Intelligent Vehicle Systems
Southwest Research Institute

Autonomous Vehicles: State of the Practice

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• Basic question:
  o What is the PURPOSE of a driverless vehicle?

• Possible answers:
  o Ultimate solution to the driver distraction problem
  o Should reduce accidents (although until a significant penetration the overall effect is questionable)
  o Should enable a reduction in traffic fatalities
  o Make transportation systems much more efficient (more vehicles in the same space)

• Sustainability of the technology (at what functional level) – consider driving levels model – expected duration of autonomy:
  o 5 seconds
  o 30 seconds to 1 minute
  o > 1 hour
Automated Vehicle Technology Evolution
Self-driving, UGV, Driverless, Autonomous, Automated, etc…

Automated/Autonomous
- First RC vehicles used in 1930s
- FHWA’s Automated Highway System in the 1990s, and demo in 1997.
- DARPA Urban Challenge (on-road automated driving) in 2007.
- Demonstration on the streets of Manhattan, NYC at the 2008 World Congress
- U.S. DoD Investment
- Google’s Demos/Efforts
- Aggressive Marketing Campaigns leading to announcements by OEMs of their plans for production.

NHTSA Levels of Automation
- No-Automation (Level 0)
- Function-specific Automation (Level 1)
- Combined Function Automation (Level 2)
- Limited Self-Driving Automation (Level 3)
- Full Self-Driving Automation (Level 4)
NHTSA / SAE Driving Levels

- **Descriptive**
- **Minimum levels**
- **Compare to:**
  - Germany Federal Highway Research Institute (BASt)
  - NHTSA

### NHTSA / SAE Driving Levels

<table>
<thead>
<tr>
<th>SAE level</th>
<th>SAE name</th>
<th>SAE narrative definition</th>
<th>Execution of steering and acceleration/deceleration</th>
<th>Monitoring of driving environment</th>
<th>Fallback performance of dynamic driving task</th>
<th>System capability (driving modes)</th>
<th>BAS level</th>
<th>NHTSA level</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No Automation</td>
<td>the full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Human driver</td>
<td>n/a</td>
<td>Driver only</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>Driver Assistance</td>
<td>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</td>
<td>Human driver and system</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
<td>Assisted</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>Partial Automation</td>
<td>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</td>
<td>System</td>
<td>Human driver</td>
<td>Human driver</td>
<td>Some driving modes</td>
<td>Partially automated</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Conditional Automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>Human driver</td>
<td>Some driving modes</td>
<td>Highly automated</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>High Automation</td>
<td>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</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>Some driving modes</td>
<td>Fully automated</td>
<td>4/4</td>
</tr>
<tr>
<td>5</td>
<td>Full Automation</td>
<td>the full-time performance by an automated driving system under all roadway and environmental conditions that can be managed by a human driver</td>
<td>System</td>
<td>System</td>
<td>System</td>
<td>All driving modes</td>
<td>Full automation</td>
<td>5</td>
</tr>
</tbody>
</table>

Source: SAE

Semi-Autonomous Driving – available TODAY
Who is Developing Autonomous Vehicle Capabilities
(list may incomplete because information is not openly shared)

- **US OEMs:**
  - GM
  - Ford
  - Tesla
- **European:**
  - Mercedes
  - BMW
  - Audi
  - Volvo
  - Renault
  - Scania (trucks)
  - Jaguar Landrover
  - Deihl
  - RUAG
  - Rheinmetall Defence

- **Japan:**
  - Nissan
  - Honda
  - Toyota
  - Hino
  - Isuzu

- **Tier 1 Suppliers:**
  - Bosch
  - Continental
  - Delphi

- **US non-OEMs:**
  - Lockheed Martin
  - Southwest Research Institute (SwRI)
  - Smaller Defense Contractors:
    - TORC, GDRS, ASI, etc.
  - University Research
    - CMU, Stanford, Virginia Tech
  - Google
  - **Government (non DoD)**
    - US:
      - Human Factors for Vehicle Highway Automation
      - USDOT Automation Program
    - European Union:
      - CitiMobil and CyberCars
      - Safe Road Trains for the Environment (SARTE)
      - Energy ITS Project (Japan)
Autonomy Examples

• Commercial Space:
  o Google / Auto OEMs
  o PEVs (Personal Electrical Vehicles)
  o Agricultural
  o Mining

• Military space (major programs in last 5 years):
  o AMAS - Army
  o GUSS - Marine Corps / Navy
  o SMSS – Army
  o SUMET – Marine Corps / Navy
  o DSAT – Army

  o Long term success: blending Connected Vehicle and Automated Vehicle:
    ▪ Cooperative Vehicles
    ▪ Cooperative Automation
State of the Practice (commercial): Google

- **Pros**
  - Well funded
  - Previously only freeway, adding arterial capability

- **Cons**
  - Expensive sensor suite
  - Must pre-drive route
  - Requires high precision map database
  - For the U.S. - only 3,200 km of the 6.4M kms of highway “mapped”
Google: Newest Announcement - PEVs

• In May 2014 Google has revealed a prototype of its latest driverless car:
  o No steering wheel
  o No braking or acceleration pedals
  o A stop and go button.
• Platform developed from scratch – not based on existing chassis:
  o No need to accommodate a driver
  o Two passengers
  o Maximum speed of 25 miles per hour
• Google says the car’s most important feature is its safety:
  o Sensors that remove blind spots
  o “…can detect objects out to a distance of more than two football fields in all directions…” (note: unknown sensor technology).
• Visually appealing

• Development timeframe:
  o ~100 prototypes
  o Testing in summer of 2014
  o Available for purchase by 2020

Other companies are developing also – names are proprietary
OEMs

Mercedes

Source: Mercedes

Volvo

Source: Volvo
State of the Practice (agricultural/mining): John Deere / Komatsu

• Deere
  o Agriculture
  o Constrained environment

• Komatsu
  o Fixed route
  o Very dirty conditions
Work Zone Safety: Automated Attenuator Truck

- Pilot Texas DOT Project
  - Moving work convoys:
    - Linear spacing
    - Lateral offsets
  - Static: reposition with hand signals
TARDEC Roadmap

TARDEC is the R&D Center for the Army
On-Road and Off-road are Very Different…

- Identifying Terrain
  - Path Planning in Rough Terrain
  - Vegetation
  - Water
  - Soft VS Hard Terrain

- Environment Conditions
  - Predestains
  - Weather
GUSS (Ground Unmanned Support Surrogate)

- Reducing exposure to unsafe environments and to lethal enemy actions.
- Lighten soldier's loads by carrying supplies.
- Automate external re-supply.
- Reduce time in-between missions by not having to return to their base to retrieve and return items.
Lockheed Martin K-MAX

- Marine Corps program

- Capable of delivering a full 6,000 lb of cargo at sea level and more than 4,000 lb at an altitude of 15,000 feet.

- First mission in Afghanistan on December 17, 2011.

- Still being used.
State of the Practice (military): AMAS (LM)

- Autonomous Mobility Appliqué System (AMAS)
- Portable Autonomy:
  - A-kit (autonomy)
  - B-kit (vehicle interface)
  - C-kit (payload)

Source: Lockheed Martin
State of the Practice (military):  
(mules and support tools)

- Squad Mission Support System (SSMS)
  - Active sensor technology
  - Carry loads over difficult terrain

Source: Lockheed Martin
State of the Practice (military)
Oshkosh TerraMax
SUMET EO-Only Perception and Autonomy Path Planning

Material Classification

Cost Map and Path Planners
Sample Unmanned Demo Video: Marine Corps SUMET Program

Office of Naval Research – Code 30
Ground Vehicle Autonomy Program:
Small Unit Mobility Enhancement Technology (SUMET)

SUMET v2.0 Experimentation

SwRI – San Antonio, TX
29 November 2012
AMAS (Autonomous Mobility Applique System) Retrofitting Existing Fleet
Army: DSAT (Dismounted Soldier Autonomy Tools)
ATEC Tested and Deployed System
Capability Video

Dismounted Soldier Autonomy Tools
State of the Practice (defense): RUAG

- Material classification
- Snow and ice environments
- “New” environment to the system

Source: RUAG
Where will we see Autonomy First?

- Lots of press and widely spread articles about on-road projects….

- Domains other than passenger vehicles have experienced success:
  - Agriculture
  - Mining
  - Military

- Common thread in these areas include:
  - Constrained environments
  - Can accept some level of “collateral damage” (with no legal implications)

- However, we keep hearing “they will be here in 2017 (or 2020”)….
Automated Vehicles Forecast (AVS14)
Data courtesy of AVS14 (held in California, July 2014)

• What do the industry professionals think (as opposed to the media looking for an interesting story or a self-serving company promotion):

• At industry event in California in July 2014 some polling was done:
  • ~250 responses, 80% MS+ degree
  • 64% EE/ME/CS/HF, 24% CE
  • 31% Univ/Research Inst, 24% Auto Ind, 17% Govt
  • 80% US, 44% CA and MI

• Results were insightful….
Automated Vehicles Forecast (AVS14)
Data courtesy of AVS14 (held in California, July 2014)

- **Top 3 barriers:**
  1. Legal
  2. Regulations
  3. Cost

- **Equal number rated Technology highest and lowest**

- **Level of safety compared to today**
  - 56%: as-safe to 2x
  - 36%: 10x to perfect safety

- **73%: Society will accept some automation-caused accidents**

- **46%/54%: Level 3 practical/not practical (driver expected to respond)**

- **67%: V2V essential for Level 5**
When do you expect to be able to trust a fully automated taxi to take YOUR elementary school-age child or grandchild to their school (with no licensed driver onboard)?
What do the Experts (collectively) Say?

Data courtesy of AVS14 (held in California, July 2014)

Q16: When do you expect to be able to trust a fully automated taxi to take your elementary-school-age child or grandchild to their school (with no licensed driver onboard)?

![Bar Chart](chart.png)
**Economic Driver: What Would People Pay…**

- **Surveys or economists suggest (~$3,000):**
  
  **Public opinion surveys**

  According to a survey of 17,400 vehicle owners conducted by J.D. Power and Associates, 37 percent of all survey responders initially said they would be interested in purchasing a fully autonomous car. However, that figure dropped to 20 percent once they learned the technology would cost an additional $3,000. With an additional cost of $3,000, 25% of the male vehicle buyers were willing to pay for a fully autonomous vehicle, while only 14 percent of women wanted the feature.

  According to a 2011 online survey of 2,006 consumers in the US and the UK conducted by Accenture, 49 percent of all survey responders said they would be comfortable using a "driverless car".

  - **Sources:**

- **Today’s cost of hardware on ‘operational vehicles’:**
  - $110K to $280K
  - Mass production should help lower this number but how much?
Punchline: Perception/Behaviors are Challenging

- “Deer in the headlights”
- “Realistic” driving
  - June 2014 in DC
  - Taxi “strike”
  - How to “nose” into traffic
Looking out to the Horizon: What is Next?,

- Next 3 to 20 years:
  - Don’t expect to see automated vehicles regularly used on public roads
  - Military operations can accept collateral damage
  - Closed operations (such as mining, agriculture) have less unpredictability:
    - No teenage / crazy drivers
    - Limited obstacles
    - Very well known environment (that does not change much)
  - Possible areas:
    - Ports / freight yards
    - Retirement communities
  - Potential game changed: dedicated transit or truck or “technology lanes"

- Need “connected” to get “automated”

- Holy grails:
  - Perception (sensors) / Behaviors
  - Cost
  - “Use of technology”: generational (millennials may be more accepting)