Impact of Automated Vehicles on Highway Safety and Operations

November 2013

PREPARED FOR
Tampa Hillsborough Expressway Authority

PREPARED BY
Pei-Sung Lin, Ph.D., Program Director
Zhenyu Wang, Ph.D.
ITS, Traffic Operations and Safety Program
Center for Urban Transportation Research
University of South Florida
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Introduction

The demand on the overburdened highway system is increasing every day. The highway system is even more sluggish, unpredictable, and nonresponsive to driver needs because of drivers’ serious limitations in (Shladover, 2006):

- Perceived 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 that is highly dependent on workload and level of stress
- Vulnerability to inattention
  - Physical impairments—drugs, disease, age
  - Emotional state
  - Distractions inside and outside vehicle
  - Fatigue

These driver characteristics decrease the safety and operational performance of highway systems: lane capacity is limited by long car-following distance, lane width must accommodate steering inaccuracies, shock waves are caused by diverse driver response lags, and traffic accidents are caused by errors in judgment or inattention (Shladover, 2006). The automated vehicle (AV), with recent and continuing advances in automotive technology and current research on/and testing of vehicle innovations, has created completely new possibilities for improving highway safety, expanding mobility, increasing environmental benefits, and creating new economic opportunities for jobs and investment.

The AV, also known as a driverless vehicle, self-driving vehicle, or robot vehicle, is an autonomous vehicle able to fulfill the human transportation capabilities of a traditional car (NHTSA, 2013). As an autonomous vehicle, it is capable of sensing its environment and navigating without human input. AVs may use on-board sensors (radar, Lidar, camera, GPS, etc.) and telecommunications (vehicle-to-vehicle [V2V], vehicle-to-infrastructure [V2I], etc.) to obtain information to make judgments regarding safety-critical situations and act appropriately by effectuating control at some level. An example of autonomous driving is shown in Figure 1.

Detecting surrounding environment and conducting vehicle control (steering, acceleration, and deceleration) are the primary functions of an automated vehicle. Thus, there are two “key” technologies in development of automated vehicles: automation and connection. Automation is the use of computer-based control systems instead of human input to operate vehicles, partially or fully. According to the National Highway Traffic Safety Administration (NHTSA), the degree of automation can be scaled at five levels (NHTSA, 2013), as shown in Figure 2.
Source: Google.com, autostime.com, and eenews.net

Figure 1. Example of Autonomous Driving

- **Level 0**
  - **No Automation**
  - Drivers handle all aspects of dynamic driving tasks
  - Application: radar, camera, and/or V2V enabled crash warning systems.

- **Level 1**
  - **Function-Specific Automation**
  - One or more specific automation control functions (braking, throttle, and/or steering) are independent from each other.
  - Drivers have overall control.
  - Application: Automatic braking systems.

- **Level 2**
  - **Combined Function Automation**
  - Integration of braking, throttle, and steering control designed to enable "hands/foot free operations."
  - Drivers are available at all time to retake control.

- **Level 3**
  - **Limited Self-Driving Automation**
  - Integration of braking, throttle, and steering control.
  - Drivers are expected for occasional control.
  - Drivers can cede full monitoring and control authority.

- **Level 4**
  - **Full Self-Driving Automation**
  - Integration of braking, throttle, and steering control.
  - Drivers are NOT expected for occasional control.
  - Responsibility for safe operation is solely with the vehicle.

Figure 2. Levels of Automated Driving
Detection on roadway conditions can be used in two different ways: (1) on-board sensors (camera, radar, Lidar, etc.) to monitor the environmental conditions surrounding the vehicle individually; and (2) connection technology to focus on localized V2V, V2I, and vehicle-to-pedestrian (V2P) to exchange the information of the roadway environment using vehicle Dedicated Short Range Communications (DSRC)/Wireless Access for Vehicular Environments (WAVE). The connection technologies and degree of connectivity are shown in Figure 3.

Figure 3. Connected Technologies and Connection Degree

Figure 4 shows three approaches in the future development of automated vehicles. The first approach is “autonomous vehicle,” which operates automatically in isolation from other autonomous vehicles based on in-vehicle sensors. The second approach is “connected vehicle,” which communicates with other vehicles and infrastructures without automation. The third approach is “automated-connected vehicle,” which integrates the two key technologies: connection and automation.

Figure 4. Integration of Automation and Connection
With the automated vehicle technology, the world is at a historic turning point for automotive travel. Motor vehicle and driver relationships are likely to change significantly in the next 10-20 years, perhaps more than they have changed in the last 100 years (NHTSA, 2013).

Safety Impacts

In more than 90 percent of traffic accidents, driver error is the major cause (NHTSA, 2013). Vehicle-highway automation uses advanced sensing, communication, and automation technologies to provide improvements over human performance. These include full attentiveness, consistent responses, and lightning-quick reaction times. Applied in carefully selected operating environments and with appropriate fault-handling features, vehicle-highway automation will result in significant decreases in the frequency and severity of highway crashes. Some estimates state that an overall 50 percent improvement can be realized with automated vehicles (FHWA, 1997).

Safety impacts of AV technology include:

- **Enhanced awareness** – Automated vehicles provide enhanced awareness and longer response time for drivers who have limited performance in detecting and judging surrounding conditions, especially in a hazardous environment (darkness, bad weather, etc.). The system uses in-vehicle sensors (camera, radar, Lidar, etc.) to detect the presence of surrounding vehicles, trucks, motorcycles, pedestrians/bicyclists, or other objects. The information also can be exchanged between vehicles (V2V), vehicles to infrastructures (V2I), and vehicles to pedestrians/bicyclists (V2P). If some “dangerous” events are predicted, warning information will be provided to drivers.

- **Driving assistance and crash avoidance** – In some situations, automated vehicles (Level 1 and up) override drivers to take maneuvers (automated braking, lane change assistance, etc.) to avoid conflict/crash occurrence. The avoidance control functions can eliminate human error, including erroneous decision making, poor driving experience and training, unfamiliarity with vehicle and roadway, distraction/ inattention, risk-taking behaviors, etc. This driving assistance system makes traffic smoother. Low speed variance is more likely to decrease the probability of accident occurrence.

- **Self-driving automation** – Automated vehicles (Level 3 and up) monitor the roadway environment and control vehicles without human interference such that human factors contributing to traffic accidents can be eliminated fully. This is especially true for older adult drivers and people with disabilities who may have limited driving capacities, as shown in Figure 5. Self-driving automation can provide opportunities for these travelers in regards to safe driving on highway systems. The benefits can be enhanced with connectivity between vehicles and between the vehicle and infrastructure.
Operational Impacts

While increases in safety will have the most benefit for society as AV technology is implemented, there are also many operational gains:

- **Reduced congestion** – Recurring congestion is caused by traffic demand over capacity. Automated vehicles (Level 1 and up) have the automation function to eliminate human diversity and response time, which result in long headways and diverse speeds. The number of vehicles per hour per lane can be significantly increased as traffic speeds are standardized and increased and headway distances are decreased. It is expected that 2–3 times more vehicles could be accommodated through elimination of inefficiencies caused by in attentiveness, merging, weaving, and lane-changing with safer overall operations (FHWA, 1997). Non-recurring congestion is caused by incidents. With AVs (Level 0 and up), drivers—or the vehicles themselves—will be able to make more intelligent route selections based on weather and traffic data received by the vehicle in real time to avoid the non-recurring congestion.

- **Improved mobility** – Mobility for those with a range of disabilities will be greatly enhanced if the basic driving functions can be safely performed by the vehicle itself (Level 3 and up), opening new windows for millions of people. In addition, for long-distance intercity travel, AVs (Level 1 and up) permit higher cruising speed than current driving. Therefore, the time that automated vehicles free up could be used for other purposes (Shaldover, 1998).

- **Optimized traffic control** – The “connected” vehicle (Level 0 and up) can communicate with traffic controllers at intersections, ramps, and/or railroad crossings through the V2I technology. The controllers can receive information on comprehensive traffic conditions and develop optimal traffic control strategies. At the same time, the traffic control strategy can give feedback to the “connected” vehicles so that the vehicle system can provide longer response time to drivers or optimize vehicle operations automatically. The two-way communication can improve mobility and productivity of urban arterials.
Other Impacts

Other impacts of AV technology include the following:

- Preventing a significant numbers of crashes will greatly reduce the enormous related societal costs—lives lost, hospital stays, days of work missed, and property damage—that total in the hundreds of billions of dollars each year.

- Automated vehicles need much narrower lane widths than traditional vehicles since the vehicles eliminate the diversity of driver steering. The requirement of traffic signs and markings will be lowered due to the implementation of automated vehicles. Thus, the investment in and maintenance of roadway facilities may be reduced after implementation of automated vehicles.

- Vehicle control systems that automatically accelerate and brake with the flow of traffic can conserve fuel more efficiently than the average driver.

- By eliminating a large number of vehicle crashes, highly effective crash avoidance technologies can reduce fuel consumption by eliminating the traffic congestion that crashes cause every day. Reductions in fuel consumption will yield corresponding reductions in greenhouse gas emissions.

- These dramatic changes will offer significant new opportunities for investments in the underlying technologies and employment in the various industries that develop, manufacture, and maintain them.

Potential Challenges

In spite of the various benefits to increased vehicle automation, some foreseeable challenges may persist:

- **Safety concerns** – Although automated vehicles eliminate human errors, which are the major cause of traffic accidents, new accident causes (for example, system errors) may be introduced in the implementation of automated vehicles.

- **Liability for damage** – Unlike traditional vehicles, if AVs (either partial automation or full automation) are involved in accidents, it will be difficult to identify the responsibility: the vehicle owner (driver) or the vehicle manufacturer. The current model clearly puts the onus on the operator in nearly all incidents.

- **Mixed traffic** – An isolated roadway facility for AVs can produce the best safety and operational performance but will need extra investments to allow access. A roadway facility that mixes AVs and traditional vehicles would be a low-cost alternative. However, driverless vehicles may introduce several issues, including pressure on drivers of traditional vehicles, cooperation between automated and traditional vehicles, etc.

- **Public acceptance** – Expert members of the Institute of Electrical and Electronics Engineers (IEEE) have estimated that up to 75 percent of all vehicles will be
autonomous by 2040. At the beginning stage, the public may have less confidence in automated vehicles. Drivers may resist forfeiting control of their cars. Successful demonstration projects are necessary to show the benefits and establish confidence in AVs to the public.

Conclusions

Automated vehicles are expected to thrive early in the 21st century in all aspects of private vehicle, commercial, transit, and specialized vehicle operations. They will significantly reduce vehicle crashes, improve operational efficiency, and improve mobility. However, with increased vehicle automation, some foreseeable challenges may persist. Overall, AVs will bring a dramatic change in how people drive their vehicles in the future.
References


