Global and Local Innovations for

Next Generation of Vehicles

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Presentation Outline

- **Trends in Automated Vehicles (AV)**
  - **Background and Definitions**
  - **Current Status**
- **Research Activities at UC Berkeley**
  - **Selective Projects at UC Berkeley**
- **Look Ahead**
  - **Expectations for the Decade Ahead**
  - **Challenges**
- **Summary Remarks**

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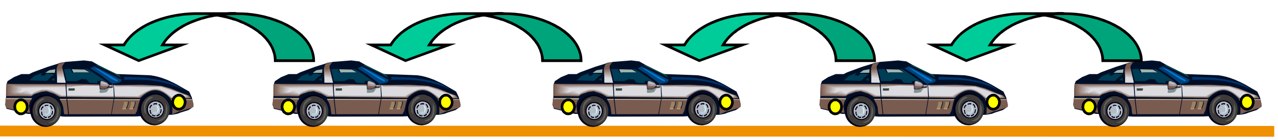
History of Vehicle Automation

- 1930s – GM Futurama Exhibition
- 1960s – 1980s
  - Various R&D in US, Japan, and Europe
- 1990s
  - US National Automated Highway Consortium
  - Continuing R&D in EU and Japan
- 2000s
  - US DARPA Grand Challenges
  - Relatively more intensive R&D globally
- 2010s
  - Google “Driver-less Cars”
  - Significant Automaker announcements

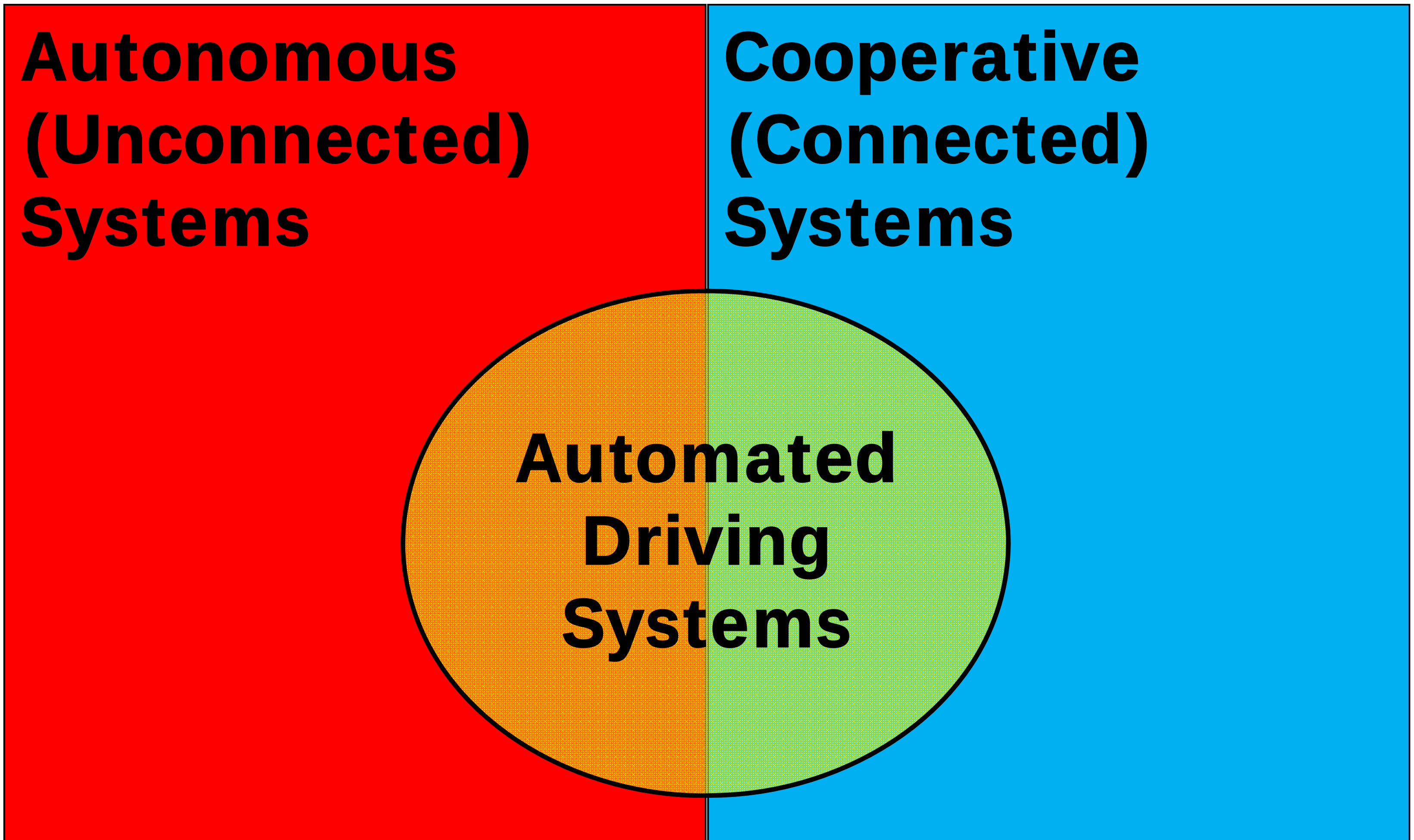
Goals that Could be Served by Vehicle Automation

- **Immediate Effects**
  - Improving user safety and minimizing driving hazards
  - Providing driving comfort and convenience
  - Freeing up time and attention demanded by driving
  - Enhancing mobility options for disadvantaged users
  - Improving fuel or energy efficiency
  - Reducing transportation cost by car for individuals
- **Longer-Term and System-Wide Effects:**
  - Reducing traffic congestion in general
  - Reducing or redistributing vehicle user costs
  - Reducing energy use and pollutant emissions
  - Making efficient use of existing road infrastructure
  - Reducing cost of future infrastructure and equipment

Automated Platoon
(1997 NAHSC Demonstrations)



Autonomous and Cooperative Vehicles



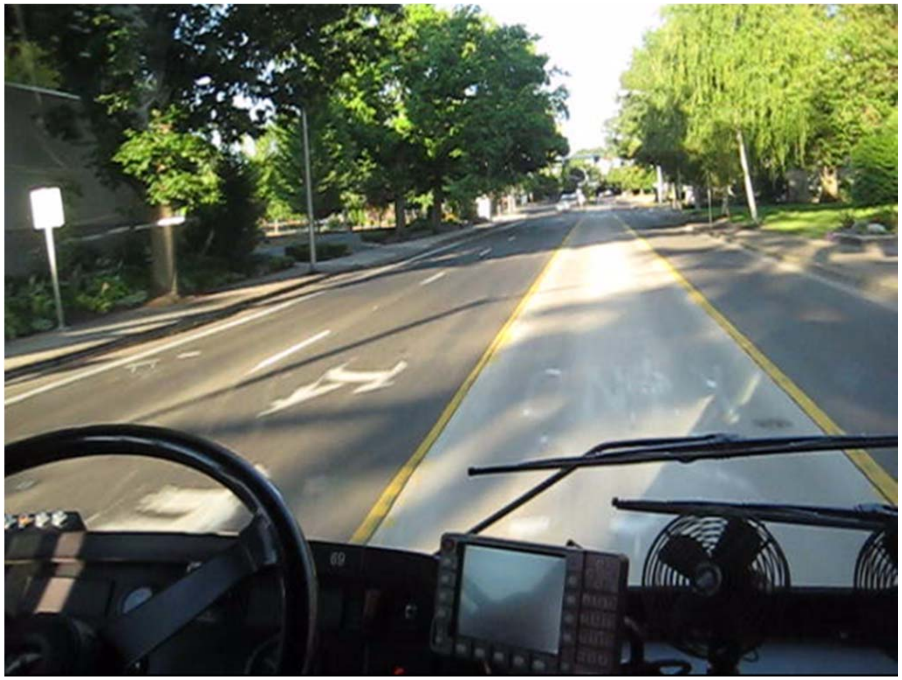
SAE J3016 - Levels of Automation
Taxonomy and Definitions for to On-Road Motor Vehicle Automated Driving Systems

SAE Level	Name	Narrative Definition	Execution of Steering/ Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
Human driver monitors the driving environment						
0	No Automation	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	Driver Assistance	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	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	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	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**

Examples at Each Automation Level

Level	Example Systems	Driver Roles
1 Driver Assistance	Adaptive Cruise Control OR Lane Keeping Assistance	Must perform other non-automated functions and monitor driving environment
2 Partial Automation	Adaptive Cruise Control AND Lane Keeping Assistance Traffic Jam Assist	Must monitor driving environment (system try to engage driver)
3 Conditional Automation	Traffic Jam Pilot Automated Parking	May read a book, text, or web surf, but be prepared to intervene when needed
4 High Automation	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 Full Automation	Automated taxi Car-share repositioning system	No driver needed

PATH VAA Project (Level 1)
Automated Bus in Eugene Oregon



LTD, Eugene Oregon
- 2.5 miles of single / double dedicated ROW
- One 60ft New Flyer BRT bus
- Functions:
  - Lane guidance for on dedicated BRT lane
  - Precision docking

Nissan Infiniti (Level 2)
Lane Keeping + ACC

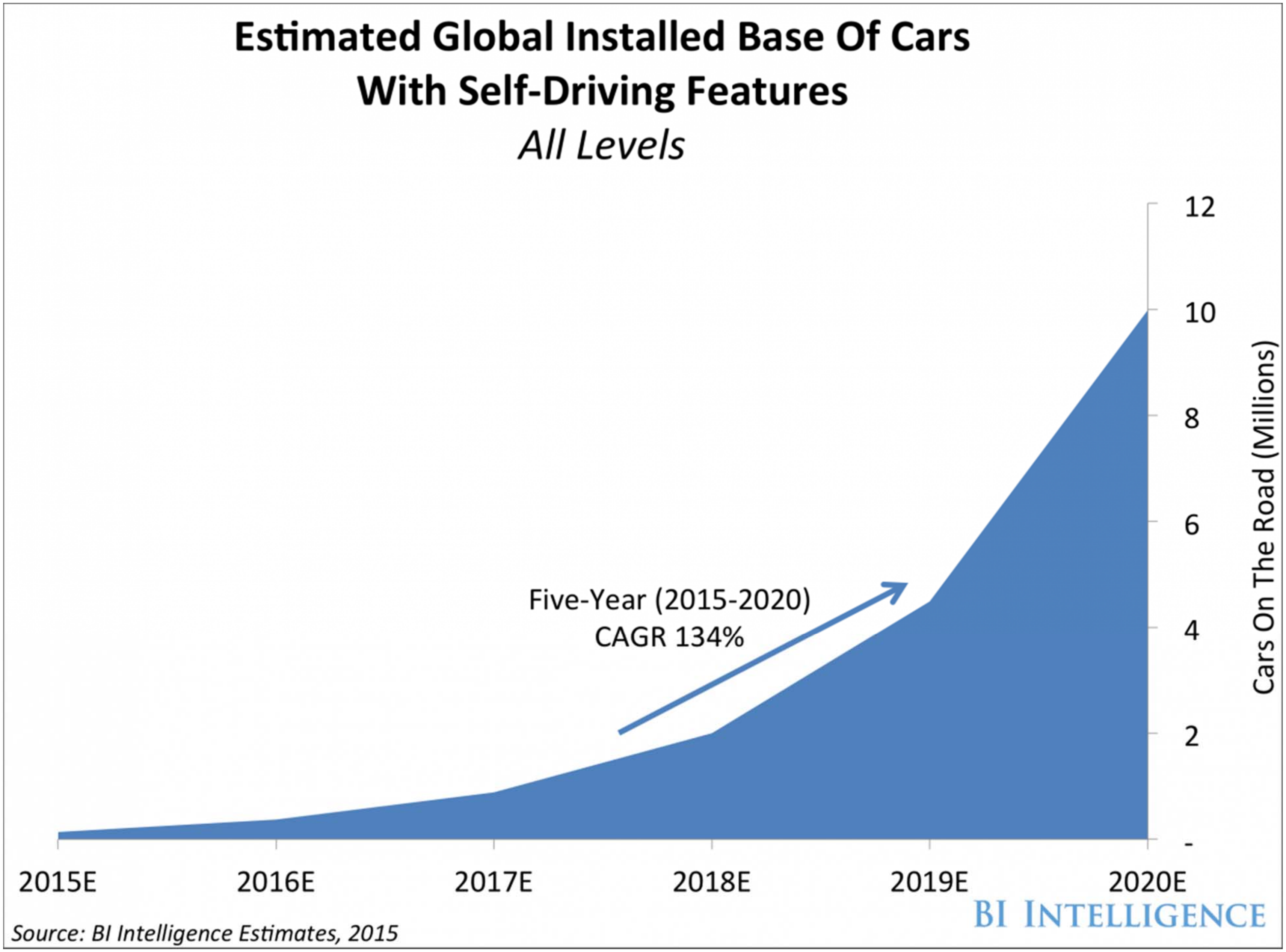
- Youtube Video (Note that driver goes to backseat at end of video, a misuse case for Level 2)

https://www.youtube.com/watch?v=zY_zqEmKV1k

Current Status - OEMs

Organization	Confirmed and Predicted Product Introduction	Predictions of Readiness for Autonomous Vehicles
Audi/VW	2016 – traffic jam assist 2014 – automated parking	Available by 2020
BMW	2014 – traffic jam assist 2014 – automated parking	Available by 2020
Bosch	2014 – traffic jam assist available for OEMs	Available by 2020
Continental		Available by 2020
Ford	2015 – fully assisted parking	
General Motors	2017 – Super cruise	Available by 2020
Google		Available by 2018
Honda	Valet parking by 2020 or earlier	
Mercedes-Benz	2014 – traffic jam assist	Available by 2020
Mobile Eye		2016 – technology ready for OEMs
Nissan	2015 – highly autonomous	Available by 2020
Tesla	2016 – highly autonomous	
Toyota	Mid 2010s – highly autonomous	
Volvo	2015 – traffic jam assist 2015 – automated parking	Zero fatality by 2020

Estimated Market Introduction



Current Status and Trends

Emerging Forces

- Significant Advancements in sensing and computing technologies
- Considerable developments by high-tech industries and automakers
- Greater publicity and awareness
- Legislations following the steps

Current Trends

- Intensive research in all regions globally
- Heavy investments by auto industry
- Commercial products highly feasible within next 3-5 years

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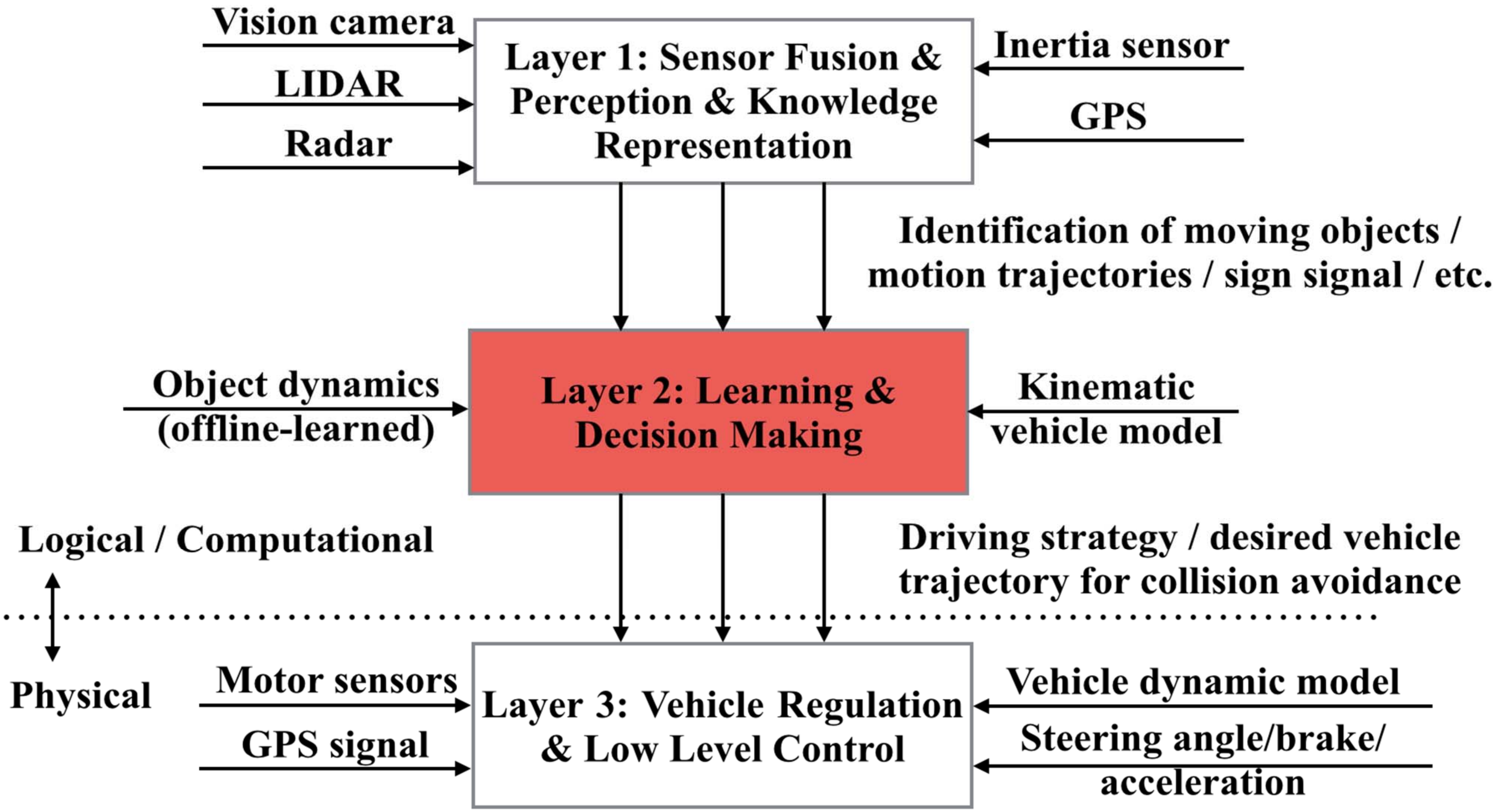
Selective Research Projects at

UC Berkeley

ROAD System for Automated Driving

- Changliu Liu and Masayoshi Tomizuka

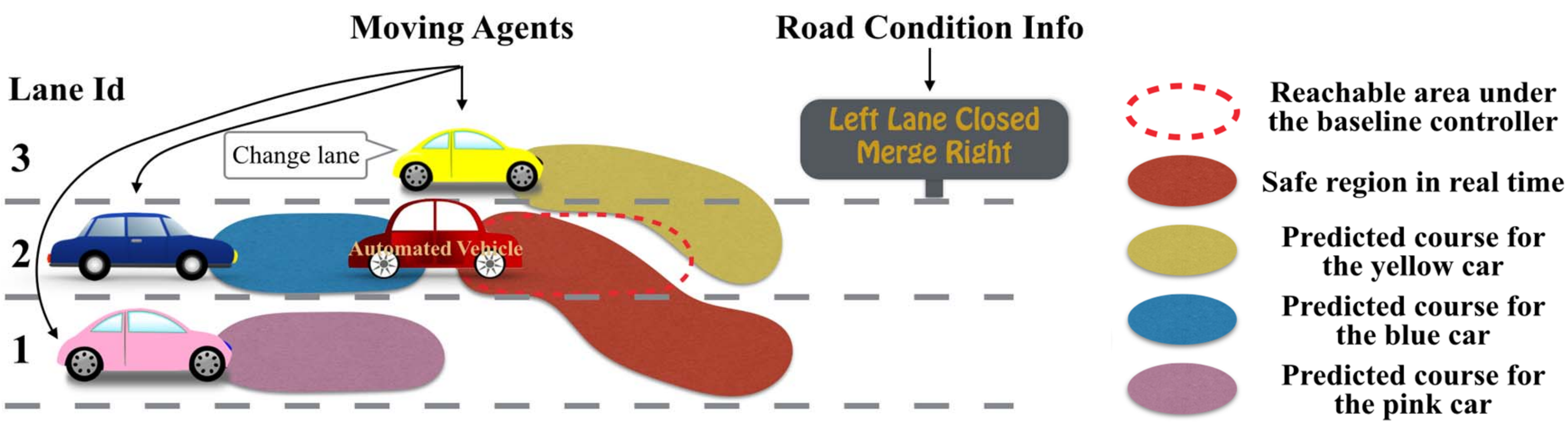


ROAD System for Automated Driving

- Changliu Liu, Masayoshi Tomizuka -

Efficiency: Navigate to the destination in minimum time

Safety: Interact with surrounding vehicles properly



- **Predict the future course for each surrounding vehicle (learning and prediction);**
- **Find a trajectory in the safe region (decision making).**

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Autonomous Driving in Urban Environment
Wei Zhan, C-Y Chan, and M. Tomizuka

French “Drive for You” Foundationrench “Drive

- Foundation headquartered at Mines ParisTech
- Industrial Sponsors
  - Valeo, Peugeot, Safran
- Academic Partners
  - Mines ParisTech, France
  - EPFL, Switzerland
  - Shanghai Jaio-Tung University, China
  - PATH, UC Berkeley, USA
- Innovation Lab
  - Mines ParisTech + INRIA + IFSTTAR

Driving Behaviors and Interaction

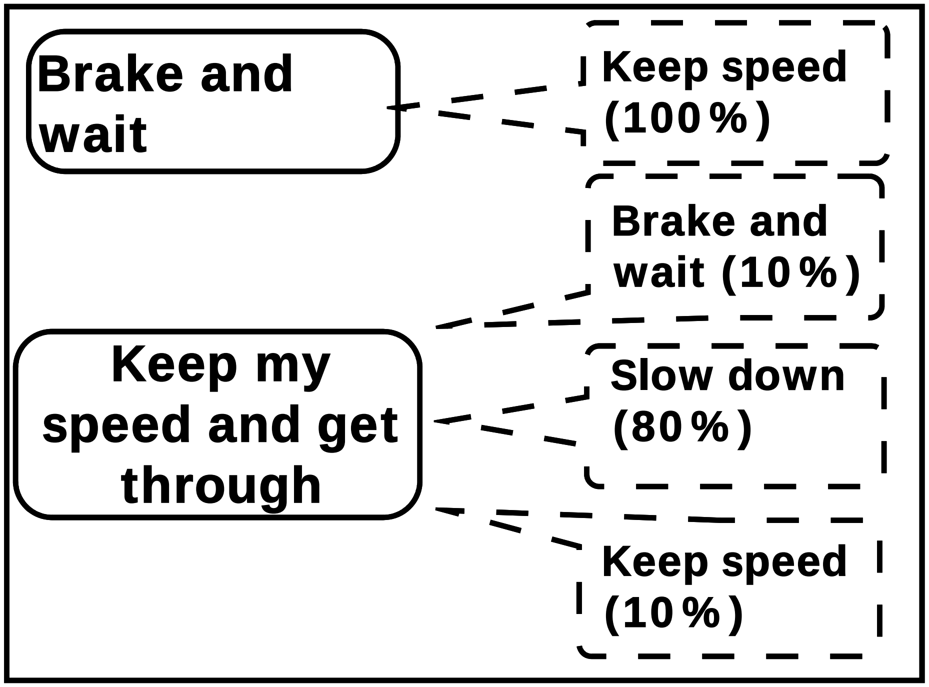
- Wei Zhan, C-Y Chan, M. Tomizuka -

- **Objectives in driving**
  - Time efficiency, comfort, courtesy
- **Constraints in driving**
  - Safety, traffic rules, obstacles, vehicle dynamics
- **Reciprocal methodology**
  - Problem formulation: Social interaction
  - Probability distribution – subject vehicle vs. others
  - Safety: to achieve the fairly best case which will probably happen, and guarantee to survive in worst cases although they will probably not happen
  - Neither purely cooperative nor adversarial

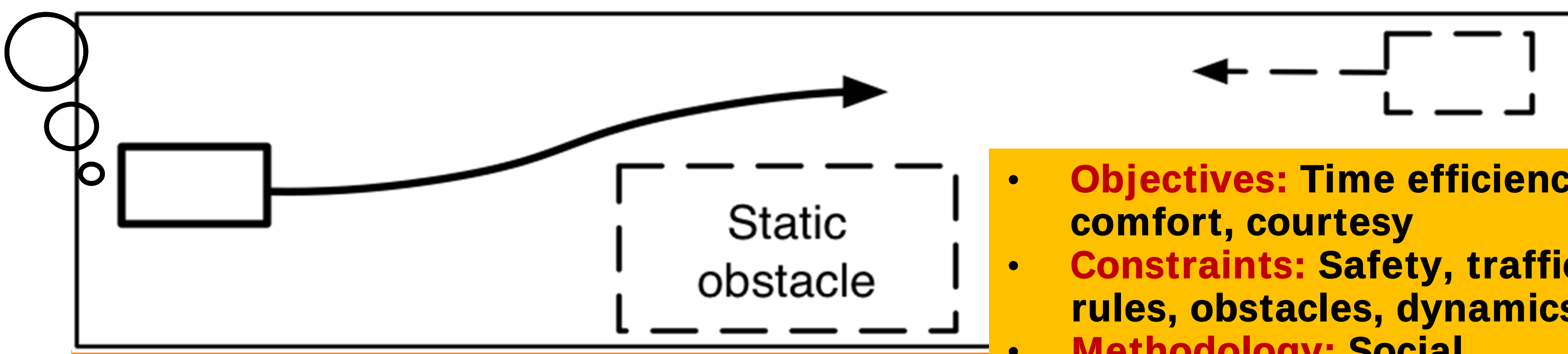


Driving Behaviors and Interaction

- Wei Zhan, C-Y Chan, M. Tomizuka -



safety	time-efficiency	courtesy	comfort	total utility
safe	2	10	8	20
safe	10	7	10	26.3
safe	10	8	10	
safe only with emergency braking	2	8	2	



- **Objectives:** **Time efficiency, comfort, courtesy**
- **Constraints:** **Safety, traffic rules, obstacles, dynamics**
- **Methodology:** **Social interaction**

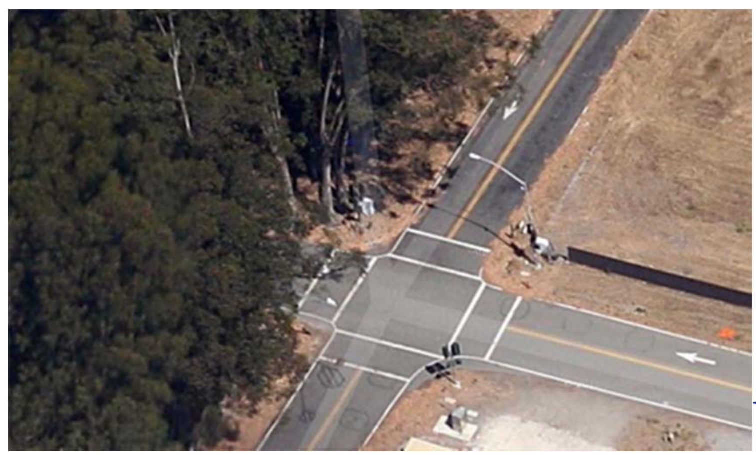
Cooperative Systems

“Connected Vehicles” Research at PATH

PATH RFS Test Facilities

Included within this Richmond Field Station (RFS) facility is

- A test track that has been used extensively for dynamic vehicle experiments in controlled environment.
- The test track is covered by a variety of sensors and instruments, which can generate high accuracy positioning data for vehicles moving along the track.
- An Intelligent Intersection is equipped with DSRC and WiFi network links that enable the use of wireless communication links for potential testing of vehicle-to-infrastructure applications.



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El Camino Real Connected Vehicles Testbed

Included within the El Camino Real are

- A 2-mile, 11-intersection stretch of El Camino Real SR-82 arterial in Palo Alto, California
- Equipped with the updated hardware and software that are compatible with IEEE 1609 and SAE J2735 and with other USDOT test beds such as one in Michigan.
- Linked security server of USDOT managed by Leidos (formerly SAIC) so that communication security protocols can be exercised.
- Signal Phase and Timing (SPaT) information
- Dedicated intersection computer to augment local computing capability
- IPv6 connectivity to backhaul
- Intersection maps as MAP broadcasts
- Use of DSRC, Wi-Fi, Bluetooth, Cellular

PATH V2X Activities

- First to deploy RSE (roadside equipment) on public Roads, Emeryville, CA, 2004
- First to publicly demonstrate VII (Vehicle-Infrastructure Integration) Concepts of Operations at ITS World Congress in San Francisco, 2005
- Build and operate VII California Test Bed, and conducts collaborative work with automakers
- Vehicle-Infrastructure Technology Affiliated Laboratory (VITAL) Consortium
  - Non-competitive joint research by members
  - Focus on use of communication technologies for safety, mobility, environment applications
  - Members include Industrial Technology Research Institute (ITRI), Taiwan and SANDEX, Japan

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Cooperative Adaptive Cruise Control
(Research at PATH in Collaboration with Nissan)

- CACC extends from Adaptive Cruise Control (ACC) with the addition of V-V communication (DSRC); 2006-2015
- 5.9 GHz DSRC, Denso WRM, 10 Hz Communication
- Potential increase in roadway efficiency without compromising safety
- Pilot collaboration research with Nissan on driver experience
  - ACC time gaps of 1.1 to 2.2 seconds
  - CACC time gaps of 0.6 to 1.1 seconds
- 2013 FHWA EARP project focus areas: traffic stream analysis, driver selection of time gaps and driving behaviors

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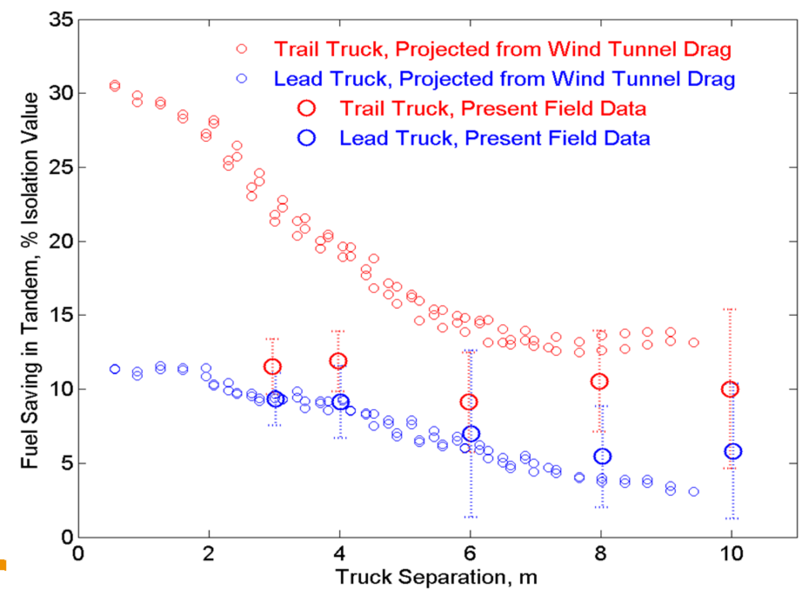
Automated Truck Platooning
- with V2V communication -

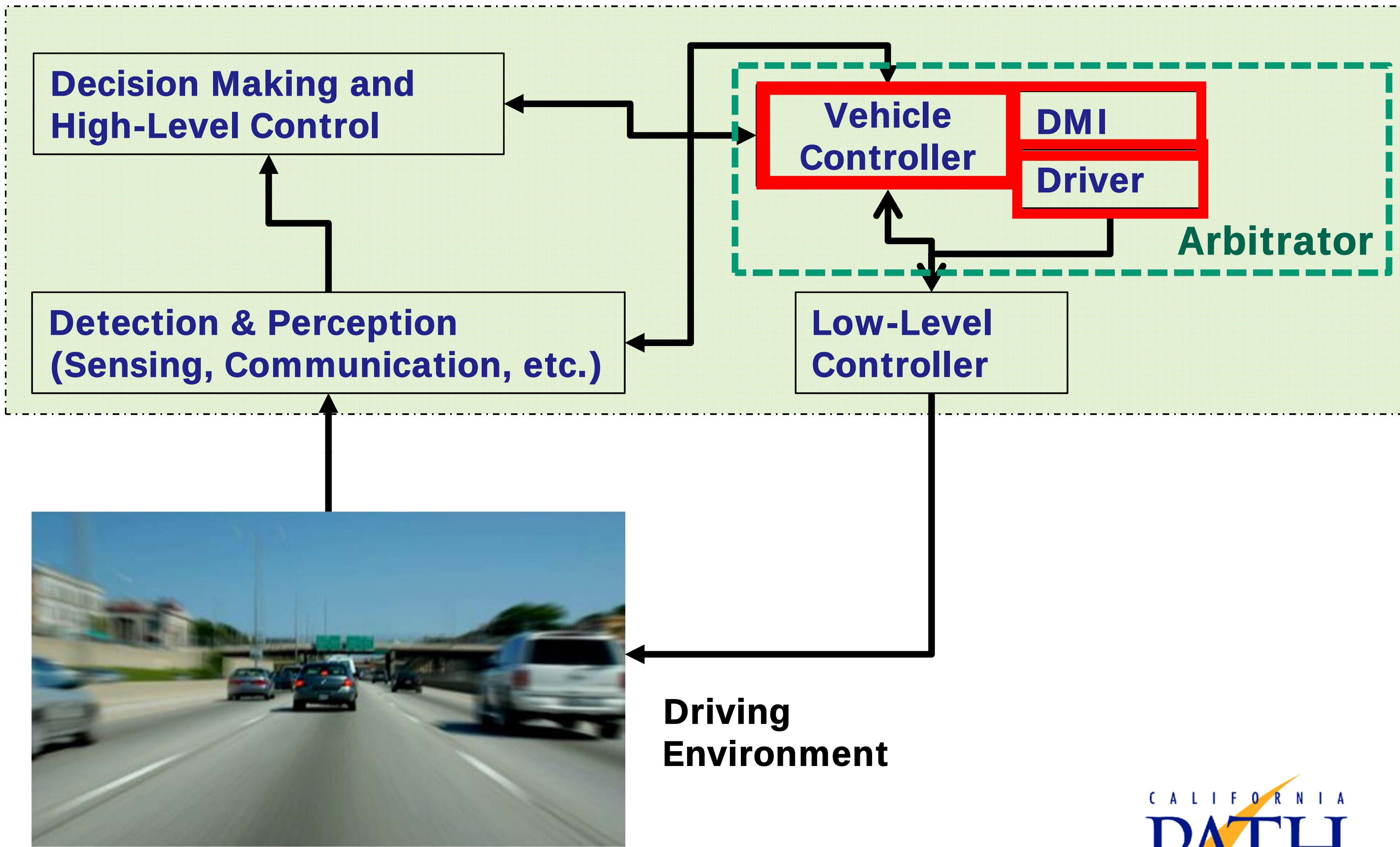
- **Similar to Japan Energy ITS project (2011-2014)**
- **Developed and tested 2- and 3- truck platoons under automatic spacing control at gaps from 3 m to 10 m**
- **Estimated Fuel savings of 10 -15% measured**



Challenges

- **What must be overcome?**
  - ➢ **Technical**
  - ➢ **Safety concerns**
  - ➢ **User Expectation**
  - ➢ **Market Acceptance**
  - ➢ **Legal**

AV with Driver in the Loop
- System Architecture and Data Flow



Challenges in Driver-Vehicle Interaction

- **DVI and HMI issues**
  - **Situation Awareness**
    - **Effective alert under reduced workloads**
  - **Carryover Effects**
    - **Automation influence on driver mental status**
  - **Decision and Control Arbitration**
    - **Machine-Human task sharing and switching**
    - **allocation of machine and human intelligence**

- **Critical for highly automated systems especially for Levels 3-4**

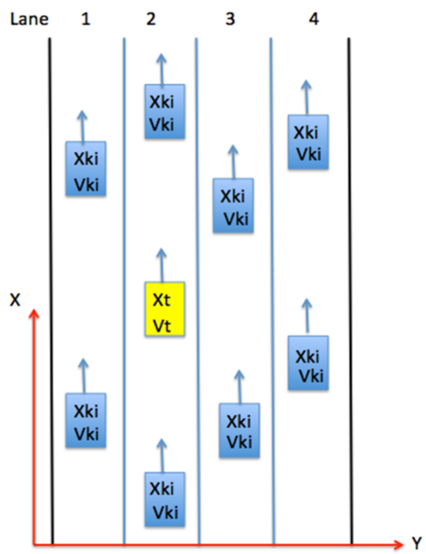
Challenges for AV/DVI Design

Information → Decision → Control

- (System) Control Requirements
  - Display content and alert mechanism
  - Appropriate (or available) options
- Drivers
  - To be alerted (awakened) from non-driving tasks
  - To be capable of taking (appropriate) actions
- Challenges for highly automated systems
  - Driver monitoring required
  - Understanding of driver intention
  - Arbitration of driver and system, if necessary

Exemplar Vehicle-Driver Interaction Situations

Information → **Decision** → **Control**

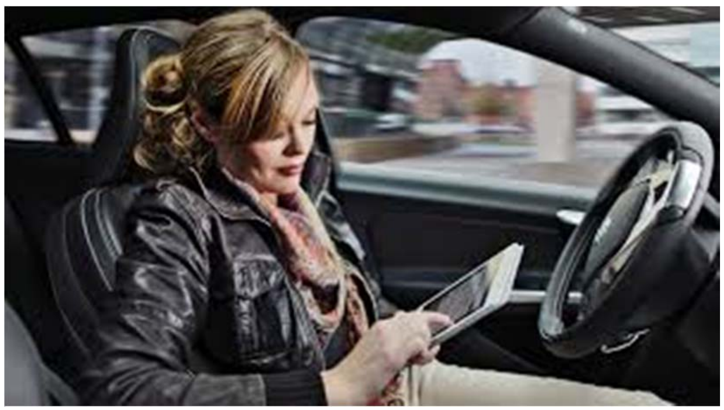


- **Assuming a Level 3 system, and while in the process of lane changing,**
  - **Under what conditions, can the system accept drivers' intervention (e.g. hard braking and large steering action)?**

- **Assuming this is a Level 4 system, and while crossing an intersection,**
  - **Avoid tempting driver to intervene in complex situations?**

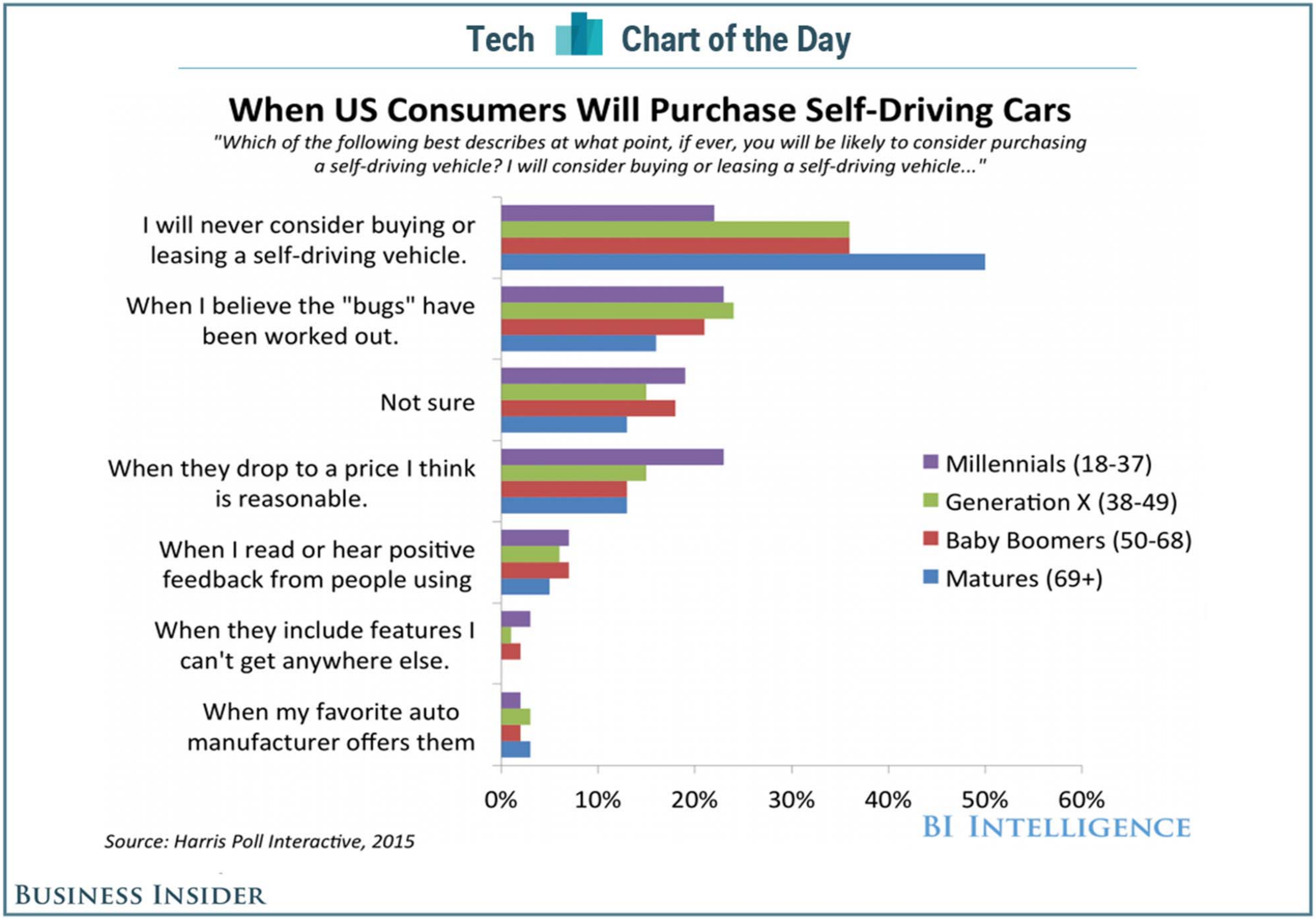
Social and Legal Issues

- **Some Laws and Vehicles Codes Need to be Changed**



Will People Buy It?

- Market Acceptance and User Expectation -



How Safe is AV Safe Enough?

Safety Records of Human Drivers

- According to the Accident Statistics of Germany, the injury accident rate on the autobahns is 0.08 per million vehicle-kilometers.
  - In other words, on average **12 million vehicle-kilometers** are driven between the occurrences of injury accidents.
- **12 million vehicle-km per injury incident**
  = 30,000 km/per year X 50 years X 8 vehicles

- The fatal accident rate on the autobahns is 1.9 per billion vehicle-kilometers.
- For most states in US, the numbers are between 1.0 and 3.0.

- **Current vehicles driven by humans have very strong safety records, and autonomous vehicles have to be implemented at a very high performance level to be comparable.**

Look Ahead in the Coming Decade

- Highly functional automation will be available (such as valet parking and freeway driving assist)
- Carmakers will offer Level 2 and maybe Level 3 systems
- Deployment of Level 4 will be local (such as Google "pods")
- Social and technical challenges remain for completely driverless cars to be widely deployed

A Paradigm Shift

- **Cars will "do things" for us when we are on the move.**
  - **We used to tell them what to do**
  - **Now they are more likely to tell us what to do**

- **The Google and Uber of the world are already causing a paradigm shift in the car culture.**
  - **Do you really need to own a car?**
  - **Liberty of going places for the disadvantaged and unlicensed**

As good as it Gets!
- Connected Automation -

- **Nissan Motors Commercial (Youtube video)**

https://www.youtube.com/watch?v=nrNfKbk8_Og