The Revolutionary Development of Self-Driving Vehicles and Implications for the Transportation Engineering Profession

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Abstract
Significant numbers of self-driving vehicles are expected to be on the roads within the next decade. This paper documents current technology development and potential safety and mobility benefits. It poses questions and proposes some initial actions to prepare the profession for the challenges presented by this new technology.

Introduction

Highway travel is about to undergo a dramatic transformation, unprecedented in the history of transportation, and the Institute of Transportation Engineers and its membership will face both opportunities and challenges that will re-shape the future for our discipline.

The rapid development of autonomous vehicles, self-driving cars, is under way as this is being written, and there is some urgency for the transportation engineering profession to become actively engaged in dialogs and partnerships with a variety of stakeholders including software and systems developers, auto manufacturers, and regulatory bodies.

Based on technology developed through competitions sponsored by the Defense Advanced Research Projects Agency (DARPA), Google (Mountain View, CA) revealed in 2010 that it had developed and was testing a fleet of self-driving cars.[1,2] Google has logged 500,000 miles of autonomous driving with no crashes under computer control.[3] Figure 1 shows one of the Lexus RX 450h's equipped with Google's self-driving technology.[4] The technology used to control the self-driving car employs sensors that can "see" 360 degrees around the vehicle and sample data points thousands of times per second. It is capable of tracking vehicles in the traffic stream far more accurately than can a human driver, and it can react more quickly. Figure 2 shows an image of the various sensor inputs used by the Google technology.[5]

Autonomous systems do not get drunk. Nor do they get tired, or suffer from distractions like texting while driving.

Potential Safety Benefits of Autonomous Driving

World-wide, 1.24 million people were killed on roads in 2010, a staggering toll.[6] In the United States, for 2010, 5.4 million reported motor vehicle crashes killed 32,885 people and injured more than 2.2 million.[7] For 2009, the AAA estimates the total cost of crashes at $299.5 billion.[8] According to the National Highway Traffic Safety Administration (NHTSA), "injuries resulting from motor vehicle crashes are the leading cause of death for age 4 and every age 11 through 27." [9] Even more tragic is that most of these fatalities and injuries did not need to happen.

Analysis of a nationally representative survey sample of 5,471 crashes in the period 2005-2007 showed that 92.3 percent of all crashes were attributed to errors made by drivers.[10] In 2011, 9,878 vehicle crash fatalities, 31 percent of all motor vehicle traffic fatalities, were attributed to alcohol impaired driving.[11] Self-driving cars have the potential to eliminate virtually all driver error and most auto crashes.

Mobility Benefits

According to projections by the US Census, the population of Americans age 64 and older will increase from 47.7 million, or 14.8 percent of the US population in 2010, to 65 million, or 18.8 per cent of the population by 2025.[12,13] Older Americans will constitute an increasing share of the driving population.

Figure 1 Google Self-Driving Car (Google) Google and the Google logo are registered trademarks of Google Inc., used with permission

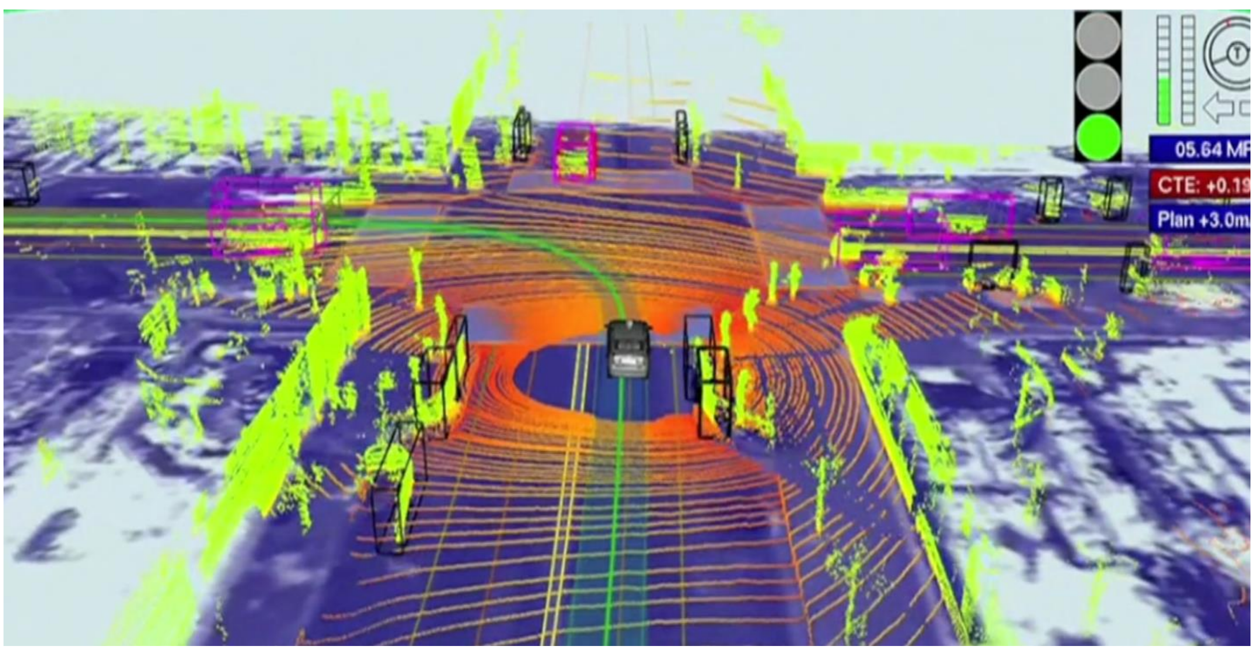

Figure 2 Depiction of Sensor Inputs to Google Self-Driving Car (TED.com Creative Commons License) Google and the Google logo are registered trademarks of Google Inc., used with permission

As age increases, changes in visual acuity, flexibility and strength, reaction time, and memory all impact one's ability to drive.[14] According to Rosenbloom, "…people over age 75 have more motor vehicle deaths per 1,000 than any other cohort of the population except those under age 25. Per mile driven, they have more crashes than all other drivers except teenagers."[15]

Many older drivers choose to give up their licenses voluntarily when they become aware of their diminished capacity to drive. Some self-limit their driving to daylight hours only, or to avoid heavy traffic or high speed roads. Yet many do not, and continue to drive although they may constitute a hazard to themselves and other drivers.

For those who, either voluntarily or otherwise, lose the privilege to drive, lack of mobility can lead to a serious reduction in one's quality of life and health. Social isolation due to the inability to interact with friends and family, and the inability to shop and get to health care services can lead to depression and degradation of one's physical and emotional well-being. While public transportation can fulfill many needs, some of the same disabilities that prevent one from driving can limit one's ability to use transit, and for many, especially those living in suburban and rural areas, public transportation may be limited or unavailable for many trips.[16]

Self-driving cars offer the promise of allowing older citizens and those with disabilities to enjoy a level of mobility on a par with that enjoyed by licensed drivers with ready access to cars. A dramatic demonstration of this potential can be seen in a You Tube video posted by Google in March 2012, a frame of which appears in Figure 3.[17] Steve Mahan, who is 95% blind, is shown in the driver's seat of a Google self-driving Toyota Prius. Driving along a pre-programmed route, Mahan uses the car to get a taco at a drive through fast food restaurant, and picks up dry-cleaning at a laundry. Being able to accomplish such tasks, which seem very mundane to those of us who can drive, would liberate many disabled individuals. Mahan says, "Where this would change my life is to give me the independence and flexibility to go to the places I both want to go and need to go when I need to do these things."

Productivity Benefits

In addition to the safety and mobility benefits, self-driving cars would allow significant productivity increases for commuting, goods movement and care-giving. Being able to use time spent in motion for work, recreation, study and sleep would greatly improve the quality of life. Being able to send goods and passengers from origin to destination without a driver would significantly reduce labor costs. The potential is limited only by one's imagination.

Basic Aspects of Autonomous Vehicle Technology

In addition to the Google fleet, other vehicle manufacturers and software developers are developing automated vehicle technology, however, most are introducing the technology incrementally. NHTSA has defined five suggested levels for vehicle automation.[18]

<u>Level 0 (No automation):</u>

- The human is in complete and sole control of safety-critical functions (brake, throttle, steering) at all times.

Figure 3 Google Self-Driving Car Video on You Tube (Google and You Tube) Google and the Google logo are registered trademarks of Google Inc., used with permission

Level 1 (Function-specific automation):

- The human has complete authority, but cedes limited control of certain functions to the vehicle in certain normal driving or crash imminent situations.

- Examples: adaptive cruise control, ESC, automatic braking (but not in combination so as to enable hands-off-steering wheel/foot-off-pedal operation)

Level 2 (Combined function automation)

- Automation of at least two control functions designed to work in harmony (e.g., adaptive cruise control and lane centering) in certain driving situations.

- Enables hands-off-wheel and foot-off-pedal operation.

- Driver still responsible for monitoring and safe operation and expected to be available at all times to resume control of the vehicle.

Level 3 (Limited self-driving)

- Vehicle controls all safety functions under certain traffic and environmental conditions.

- Human can cede monitoring authority to vehicle, which must alert driver if conditions require transition to driver control.

- Driver expected to be available for occasional control.

Level 4 (Full self-driving automation)

- Vehicle controls all safety functions and monitors conditions for the entire trip.

- The human provides destination or navigation input but is not expected to be available for control during the trip.

- Responsibility for safe operation rests solely on the automated system.

Most car-makers offer level 1 technology today. Some have advanced to level 2, such as parking assist and lane keeping systems. The Mercedes Benz Intelligent Drive system is an example. It uses sensor data to autonomously brake the vehicle in anticipation of a collision and can apply brakes on one side to assist in centering the vehicle in the lane.[19] The Google cars are examples of level 3, in that a driver has always been present. Level 4 represents the ultimate stage of autonomous vehicle development.

At this time, California, District of Columbia, Florida, and Nevada have enacted regulations allowing autonomous vehicles on roads with a driver present. Other states are working on similar regulations.[20] None have yet permitted on-road operation of fully driverless vehicles.

Although autonomous vehicle technology is complex, its elements can be divided into four basic component categories: sensors, mapping, perception, and communication. Sensor technology includes a variety of hardware such as multiple video cameras for daylight conditions, forward looking infrared sensors for night conditions and detection of humans and animals, radar for measuring range and velocity, global positioning systems (GPS) to determine location, accelerometers and gyroscopes to detect changes in speed and direction, and light detection and ranging (LIDAR) that employs spinning lasers and photoreceptors to create a three dimensional model of the immediate environment.

Mapping typically uses coordinate files of points and line segments representing streets, origin and destination addresses, and other features, including digital aerial photography, ground level imagery of roadway features, traffic control devices and obstacles. Mapping also may include stored terrain models created with LIDAR. Built off line, highly precise, annotated mapping has been a key element to create a “virtual infrastructure” for the Google car program.[21]

Perception includes the set of software processes that fuse data from the various sensors, compare it with stored mapping and determine how the vehicle will react to the various inputs. Perception includes determining and maintaining the vehicle’s position within the traffic lane and with respect to other moving vehicles, monitoring and reacting to traffic control devices, detecting and reacting to pedestrians and other obstructions in the vehicle’s path, keeping track of the vehicle’s location with respect to the map, and monitoring and reacting to the forces acting on the vehicle. Other functions include monitoring the health of the vehicle and its automated systems.

Communication technology, also termed “connected vehicle”[22,23] or “Cooperative Vehicle-Highway Automation Systems (CVHAS)”[24] can include vehicle to vehicle (V2V) and vehicle to infrastructure (V2I). V2V communication can allow vehicles to exchange information about their position and movement intentions, allowing other vehicles to anticipate and respond to maneuvers. V2I communications can allow vehicles to communicate with traffic control devices and allow the exchange of mapping data between stationary sources and vehicles.

A key question is “When will we see autonomous vehicles as a significant component of road traffic?” Google sources reportedly have said three to five years.[25] Audi, BMW, GM and Nissan reportedly expect to introduce self-driving cars by 2020.[26] Continental Automotive Systems expects to produce highly automated cars by 2025.[27] Using fleet turnover projections for alternative powertrains/fuels as a model, market penetration could range from eleven to 34 percent in five years to 22 to 59 percent in ten years, which means that self-driving autos could plausibly be present on the roads in significant numbers within a decade. [28]

Implications for the Transportation Engineering Profession

Accommodating self-driving vehicles will introduce many challenges for those who plan and design transportation facilities. A few potential examples include the following:

Platooning - The formation of “road trains” of vehicles electronically linked to a lead vehicle with a professional driver is being tested in Europe and offers the potential for safe hands-off driving on limited access highways.[29] Special lanes may be needed for platooning, and additional space required for vehicles joining and separating from platoons.

Loading, unloading and parking – Parking assist systems are already being offered as options for some cars. This technology is likely to be enhanced to allow drivers and passengers to be dropped off and picked up, while the vehicles self-park and un-park. Curb frontage loading areas may need to be expanded and parking areas can be re-designed to be more compact and perhaps located farther away from the buildings they serve.

Lane widths and Pavement Design – Self-driving vehicles are expected to track more precisely within lanes, which could allow lanes to be narrowed. More precise tracking also could lead to wear patterns that may require changes to pavement design.

"Rules of the Road" such as speed limit enforcement – In mixed traffic with both self-driving and manually-driven vehicles should self-driving vehicles mimic driver behavior? Should they be allowed to exceed the posted speed limit if safe operation would be enhanced by keeping pace with other vehicles traveling above the limit? Could the concept of posted speed limits be modified to allow dynamic speed limits that adjust to conditions in real-time?

Regional traffic volumes – When fully-autonomous vehicles are permitted on the roadways, the fundamental nature of vehicle trips will change. Vehicles can shuttle empty to pre-position themselves where they are needed. Parents could let cars drive their children to school and soccer practice. Congestion patterns at local and regional levels are likely to change with the addition of self-driving vehicle flows.

Goods movement and public transportation - Vehicles transporting goods unescorted by a driver might require more queue space as they wait to be loaded and unloaded. Public transportation, taxi, limousine, and trucking industries will likely undergo major transformations. The current model of individual auto ownership also is likely to experience significant shift.

Recommended Actions
The Institute and its members will undoubtedly be called upon to answer such questions and more. Some already have started to discuss the issues.[30] The future of our profession may depend on how we prepare ourselves for the challenge of self-driving vehicles. To that end, we suggest that the Institute promote the following actions:

Organize – In March 2013, the International Board of Direction of ITE established a task force to examine the rapidly evolving "Next Generation of ITS" and its impact on the transportation engineering profession. The task force is working on two fronts, one a longer-term strategic plan for ITE and the next generation of ITS and the other a shorter-term "must-do" list of initiatives for engaging the ITE membership with fast-moving developments in all aspects of transportation technology, including autonomous vehicle technology. Although the task force will sunset in August 2013, it is expected that its final report will include recommendations for continued ITE leadership and initiatives that will include positive contributions to the development and safe use of autonomous vehicles.

Educate – ITE members include traffic engineers and transportation planners whose previous education, training and experience were based on human-operated motor vehicles. Traffic control signage, speed enforcement, trip generation rates, parking requirements and other basic and fundamental components of the engineer's and planner's guidebooks will require updating for the advent of self-driving cars. Educating today's professionals in order for them to update essential tenets of the profession will be crucial.

Form Partnerships – Vehicles and travelers are rapidly getting "smarter" thanks to breakneck developments in automotive and smart phone technologies. Traffic engineers and transportation planners are the professionals who plan, design, engineer and operate the infrastructure that services vehicles and travelers. These are very different fields of expertise. ITE should reach out and form robust collaborations with vehicle manufacturers, systems and app developers, professional organizations, and governmental bodies that are already actively promoting autonomous vehicle technologies and strive to find ways to achieve synergies that will benefit not only ITE members but society as a whole as well.

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