Research Challenges for Automated Vehicles

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Overview

- Reasons for automating vehicles
- How automation can improve efficiency
- Progress already achieved
  - (don't reinvent the wheel!)
- Challenges remaining

Drivers are very good at some things:

- **Perceiving complex, unstructured driving environments**
- **Anticipating maneuvers of other drivers**
- **Adapting to changing traffic conditions**
- **Avoiding crashes:**
  - **Rare events in "Mean Time Between Faults"**
  - **Fatal crashes at MTBF ~ 2 x10^6 vehicle hours**
  - **Injury crashes at MTBF ~ 5 x10^4 vehicle hours**

But drivers have serious limitations:

- **Perceiving distance and closing rate to other vehicles (accurately)**
- **Steering and car following (accurately)**
- **Great diversity of response characteristics across population and time (both time of day and aging)**
- **Reduced visibility in adverse weather**
- **Significant response delays (0.5 – 2 seconds)**
- **Performance highly dependent on workload and level of stress**
- **Vulnerability to inattention**
  - **Physical impairments – drugs, disease, age**
  - **Emotional state**
  - **Distractions inside and outside vehicle**
  - **Fatigue**

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Highway System Performance is Limited by Driver Characteristics

- **Lane capacity is limited by car-following distance**
- **Lane width must accommodate steering inaccuracies**
- **Shock waves in traffic are caused by (diverse) driver response lags**
- **Crashes are caused by errors of judgment or inattention**

…So in order to improve performance, we need to address these problems

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Inefficient Utilization of Costly Infrastructure

- **We only use half the lane width:**
  - **U.S. standard 3.6 m highway lane**
  - **Large passenger car only 1.8 m wide**
- **We only use one ninth of the length of the lane:**
  - **Maximum throughput of 2200 veh/hr represents headway of 1.64 sec.**
  - **Los Angeles region PeMS data shows this throughput reached at speed around 100 km/h**
  - **For vehicle length of 4.6 m, *average* separation is ~40 m at that speed**
- **Net utilization: 5.5% of road surface occupied by vehicles *when used at highest efficiency***

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Automation Technology Can Help

- Detecting problems faster than drivers can
- Measuring driving conditions (lane position, distances to other vehicles) more accurately than drivers can
- Controlling vehicle motions (lateral and longitudinal) more accurately than drivers
- Not vulnerable to distraction or impairment
- Ensuring consistent behavior among vehicles and over time
- Results → higher capacity and safety

Automated System Design Principles

- **Automated driving in dedicated, protected lanes, not mixed with other vehicles**
  - **Safety**
  - **Maintain free flow without interference**
- ***Cooperative* vehicles, not *autonomous***
  - **Exchange information with other vehicles and roadway infrastructure**
  - **Autonomous vehicle = deaf, mute**
- **Automated driving OR manual driving, not a mixture**
  - **Avoid driver confusion**
  - **Overcome driver limitations**

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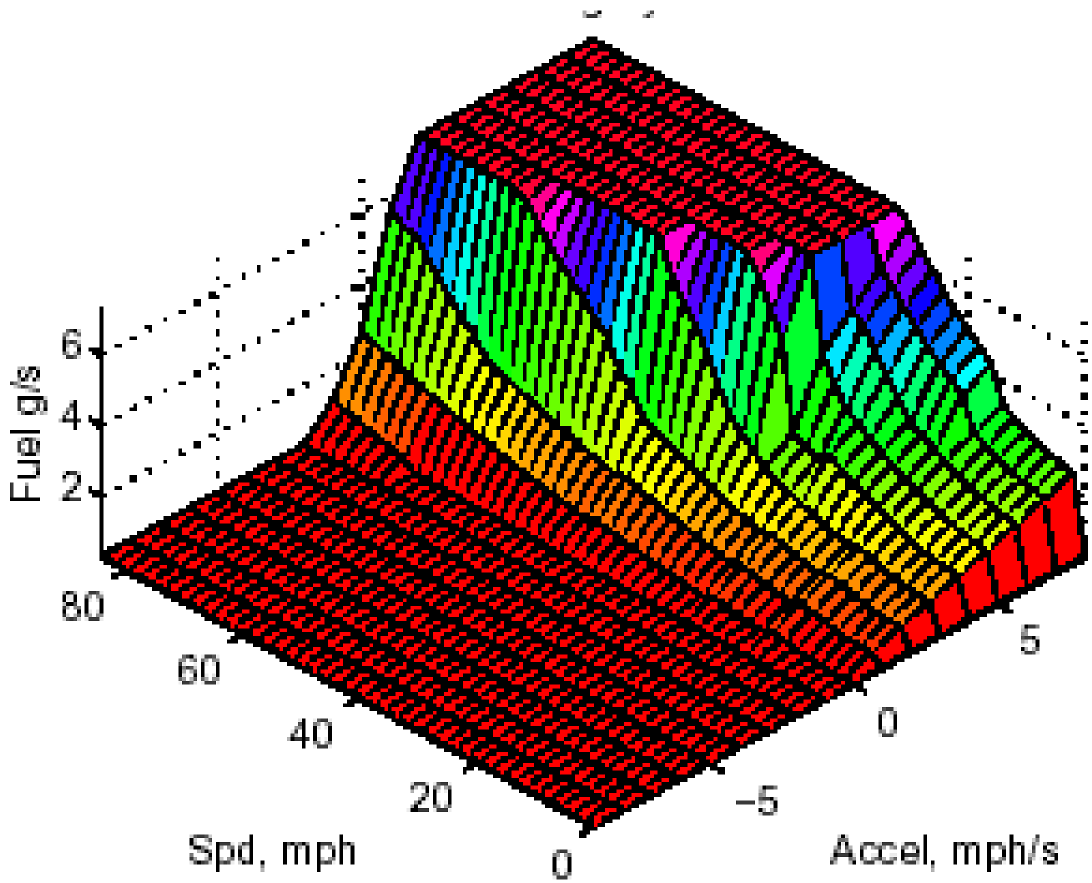
Automation Improving Efficiency

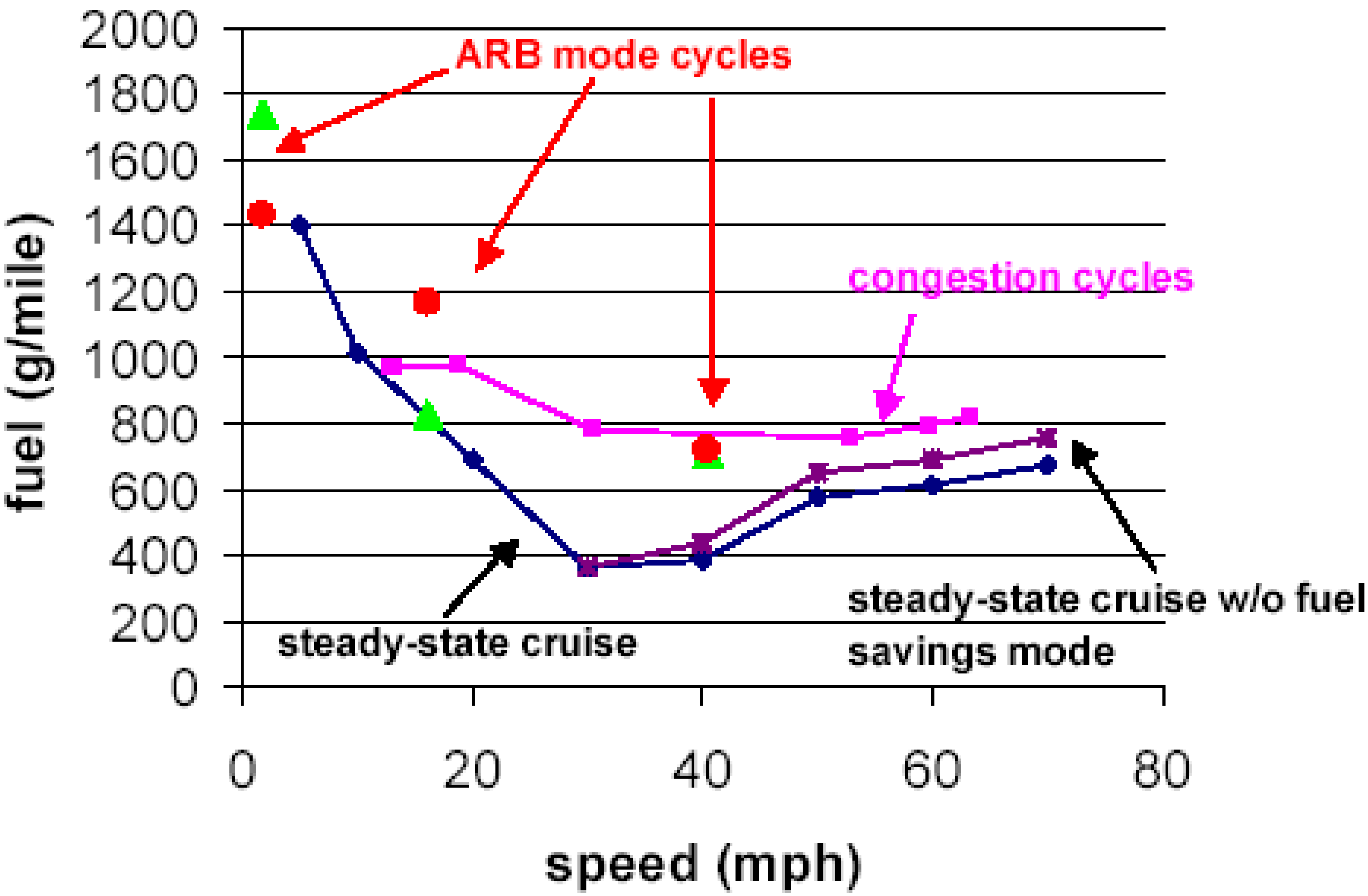
- Close vehicle following reduces drag
  - Fred Browand to cover in next session
- Acceleration and deceleration maneuvers profiled for efficiency, adjusted for grades
  - No jackrabbit starts
- Increased lane capacity and metered access reduce congestion
  - Automated lanes cruise at constant speed
  - Avoid traffic shock waves ("stop and go")
  - Avoid idling losses when stopped
  - Relieve stress on parallel (non-automated) roads

Effect of Speed Variations on Efficiency (Passenger Car Example)



Data from Barth, 2002

Effect of Congestion on Efficiency (Heavy-Duty Diesel Truck Example)



Data from Barth, et.al., 2002

Key Accomplishments to Date

- Definition of hierarchical architecture to simplify design and development of vehicle automation systems
- Definition and verification of vehicle maneuver protocols
- Creation of modeling and simulation tools to evaluate system designs and performance
- Development of high-performance automated test vehicles: passenger cars (15+), heavy trucks (4), transit buses (3), snowblower (1)
- Proving feasibility of high-accuracy vehicle control, while maintaining passenger comfort
- Demonstrating that automated driving can be pleasant rather than threatening

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Automated Driving of Diverse Vehicles

Fundamental Challenges Remaining

- Exceeding MTBF of today's vehicle/highway system:
  - Software safety design
  - Fault detection and identification
  - Fault management and accommodation
  - Robustness under all environmental disturbances
- Making it affordable
  - High-performance sensors
  - Redundancy only where essential

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Faults to be Accommodated Safely (1/2)

- **Sensors**
  - **No output, output pegged at an extreme, random noise, bias, drift, sensitivity change, interference,…**
- **Actuators**
  - **No response, response pegged at an extreme, random noise, bias, intermittent operation, deadband, hysteresis,…**
- **Controllers**
  - **Loss of power, software crash, operating system deadlock, overloaded processor or memory, software bugs, control design bugs,…**
- **In-vehicle networks**
  - **Loss of signal, interference, overload, intermittent connections, software bugs,…**

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Faults to be Accommodated Safely (2/2)

- **Wireless communications**
  - Loss of signal, interference, intermittent drop-outs, overloaded channels, noise, jamming, software bugs, spoofing, lack of acknowledgment,…
- **Environmental disturbances**
  - Rain, snow, dust, fog, poor lighting, wet, oily or icy road surface, high winds, lightning discharge,…
- **Vehicle mechanical**
  - Tire burst, engine failure, brake failure, electrical failure,…
- **Foreign obstacles in roadway**
  - Failed or crashed vehicles, crash debris, pedestrians, animals, dropped loads, fallen trees, rock slides, deliberately placed obstacles,…

Research Areas

- **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 degraded mode**
  - **General approach, then needs to be applied to specific vehicles and system designs**
- **General obstacle detection**
  - **Any object large enough to cause harm**
  - **Ignore innocuous "soft" targets**

Spin-offs from DARPA Grand Challenge?

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Highway Automation	Grand Challenge
Well-structured roads, can be marked and mapped	Unstructured, off-road, vehicle must do mapping
Need to know movements of all other vehicles	No other vehicles
Passenger safety critical	No passengers
Vehicle control must be smooth and accurate	Not an issue
MTBF 10^5 – 10^6 hours	MTBF 10^1 hours
Obstacle detection desirable	Obstacle detection essential

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It's Harder than Air Traffic Control!

Issue	Orders of Magnitude More Difficult
Longitudinal position accuracy	3
Lateral position accuracy	3
Fault response speed needed	2
Frequency of hazard encounters	3
Acceptable cost per vehicle	3
Number of vehicles coexisting	4
Cruising speed	-1