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ROAD SAFETY WITH SELF-DRIVING VEHICLES: GENERAL LIMITATIONS AND ROAD SHARING WITH CONVENTIONAL VEHICLES

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16. Abstract

Self-driving vehicles are expected to improve road safety, improve the mobility of those who currently cannot use conventional vehicles, and reduce emissions. In this white paper we discuss issues related to road safety with self-driving vehicles. Safety is addressed from the following four perspectives: (1) Can self-driving vehicles compensate for contributions to crash causation by other traffic participants, as well as vehicular, roadway, and environmental factors? (2) Can all relevant inputs for computational decisions be supplied to a self-driving vehicle? (3) Can computational speed, constant vigilance, and lack of distractibility of self-driving vehicles make predictive knowledge of an experienced driver irrelevant? (4) How would road safety be influenced during the expected long transition period during which conventional and self-driving vehicles would need to interact on the road?

The presented arguments support the following conclusions: (1) The expectation of zero fatalities with self-driving vehicles is not realistic. (2) It is not a foregone conclusion that a self-driving vehicle would ever perform more safely than an experienced, middle-aged driver. (3) During the transition period when conventional and self-driving vehicles would share the road, safety might actually worsen, at least for the conventional vehicles.

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1. Introduction

Self-driving vehicles—vehicles that would drive the occupants without any direct human control—are currently the talk of the town (although not everyone is persuaded that they will ever materialize [e.g., Gomes, 2014]). The intended benefits of self-driving vehicles are manifold. First, and foremost, the safety performance of self-driving vehicles could, in principle, be made perfect. Second, self-driving vehicles could increase the mobility of those who currently are, for many different reasons, prevented from driving. Third, the environmental footprint of self-driving vehicles is envisioned as being much smaller than the footprint of human-driven vehicles because congestion, stop-and-go, and idling could be eliminated or greatly reduced. This white paper provides a brief discussion of road safety with self-driving vehicles. Of interest are both general limitations and issues related to a transition period when both self-driving and conventional vehicles would need to share the road. This discussion will deal with completely self-driving (Level 4) vehicles (U.S. Department of Transportation, 2013).

2. Road casualties in the context of public health

The magnitude of the road-safety problem is illustrated here from two perspectives: absolute number of road casualties, and their relation to all casualties. In terms of the number of casualties, the World Health Organization (2013) estimates that in 2010 there were 1.24 million road fatalities worldwide; the latest available data for the U.S. show that in 2013, road crashes resulted in 32,850 fatalities (U.S. Department of Transportation, 2014).

Fatalities from road crashes as a percentage of deaths from all causes was examined in a recent study (Sivak and Schoettle, 2014). The three countries with the highest percentages are the United Arab Emirates (15.9%), Qatar (14.3%), and Kuwait (7.9%). The three countries with the lowest percentages are the Marshall Islands (0.3%), Malta (0.4%), and Tajikistan (0.4%). In the U.S., fatalities from road crashes represent 1.8% of all fatalities.

3. Limitations on road safety with self-driving vehicles

Road safety with self-driving vehicles will be considered from four perspectives:

- Can self-driving vehicles compensate for contributions to crash causation by other traffic participants, as well as vehicular, roadway, and environmental factors?
- Can all relevant inputs for computational decisions be supplied to a self-driving vehicle?
- Can computational speed, constant vigilance, and lack of distractibility of self-driving vehicles make predictive knowledge of an experienced driver irrelevant?
- How would road safety be influenced during the expected long transition period during which conventional and self-driving vehicles would need to interact on the road?

3.1 Contributions of other traffic participants, as well as vehicular, roadway, and environmental factors to crash causation

Not all crashes are caused by drivers. Some crashes are the consequence of inappropriate actions by other traffic participants (e.g., jaywalking pedestrians), vehicular defects (e.g., failed brakes), roadway factors (a large pothole leading to a loss of vehicle control), or environmental factors (e.g., localized, sudden, dense fog). For example, Lee and Abdel-Aty (2005) found pedestrians to be at fault in 80% of pedestrian crashes at intersections. Could self-driving vehicles compensate for all non-driver factors?

3.1.1. Other traffic participants. Self-driving vehicles could compensate for some but not all crashes caused by other traffic participants. As an example of the latter, consider a situation involving a drunk pedestrian stepping suddenly into the roadway. If the distance to the pedestrian is *very* short, the limiting factor might not be human reaction time but the stopping distance of the vehicle (i.e., the efficiency of the brakes). Thus, although a self-driving vehicle could, in principle, respond faster than a human driver and provide optimal braking performance, it still might not be able to stop in time because of braking limitations.

Another set of challenges involving other traffic participants requires recognizing and negotiating unusual road users. Examples include ridden horses and horse drawn buggies, large non-automotive farm equipment, and situations where police or construction crews are required to direct traffic.

3.1.2. Vehicular factors. A small (but non-zero) percentage of crashes are the consequence of vehicular failures. (Approximately 1% of fatal crashes in 2013 involved a vehicular equipment failure as a critical pre-crash event [U.S. Department of Transportation, 2015].) On one hand, some current vehicular failures might become obsolete for self-driving vehicles. For example, lighting failures might turn out to be irrelevant to safety from the perspective of being able to control one's vehicle at night, because self-driving vehicles might not rely on visual input. (However, such failures would not be irrelevant from the perspective of other road users being able to see the vehicle in question.) On the other hand, there is no reason to expect that certain other vehicular failures (e.g., brakes or tires) would be less frequent on self-driving vehicles than on conventional vehicles. Indeed, given the complexity of the sensing hardware and of the information-processing software, it is reasonable to expect that, overall, vehicular factors would likely occur *more* frequently on self-driving vehicles than on conventional vehicles.

3.1.3. Roadway factors. It is expected that self-driving vehicles will eventually be able to cope with most roadway factors. Examples include large potholes and large roadway debris. However, certain other conditions (e.g., a flooded roadway or a downed power line) are likely to provide difficulties to self-driving vehicles for years to come.

3.1.4. Environmental factors. The current prototypes of self-driving vehicles cannot yet operate safely in fog, snow, or heavy rain (e.g., Lavrinc, 2014). This is the case because, under such conditions, the current sensing technology cannot provide sufficient information for reliable travel. Even if solutions are eventually found for steady-state conditions, a sudden onset of such inclement weather might not be detected in time to adjust the vehicle speed sufficiently.

3.2 Availability of required information

There are two main issues here, both eloquently addressed by Gomes (2014): the extent of the detailed information required, and the need to instantaneously update this information when changes occur.

3.2.1. Extent and precision of the needed information. Gomes (2014) argued that, "all 4 million miles of U.S. public roads will need to be mapped, plus driveways, off-road trails, and everywhere else you'd ever want to take the car" and this information would need to include "locations of streetlights, stop signs, crosswalks, lane markings, and every other crucial aspect of a roadway." However, it is not yet clear to what extent self-driving vehicles will rely upon GPS, radar, lidar, computer-vision systems, or a combination of sensor inputs to navigate the roadway.

3.2.2. Need to update this information in real time. The information outlined above does not necessarily stay unchanged over time. Some changes are permanent (a new traffic-control device), while other changes are temporary (a detour due to road construction). To provide real-time updates of all relevant changes (both permanent and temporary) is a daunting task.

3.3 Computational speed, constant vigilance, and lack of distractibility of self-driving vehicles versus predictive knowledge of an experienced driver

The fatality rate per distance driven using a conventional vehicle is strongly influenced by the age of the driver (e.g., Ferguson, Toeh, and McCartt, 2007). Specifically, this relationship is a U-shaped function, with the lowest rates for middle-aged drivers. One of the likely reasons for the minimum being reached for middle-aged drivers is their predictive knowledge about the likely intentions of other road users.[1]

This predictive knowledge was acquired through years of driving experience.[2] To the extent that not all predictive knowledge gained through experience could exhaustively be programmed into a computer (or even quantified), it is not clear *a priori* whether

[1] Another major reason is their reduced risk taking.
[2] Although older drivers possess the most predictive knowledge, the risk function for them is elevated because of the increased frequency of physical and mental limitations.

computational speed, constant vigilance, and lack of distractibility of self-driving vehicles would trump the predictive experience of middle-aged drivers.

3.4 Road safety during the long transition period from conventional vehicles to self-driving vehicles

It takes a long time to turn over the U.S. fleet of light-duty vehicles, with the average vehicular age currently being 11.4 years (IHS, 2014). Furthermore the distribution of vehicle age has a very long tail to the right. For example, in 2002, 13.3% of all light trucks sold 25 years earlier were still on the road, with a corresponding percentage for cars of 2.3% (U.S. Department of Energy, 2014). As a consequence, there will likely be at least a several-decade-long period during which conventional and self-driving vehicles would need to interact. Furthermore, to the extent that some people may want to drive only conventional vehicles (Schoettle and Sivak, 2014), this overlapping period might last indefinitely.

One main concern during this transition period is that drivers of conventional vehicles would have certain expectations about the likely actions of other vehicles (depending on factors such as the location of the interaction, the type of the other vehicle, and the age and gender of the driver of the other vehicle, etc.). For example, we have shown that in several types of two-vehicle crashes, male-to-male crashes are under-represented and female-to-female crashes are over-represented (Sivak and Schoettle, 2011), suggesting the possibility that expectations of male drivers about intended behaviors of other male drivers are more veridical than expectations of female drivers about the intended behaviors of other female drivers. Furthermore, in many current situations, interacting drivers of conventional vehicles make eye contact and proceed according to the feedback received from other drivers. Such feedback would be absent in interactions with self-driving vehicles. The degree of the importance of both driver expectations and feedback from other drivers, and the consequent effects on the safety of a traffic system containing both conventional and self-driving vehicles, remain to be ascertained.

4. Conclusions

Figure 1 includes the U-shaped function of the relationship between driver age and the fatality rate per distance driven using conventional vehicles referred to above (e.g., Ferguson, Toeh, and McCartt, 2007). Superimposed on this graph are four possible risk functions using a self-driving vehicle. Because the age of the user would be irrelevant for the performance of a self-driving vehicle, these risk functions are represented in Figure 1 by horizontal lines. The question of interest is whether the line *for a fleet containing only self-driving (Level 4) vehicles* will go through zero on the vertical axis (Case 1), through a nonzero value that is lower than the current minimum (Case 2), through the current minimum with human drivers (Case 3), or through a value that is higher than the current minimum (Case 4). The issues discussed above provide a strong argument against Case 1; whether the reality will be Case 2 or Case 3, or even Case 4, remains to be seen. (It is possible that self-driving vehicles with risk functions above Case 3 might not be allowed.) Furthermore, during a transition period when both conventional and self-driving vehicles would be on the road, the risk for conventional vehicles could be elevated.

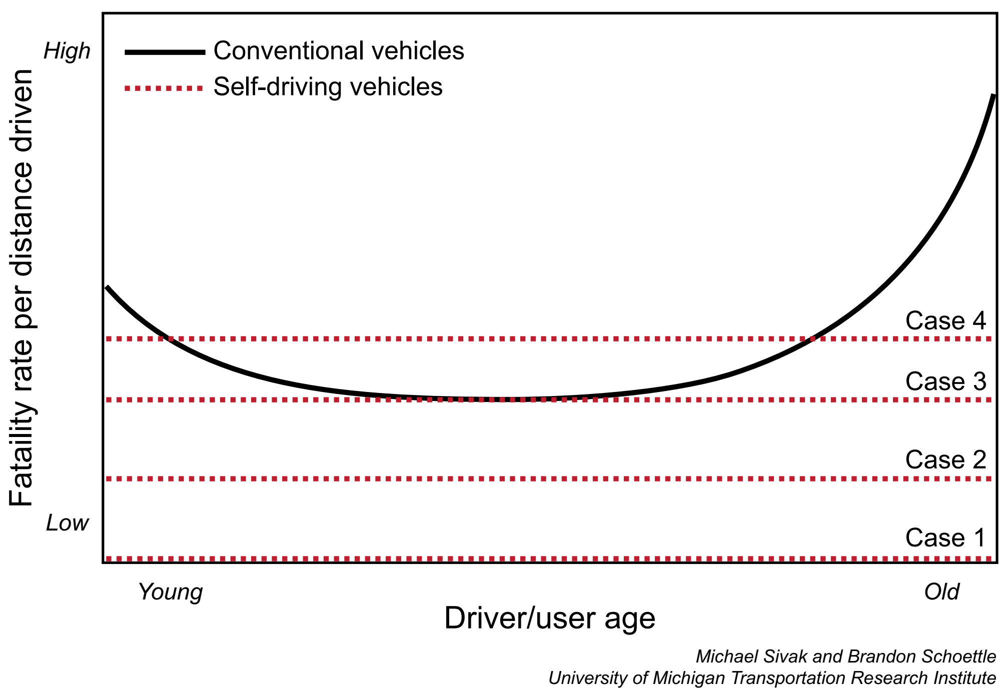

Figure 1. Fatality rates per distance driven using conventional vehicles and self-driving vehicles as a function of driver/user age.

5. Summary

Self-driving vehicles are expected to improve road safety, improve the mobility of those who currently cannot use conventional vehicles, and reduce emissions. In this white paper we discussed issues related to road safety with self-driving vehicles. Safety was addressed from the following four perspectives: (1) Can self-driving vehicles compensate for contributions to crash causation by other traffic participants, as well as vehicular, roadway, and environmental factors? (2) Can all relevant inputs for computational decisions be supplied to a self-driving vehicle? (3) Can computational speed, constant vigilance, and lack of distractibility of self-driving vehicles make predictive knowledge of an experienced driver irrelevant? (4) How would road safety be influenced during the expected long transition period during which conventional and self-driving vehicles would need to interact on the road?

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