Research Challenges for Automated Vehicles

Steven E. Shladover, Sc.D.
University of California, Berkeley

October 10, 2005
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 ~ $2 \times 10^6$ vehicle hours
  – Injury crashes at MTBF ~ $5 \times 10^4$ 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
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
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
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
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
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
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,…
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?
Spin-offs from DARPA Grand Challenge?

<table>
<thead>
<tr>
<th>Highway Automation</th>
<th>Grand Challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-structured roads, can be marked and mapped</td>
<td>Unstructured, off-road, vehicle must do mapping</td>
</tr>
<tr>
<td>Need to know movements of all other vehicles</td>
<td>No other vehicles</td>
</tr>
<tr>
<td>Passenger safety critical</td>
<td>No passengers</td>
</tr>
<tr>
<td>Vehicle control must be smooth and accurate</td>
<td>Not an issue</td>
</tr>
<tr>
<td>MTBF $10^5 – 10^6$ hours</td>
<td>MTBF $10^1$ hours</td>
</tr>
<tr>
<td>Obstacle detection desirable</td>
<td>Obstacle detection essential</td>
</tr>
</tbody>
</table>
## It’s Harder than Air Traffic Control!

| Issue                                              | Orders of Magnitude
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Longitudinal position accuracy</td>
<td>3</td>
</tr>
<tr>
<td>Lateral position accuracy</td>
<td>3</td>
</tr>
<tr>
<td>Fault response speed needed</td>
<td>2</td>
</tr>
<tr>
<td>Frequency of hazard encounters</td>
<td>3</td>
</tr>
<tr>
<td>Acceptable cost per vehicle</td>
<td>3</td>
</tr>
<tr>
<td>Number of vehicles coexisting</td>
<td>4</td>
</tr>
<tr>
<td>Cruising speed</td>
<td>-1</td>
</tr>
</tbody>
</table>