i.e., not a mere form or state of some other organism.

- **automate:** to apply automation to; to convert to largely automatic operation

  automation: automatic control of the manufacture of a product through a number of successive stages; the application of automatic control to any branch of industry or science; by extension, <u>the use of electronic or mechanical devices to replace human labour</u>

Full Automation

Control Assistance

Warning

Degree of Automation

Degree of Cooperation

Degree of Autonomy

Google's Goal

Automated Highway Systems (AHS)

Autonomous Adaptive

Cooperative Adaptive Cruise Control (CACC)

Commercially Available Automotive Collision Warnings and ACC

Intelligent Adaptation

Cooperative Warning

DOT's Safety Pilot Program

Summary of SAE International's Draft Levels of Automation for On-Road Vehicles (July 2013)

SAE's draft levels of automation are descriptive rather than normative and technical rather than legal. Elements indicate minimum rather than maximum capabilities for each level. "System" refers to the driver assistance system, combination of driver assistance systems, or automated driving system, as appropriate. NHTSA's levels of automation are provided to indicate approximate correspondence.

NHTSA level	SAE level	SAE name	SAE narrative definition	Execution of steering and acceleration/ deceleration	Monitoring of driving environment	Backup performance of *dynamic driving task*	System capability (*driving modes*)
		Human driver monitors the driving environment					
0	0	Non-Automated	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	1	Assisted	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
		Automated driving system ("system") monitors the driving environment					
3	3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task* with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	4	High Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
	5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Example Systems at Each Automation Level

Level	Example Systems	Driver Roles
1	Adaptive Cruise Control OR Lane Keeping Assistance	Must drive <u>other</u> function and monitor driving environment
2	Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist (Mercedes)	Must monitor driving environment (system nags driver to try to ensure it)
3	Traffic Jam Pilot Automated parking	May read a book, text, or web surf, but be prepared to intervene when needed
4	Highway driving pilot Closed campus driverless shuttle Valet parking in garage	May sleep, and system can revert to minimum risk condition if needed
5	Automated taxi (even for children) Car-share repositioning system	No driver needed

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Sensor Challenges
for *Autonomous* Automation

- **High-performance, costly sensors are needed (accuracy, field of regard, discriminant capability)**

- **No single sensor technology can satisfy all needs, so fusion of multiple sensors with complementary faults and vulnerabilities is necessary**

  - **Cost**

  - **Complexity**

- **Filtering is necessary, but introduces lags**

- **Remote sensors are slower and more uncertain than onboard sensors (speed, acceleration, driver actions)**

- **Sensors cannot detect subtle cues from other vehicles and drivers like experienced drivers**

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Cooperation Can Augment Sensing

- **Autonomous vehicles are "deaf-mute"**
- **Cooperative vehicles can "talk" and "listen" as well as "seeing"**
- **Communicate performance and condition data directly rather than sensing it indirectly**
  - **Reduce uncertainties**
  - **Reduce filtering lags**
  - **More sources of information available, including beyond line of sight**
- **Expand performance envelope – capacity and ride quality**

Cooperative System Advantages

- **All vehicles sharing status information**
  - **Current and planned actions**
  - **Identification of hazards**
  - **Earlier and safer responses possible**
- **Vehicles "negotiating" maneuvers for safety and efficiency**
- **Augmenting remote sensor data with more reliable and cheaper "self" state information**
- **DSRC communication may be mandated by NHTSA → likely to cost <$100 per new car**
- **Safety can be based on definitive "handshakes"**

 **→ Higher performance enabled**

Examples of Performance That is <u>Only</u> Feasible Through Cooperation

- **Vehicle-Vehicle Cooperation**
  - Cooperative adaptive cruise control (CACC)
  - Automated merging of vehicles, starting beyond line of sight
  - Multiple-vehicle automated platoons at short separations
  - Truck platoons at short enough spacings to reduce drag
- **Vehicle-Infrastructure Cooperation**
  - Precision docking of transit buses
  - Precision snowplow control

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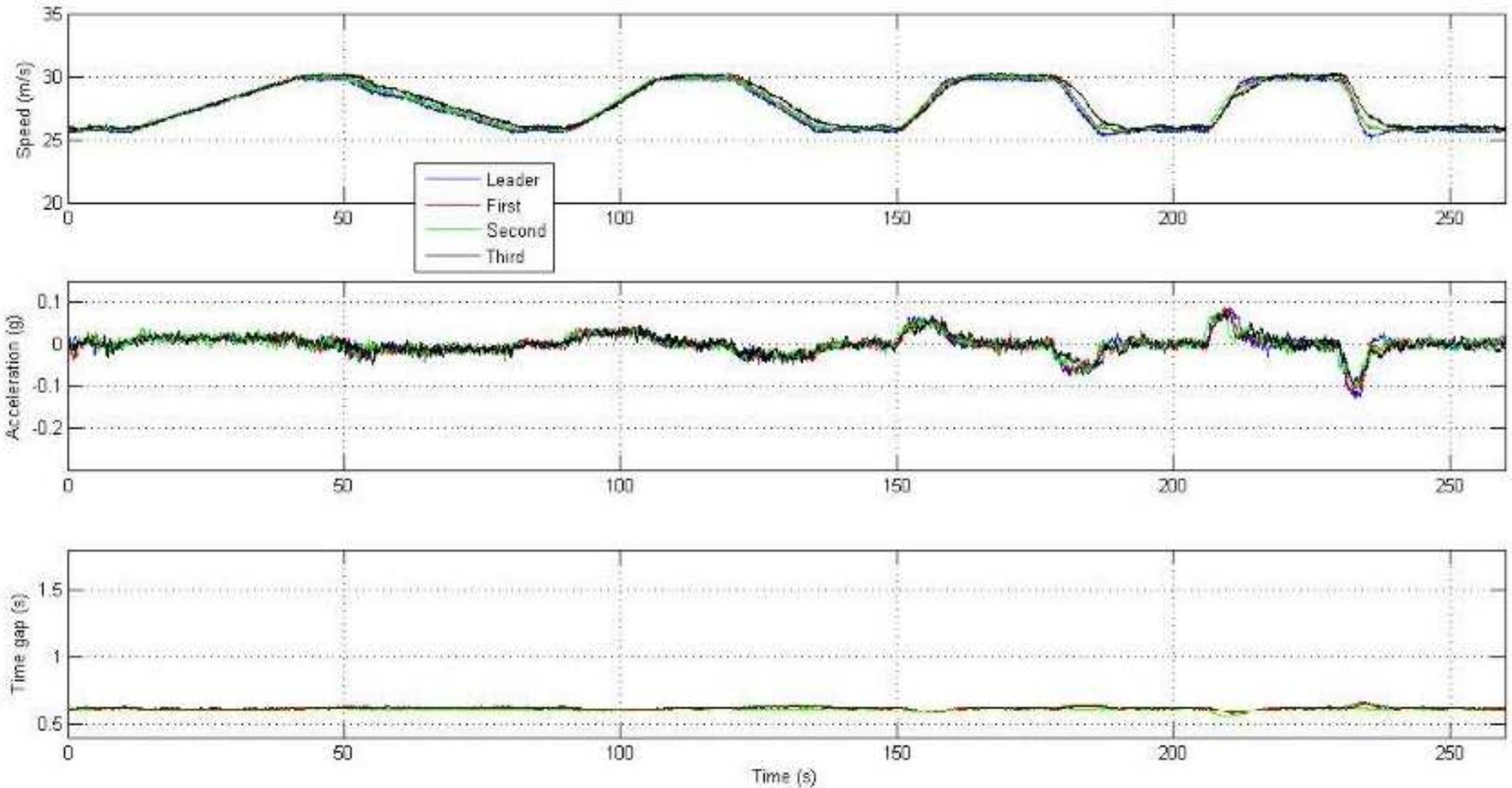# Example 1 – Production Autonomous ACC (at minimum gap 1.0 s)

Response of Standard ACC Cars
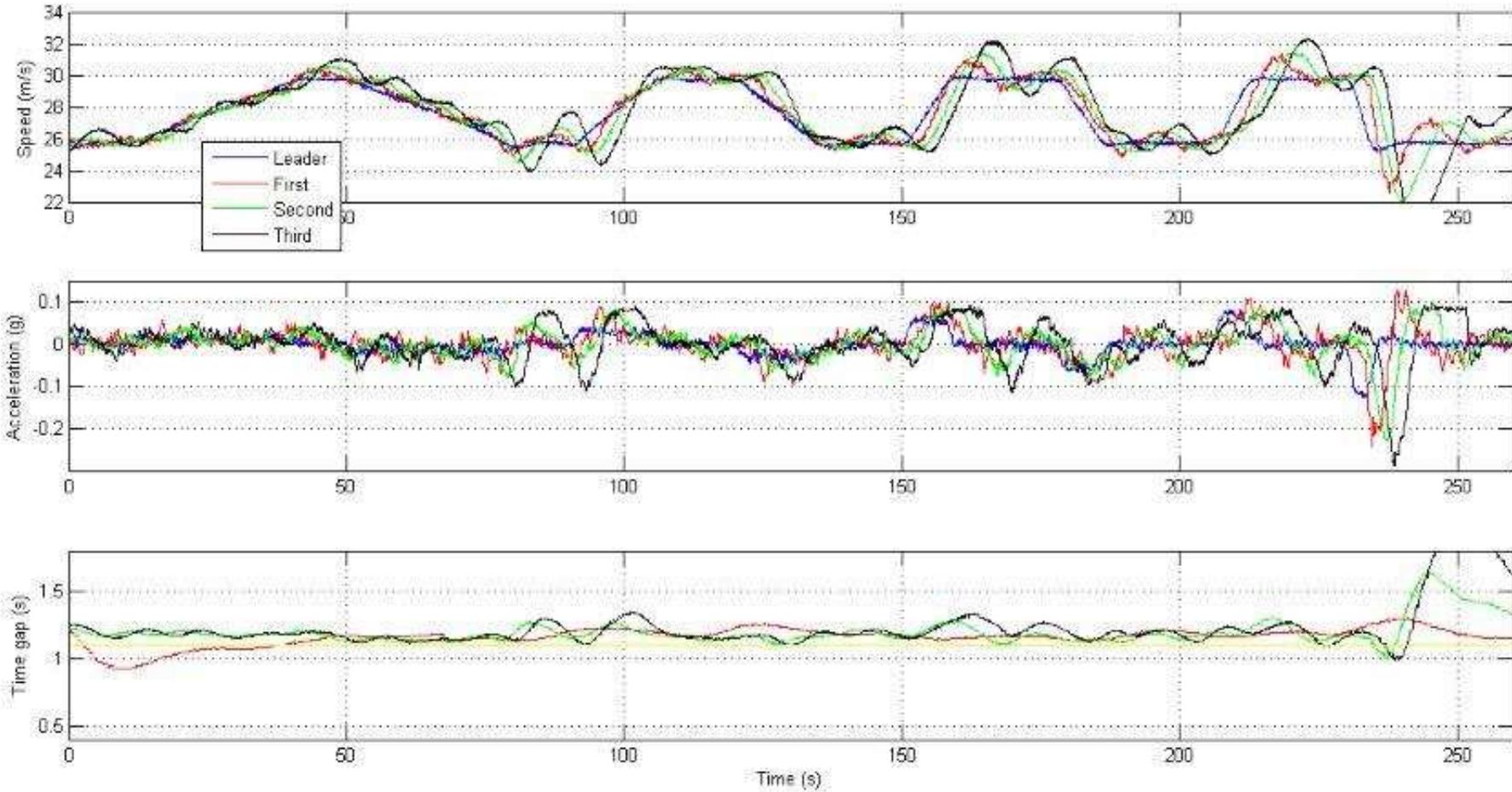
Example 2 – Cooperative ACC (at minimum gap 0.6 s)

V2V CACC Responses (3 followers)

PATH Automated Platoon Longitudinal Control and Merging (V2V)

1997

2000

PATH 3-Truck Platoon (2011)

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Safety Challenge

- **Driving today is incredibly safe:**
  - **3 M vehicle <u>hours</u> between fatal crashes**
  - **65,000 vehicle <u>hours</u> between injury crashes**

  and automation needs to be <u>at least</u> this safe
- **How many hours of testing to <u>prove</u> this?**
- **Compare to consumer electronics?**
- **To improve on current safety, <u>add</u> warnings and control assistance to driver's vigilance**
- **With full automation, driver vigilance is gone, so the system is responsible for everything**
  - **Including ethically untenable situations**

Traffic Safety Challenges for 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 act as the fall-back**

Unmet Technical Requirements

- **Real-time software safety/verification**
- **On-line fault detection, identification and accommodation**
  - **"Zero" missed detections (false negatives)**
  - **"Near-zero" false alarms (false positives)**
  - **"Instant" ability to switch to and operate in safe degraded mode (~0.1 s)**
- **Comprehensive general obstacle detection**
  - **Any object large enough to cause harm**
  - **Ignore innocuous "soft" targets**
  - **All weather conditions**
- **Cybersecurity**

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Extreme technical challenges

- **Cannot <u>prove</u> safety of software for safety-critical applications**

- **Complexity – cannot <u>test</u> all possible combinations of input conditions and their timing**

- **How many hours of <u>continuous, unassisted</u> automated driving have been achieved in real traffic under diverse conditions?**

  - **~1 hour (?) vs 10^6 hrs between fatal crashes now**

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So, what should we be doing now?

- **To improve safety → enhance collision warning and control assistance systems, with driver remaining in the loop**

- **To improve traffic flow → cooperative ACC, with priority in designated lanes**

- **To reduce energy and emissions → truck platooning, cooperative ACC**

- **Research to address continuing challenges…**

From Basic Research Toward Deployment

- **Sensing and data fusion for comprehensive vehicle neighborhood state mapping**

- **Extensive development and testing of fault management, fault tolerant control and software safety**

- **Infrastructure development case studies, with site-specific costs, benefits and constraints**

- **Human factors testing to define driver roles with viable partial automation systems**

- **Long-duration prototype testing under adverse conditions to prove technical viability**

Managing Customer Expectations

- **What level of automation is being promised to the driver?**
  - **Complete? (door-to-door chauffeuring of your 7-year-old child)**
  - **For freeway driving only? All freeways? All traffic and weather conditions or only some conditions?**
  - **Can the driver sleep?**
  - **If not, how soon does s/he need to be prepared to intervene? What happens if s/he is too slow to respond?**
  - **If required to remain vigilant and engaged, what benefit does s/he gain from the system?**