Road Vehicle Automation: Distinguishing Reality from Hype

Steven E. Shladover, Sc.D.

California PATH Program

University of California, Berkeley

March 20, 2014

Outline

- **Historical development of automation**
- **Levels of road vehicle automation**
- **Why cooperation is needed**
- **Impacts of each level of automation on travel (and when?)**
- **Technical challenges**
- **What to do now?**

History of Highway Automation in the U.S.

- **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)***
- **2010 – *Google announcement***

CALIFORNIA PATH

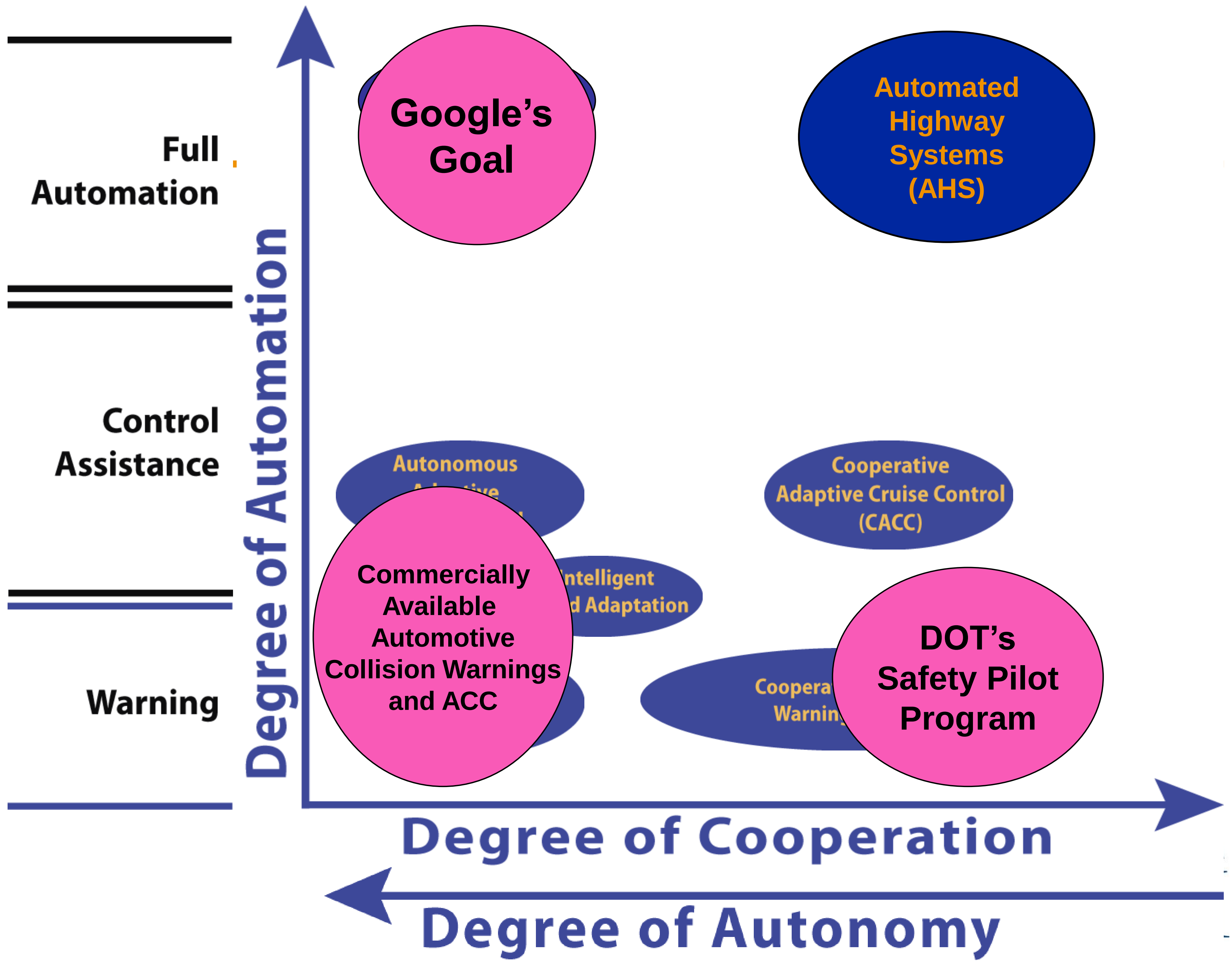
General Motors 1939 Futurama

GM Firebird II Publicity Video

GM Technology in 1960

CALIFORNIA PATH

Robert Fenton's OSU Research


Full Automation
Control Assistance
Warning
Degree of Automation
Google's Goal
Automated Highway Systems (AHS)
Autonomous
Cooperative Adaptive Cruise Control (CACC)
Commercially Available Automotive Collision Warnings and ACC
DOT's Safety Pilot Program
Degree of Cooperation
Degree of Autonomy

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
4	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 Driverless 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

Cooperation Augments Sensing

- **Autonomous vehicles are "deaf-mute"**
- **Cooperative vehicles can "talk" and "listen" as well as "seeing", using 5.9 GHz DSRC comm.**
  - **NHTSA regulatory mandate in process**
- **Communicate vehicle performance and condition directly rather than sensing indirectly**
  - **Faster, richer and more accurate information**
  - **Longer range**
- **Cooperative decision making for system benefits**
- **Enables closer separations between vehicles**
- **Expands performance envelope – safety, capacity, efficiency and ride quality**

CALIFORNIA PATH

Challenges to Achieving Cooperation

- “Chicken and egg” problem – who equips first?
  - May need regulatory “push” to seed the market
- Benefits scale strongly with market penetration
  - Need to concentrate equipped vehicles in proximity to each other
- Deployment opportunity using managed lanes
  - Economic incentives
  - Productivity increases

Examples of Performance That is Only Achievable Through Cooperation

- **Vehicle-Vehicle Cooperation**
  - Cooperative adaptive cruise control (CACC) to eliminate shock waves
  - Automated merging of vehicles, starting beyond line of sight, to smooth traffic
  - Multiple-vehicle automated platoons at short separations, to increase capacity
  - Truck platoons at short enough spacings to reduce drag and save energy
- **Vehicle-Infrastructure Cooperation**
  - Speed harmonization to maximize flow
  - Speed reduction approaching queue for safety
  - Precision docking of transit buses
  - Precision snowplow control

CALIFORNIA PATH

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

Example 2 – Cooperative ACC (at minimum gap 0.6 s)

Other Functions Only Possible with Cooperation

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? Starting this year (Mercedes S-class)**

CALIFORNIA PATH

Conditional Automation (Level 3) Impacts

- **Driving comfort and convenience increase**
  - **Driver can do other things while driving, so value 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? Unclear – safety concerns could impede introduction**

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

- **May only be available in some places (limited access highways, 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?**

CALIFORNIA PATH

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

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 value plunge**
- ***(if cooperative)* Large energy efficiency and road capacity gains**
- **When? Many decades… (Ubiquitous operation without driver is a huge technical challenge)**

CALIFORNIA PATH

Safety Challenges for Full Automation

- **Must be "significantly" safer than today's driving baseline (2X? 5X? 10X?)**
  - **Fatal crash MTBF > 3 million vehicle hours**
  - **Injury crash MTBF > 65,000 vehicle hours**
- **How many hours of testing are needed to show safety better than this?**
- **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?**

CALIFORNIA PATH

Safety and the Driver

- **If maximum safety is indeed the goal…**
  - **ADD the system's vigilance to the driver's vigilance instead of bypassing the driver's vigilance**
  - **Comprehensive hazard warnings plus some control assistance (e.g., ACC)**
- **If the driver is out of the control loop (texting, sleeping, incapable, or not present), the system has to handle EVERYTHING…**
  - **Bad scenarios none of us can imagine**
  - **Ethically untenable scenarios**

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?**

CALIFORNIA PATH

What to do now?

- **Focus on connected vehicle capabilities to provide technology for cooperation**
- **For earliest public benefits from automation, focus on transit and trucking applications in protected rights of way**
  - **Professional drivers and maintenance**
  - **Direct economic benefits**
- **Capitalize on managed lanes to concentrate equipped vehicles together**
- **Develop enabling technologies for Level 5 automation (software verification and safety, real-time fault identification and management, hazard detection sensing,…)**

CALIFORNIA PATH

Definitions
(per Oxford English Dictionary)

- **<u>autonomy</u>:**
  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.

  <u>autonomous</u>:
  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.

- **<u>automate</u>: to apply automation to; to convert to largely automatic operation**

  <u>automation</u>: 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>