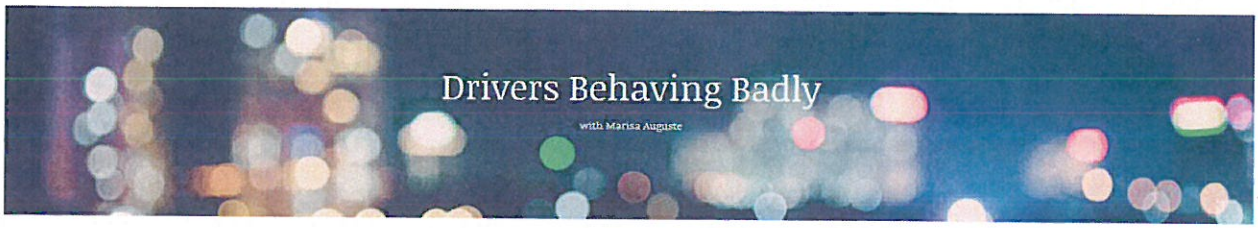
Autonomous Vehicles: An Overview



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Intelligent vehicle technologies can cover a wide range of features within a motor vehicle. The word *autonomous* does not necessarily translate into a *self-driving* car. There are in fact several steps in between, each representing a differing level of autonomy. Some recently developed features that may be better known to the general public include crash avoidance technologies in the form of anti-lock braking or collision and lane departure warnings. As the wave of technology continues to swell, the world must prepare for what is next on the horizon: **fully driverless vehicles**. Within those three words lies not only the capacity for great things but also the even greater *fear* of the unknown. Many questions have surrounded any discussions of autonomous vehicles and many questions still remain. I suppose the first and most obvious question being, what exactly is an autonomous vehicle? I myself realized just how little information I had on the subject. So I decided to investigate and here's what I found out...

What are they?

The U.S. Department of Transportation (DOT) defines autonomous vehicles, or a vehicle equipped with an automated system as, "a combination of hardware and software (both remote and on-board) that performs a driving function, with or without a human actively monitoring the driving environment"[2]. In September 2016, the National Highway Traffic Safety Administration (NHTSA) released their Federal Automated Vehicles Policy, which outlines the regulations set forth by the DOT in regards to the production and deployment of automated vehicles. In addition to laying down the framework for automated vehicle policy and legislation, the SAE International (SAE) classifications for different levels of automation are explained. SAE is a global leader in the "design, manufacturing, operation, and maintenance of automobiles, aircrafts, space vehicles," and more[5]. The SAE classification levels are as follows[2]:

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SAE Level 0	The human driver does everything
SAE Level 1	an automated system on the vehicle can *sometimes assist* the human driver conduct *some parts* of the driving task
SAE Level 2	an automated system on the vehicle can *actually* conduct some parts of the driving task, while the human continues to monitor the driving environment and performs the rest of the driving task
SAE Level 3	an automated system can both actually conduct some parts of the driving task and monitor the driving environment *in some instances*, but the human driver must be ready to take back control when the automated system requests
SAE Level 4	an automated system can conduct the driving task and monitor the driving environment, and the human need not take back control, but the automated system can operate only in certain environments and under certain conditions
SAE Level 5	the automated system can perform all driving tasks, under all conditions that a human driver could perform them

Within the Federal Automated Vehicles Policy, the DOT classifies SAE Levels 0-2 and Levels 3-5 separately, the distinction lying with whether the driver or the vehicle is principally responsible for monitoring the driving environment. The DOT refers to SAE levels 3-5 as "highly automated vehicles" or HAVs which "can take full control of the driving task in at least some circumstances"[1,2]. A more simple classification method might be to break down vehicles possessing **any** level of autonomy into those that are *semi-autonomous* and those that are *fully autonomous*.

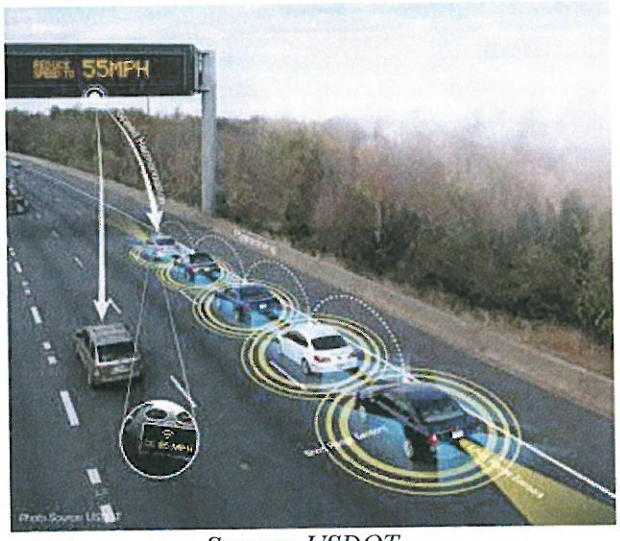
Semi-Autonomous

Semi-Autonomous is defined as "vehicles with advanced technology to communicate with external systems", where primary driving responsibility falls to the driver[21]. The driver must be available to resume full control of the vehicle in certain situations such as adverse weather or rugged terrain. Depending on the car manufacturer, specific semi-autonomous functions can vary by vehicle type and model and may include some of the following:

- Auto-parking/auto-pilot;
- Lane departure/blind spot warning;
- Forward collision warning;
- Pedestrian and bicyclists detection; and
- Traffic sign recognition.

Fully Autonomous

After entering a destination into the navigation system, full operational control is performed by the vehicle, including monitoring of the driving environment. Vehicles are designed to perform all safety critical driving functions in place of a human driver. Also referred to as "driverless" or "self-driving" cars[21].



Source: USDOT

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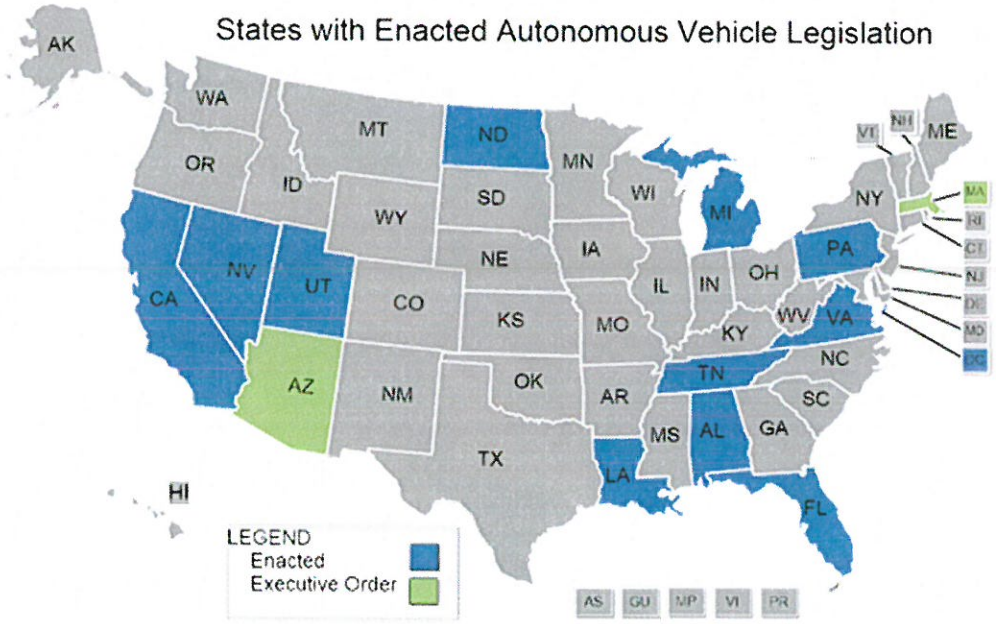
Federal, State & Manufacturer Regulations

Within their policy, NHTSA covers the current federal and state regulations concerning autonomous vehicles in extensive detail. There is only a slight difference between the guidelines set forth for HAVs and vehicles with lower levels of automation, i.e. SAE levels 0-2. With greater automation capabilities naturally comes stricter and more encompassing guidelines. Beyond the standards already set forth within the Federal Motor Vehicle Safety Standards, each state is "responsible for determining liability rules for HAVs and who (owner, operator, passenger, manufacturer, etc.) must carry insurance"[2]. In addition, a jurisdictional committee, involving stake holders and the lead agency primarily responsible for vehicle testing (i.e. state DOT), should be established. For manufacturers of HAVs, NHTSA includes a set of 15 best practices for pre-deployment design and testing such as data recording and sharing procedures, vehicle cyber security and much more. NHTSA also reserves the right to issue recalls on new technology within the vehicles, should they find that it poses "an unreasonable risk to safety"[2]. A safety assessment is requested from all manufacturers that is to include a detailed account of how the technology functions, and how closely the manufacturer followed NHTSA's suggested best practices.

Legislation

The National Conference of State Legislatures States that "each year, the number of states considering legislation related to autonomous vehicles has gradually increased" with 20 states introducing legislation in 2016[24]. The map below displays the eleven states, and D.C. who have enacted autonomous vehicle legislation as recently as February 2017. Currently, 26 states have bills pending that cover a wide range of topics like vehicle testing, requests for studies, and privacy of collected vehicle data. **The state of Connecticut introduced two bills in January 2017, concerning the study and eventual testing of autonomous vehicles, both of which are still pending.**



Source: www.ncsl.org[24]

Connecticut Transportation Safety Research Center

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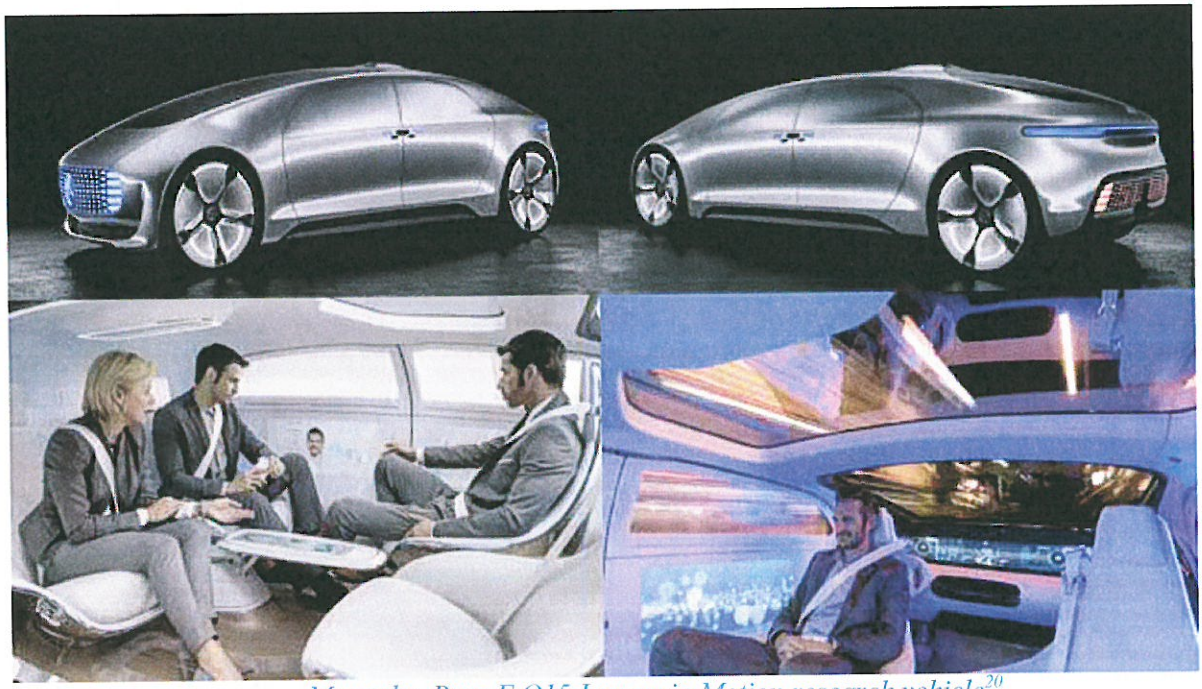
Leading the way for autonomous vehicle legislation in Europe is the UK with their recent Vehicle Technology and Aviation bill. The bill, which is specifically applicable to crashes involving fully driverless vehicles, states that "the insurer whose policy covers the car will be liable" but that the insurer may recover compensation from their policyholder if they can find negligence was involved, i.e. if any alterations were made to the car's operating system or necessary updates failed to be installed[25]. In instances where the vehicle is not insured, the bill states that liability would then fall to the vehicle owner.

Where are they?

Now all of this may sound like some futuristic, *Jetsons*-type of science but many vehicles are already equipped with loads of semi-autonomous features. In fact, very few modern vehicles would even fall into the SAE Level 0 classification because most vehicles are manufactured to assist with at least some portion of the driving, be that cruise control, steering and braking assistance or blind spot detection. Additionally, automotive and technology titans such as GM, Audi, Intel and Google are already testing vehicles with more advanced self-driving features on the roads in California, Nevada, Massachusetts, and Singapore[7,13,14]. Bosch has been on board with driver-less technology for several years, testing vehicles in the U.S. as well as Germany and Japan[16]. Daimler, the same company that makes Mercedes-Benz, launched a production model of a semi-autonomous commercial vehicle on the highway in Germany in October 2015 in a project called Highway Pilot. The company says they "may be ready for real-world application by [as soon as] 2020"[15].



Mercedes-Benz F 015 Luxury in Motion research vehicle[20]

Volvo, a notable leader of intelligent vehicle technologies, currently has vehicles equipped with a host of various automated features on the roads in Sweden. The company's website provides an info-graphic illustrating a timeline of their release of these technological innovations. Beginning

in 2006, with Volvo's introduction of collision and lane departure warning features, the timeline carries all the way through to present day, providing a summary of each new feature released by year. 2012 was an exciting year for the company, bringing the addition of several vehicle features including Park Assist Pilot, cyclist detection with full auto brake, and traffic sign information, which recognizes road signs, like yield and speed limits, and displays them on the vehicle's dashboard[7]. Vehicles equipped with automatic breaking at intersections were released in 2014, a feature that could be particularly beneficial to mature drivers (65+), who research shows have difficulty with turn maneuvers in intersections[9,10,11]. With the driving population steadily aging, these type of innovative developments are crucial and the industry giant shows no signs of stopping[8]. With an estimated 10 million autonomous vehicles expected to be on the road by 2020, Volvo has embarked on a full scale project called Drive Me, in which they ask ordinary families and residents of Gothenburg, Sweden to test drive their autonomous vehicles[12,13].

How can they help?

I will not deny that in the recent years, I was skeptical of new vehicle innovations' potential to increase driver distraction. In fact, around this time last year, I published a blog post questioning whether or not drivers were relying *too* much on vehicle technology and foregoing driving all together. And while this is still a concern of mine, especially in cars with only semi-autonomous capabilities, once I developed a better understanding of all that an autonomous vehicle entails, it became clear to me why traffic safety professionals were embarking down this path. The potential benefits in the area of traffic safety alone are both obvious and plentiful. As I previously mentioned, one benefit is the possibility for the continued mobility of an aging driving population. Mature drivers (65+) are often at a disadvantage in comparison to other drivers because of the strain that declining health can place on the body and mind. At a certain point, it can become incredibly risky for an elderly person to continue operating a vehicle, for both their own safety as well as others on the road, as some of the common challenges they face include pedal errors and slow reaction time[11,19]. However, it is also impractical to assume, or ask, an individual who has been driving for several decades to suddenly never leave their house or become regular users of public transportation. The independence and freedom that accompanies owning your own vehicle is not all that easy to give up. The implementation of fully autonomous vehicles could be the perfect solution to this problem.

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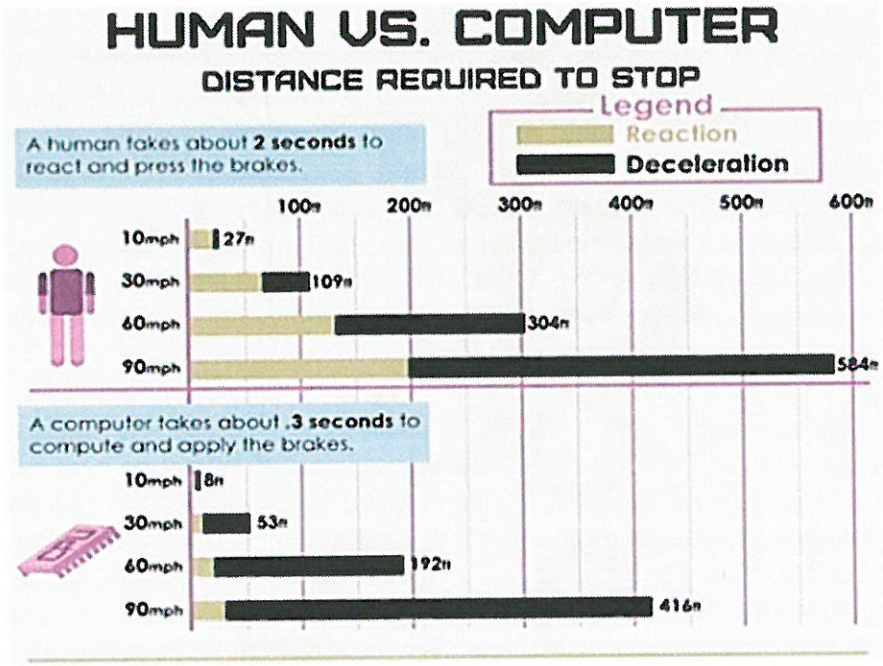
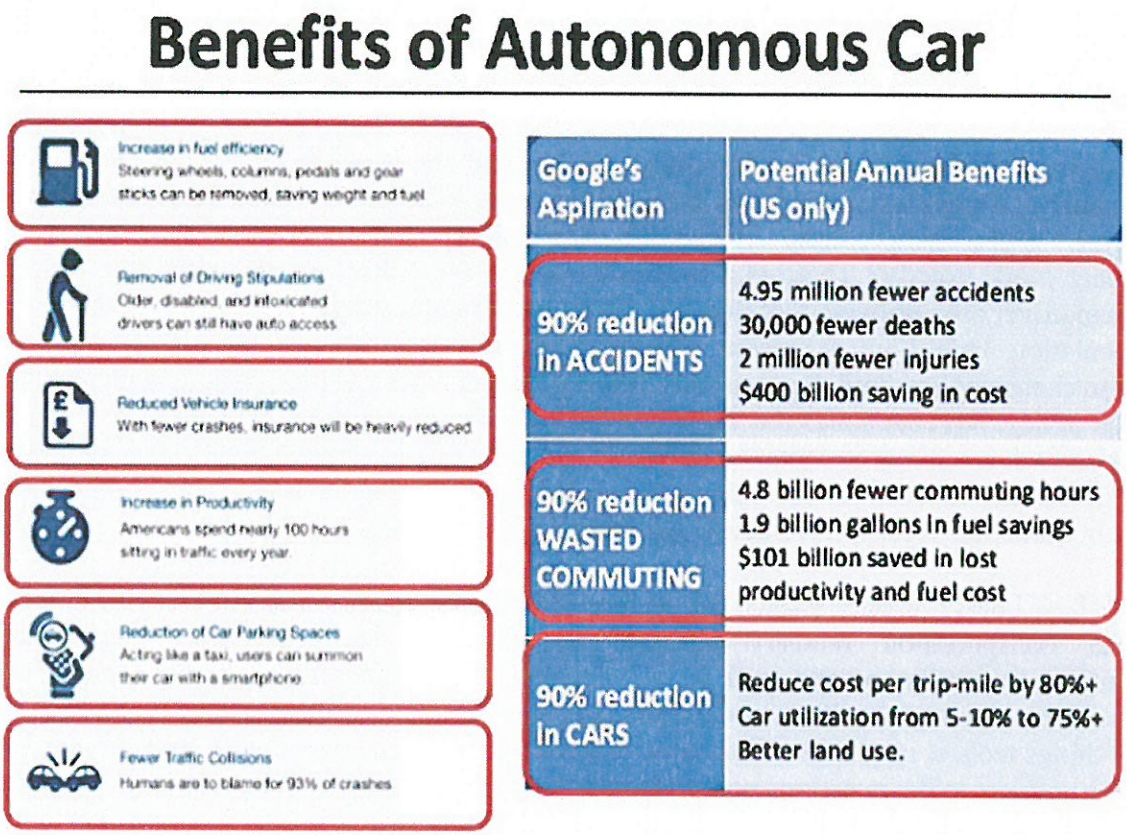
Despite significant advances in the automotive industry, specifically in the area of intelligent vehicle technologies, in 2015 the nation as a whole experienced a spike in crash-related fatalities[6]. Prior to this upsurge, traffic fatalities were on a steady decline for several decades, due in large part to the implementation of safety programs and vehicle improvements[3,6]. It may be a combination of economic, social and environmental variables that contribute to the random spikes sometimes found in crash trends. However, it is well documented within traffic safety research that human error is a factor in over 90% of motor vehicle crashes[4,18]. One of the most glaringly obvious benefits of fully autonomous vehicles is the possibility for the reduction in crashes with the removal of risky driving behavior. Texting, drinking, speeding, falling asleep, and inattentiveness: all factors related to motor vehicle crashes and all behaviors that could be eliminated as crash variables with fully driverless vehicles. Individuals with self-driving cars would be free to engage in these activities without any risk to themselves or other people on the road. Beyond the scope of reducing driver error, intelligent vehicle technology has the potential to greatly impact current economic concerns caused by crashes, for the better. NHTSA reports that in 2010, the total economic costs and value of societal harm from motor vehicle crashes was $836 billion[17]. This estimate includes costs such as medical treatment, workplace losses, legal expenses and loss of quality of life. Fewer crashes could also mean less congestion and pollution, which continues to be a huge environmental concern with the effects of global warming becoming more and more apparent. Lastly, autonomous vehicles, whether semi or full, will also begin to change the way the world drives. This could lead to design changes in our infrastructure, which could benefit other areas or groups of transportation such as pedestrians and bicyclists, by creating more room for them to maneuver safely.





Ref: http://www.carloan4u.co.uk/infographics/the-ultimate-car-of-the-future/
Google, US NHTSA, AAA, Texas A&M Transportation Institute, Columbia University Earth Institute and Devil's Advocate Group's analysis

How can they hurt?

Above are just a few of the potential big picture impacts autonomous vehicles could have. However, with more inquiry comes more questions. One of the primary challenges facing the deployment of fully autonomous vehicles is trying to define what the exact "rules of the road" will be with a mixture of vehicles with differing levels of automation or none at all[21]. The first incident involving a fatality and a semi-autonomous vehicle occurred in Florida in May of 2016[23]. Although a thorough investigation into the death revealed the autopilot technology in the Tesla Model S was working correctly at the time of the crash, many are understandably concerned about something like this happening again. Perhaps training of owners of vehicles with more advanced levels of automation will be necessary, to ensure that the vehicle functions are used safely and correctly. In that same line of thinking, vehicles equipped with intelligent technology are essentially computers, developed by humans. So the potential for malfunctions, even minor ones, is unfortunately always there. Also, fully autonomous vehicles are meant to execute all driving functions as a human being would do. However, when a human is driving, they have to make split second decisions sometimes to avoid collisions. With a self-driving car, "controlled by algorithms, it is a choice predetermined by a programmer"[22]. So how can one *always* predicted what will happen when these programmed smart cars interact with human drivers and their risky driving behaviors? Some things unfortunately cannot be programmed.

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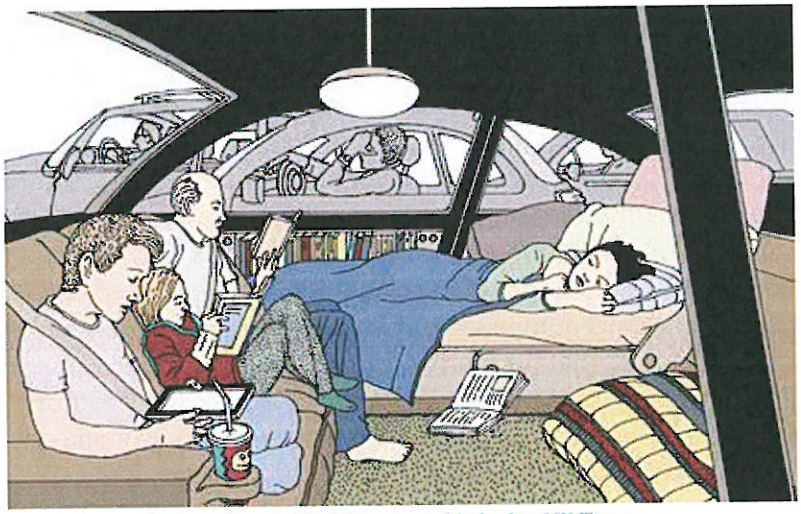
At this time, the current infrastructure is not equipped to support fully autonomous vehicles, and with this great of a change, it is natural to assume that eventually those design changes will need to be made. What affect will the added costs of infrastructure changes to accommodate these vehicles have? The end result, as I mentioned earlier, could be very positive for non-motorists but we also have to consider the journey to get to that end result and what exactly that will entail. Additionally, if drivers are not doing the actual *driving*, then who's at fault in the event that there *is* a crash? Will owners of these vehicles still need to obtain *driver's* licenses? And how would car insurance work exactly? There is a possibility that if the unknowns and risks that accompany a human driver are removed, that insurance rates would reduce significantly, but at this point this is speculation. Things are, at present, unclear and the insurance industry most likely won't make a move to change policy until they can fully assess potential repercussions. Within in their automated vehicle policy, NHTSA states the "rules and laws allocating tort liability could have a significant effect on both consumer acceptance of HAVs and their rate of deployment"[2]. It may be that the level of liability reduces for the vehicle owner but increases for the manufacturer, but this could result in numerous lawsuits eventually bankrupting companies.

All of these questions only scratch the surface of potential benefits and conflicts that could arise as the transportation industry attempts to navigate the preliminary stages of this revolution. Generally, people tend to feel uncomfortable relinquishing control and in a fully autonomous vehicle, most if not all control is given up. So while we seem to be living in the world of all things tech, it may take a little time to garner public acceptance with fully driverless cars. Getting answers to the questions posed above is an important step in that process. However, it can be difficult to develop policies and regulations for the unknown. It is only after extensive research and testing of these features for their real world implications, that more concrete guidelines can be set. But as it has been done in the past with every new innovation, the top safety professionals will continue to probe, discuss, and strategize until they reach a conclusion that is in the best interest of the entire transportation community and I will continue to update you along the way.

Could the future of intelligent vehicle technologies look something like this...?



Source: Steven M. Johnson, published in NY Times

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Sources:

1. National Highway Traffic Safety Administration. (2017). Automated Vehicles. [Online]. https://www.nhtsa.gov/technology-innovation/automated-vehicles. Accessed: Feb. 2, 2017.
2. National Highway Traffic Safety Administration. (2016). Federal Automated Vehicles Policy: Accelerating the Next Revolution In Roadway Safety.[PDF]
3. Fisher, D., Lohrenz, M. Moore, D., Nadler, E., & J. Pollard. (2016). Humans and Intelligent Vehicles: The Hope, the Help, and the Harm. *IEEE Transactions on Intelligent Vehicles* 1(*1*).
4. Singh, S. (2015, February). Critical reasons for crashes investigated in the National Motor Vehicle Crash Causation Survey. (Traffic Safety Facts Crash Stats. Report No. DOT HS 812 115). Washington, DC: National Highway Traffic Safety Administration.
5. SAE International (2017). http://www.sae.org/. Accessed Mar. 3, 2017.
6. National Highway Traffic Safety Administration. (2016). Traffic fatalities up sharply in 2015. [Online]. https://www.nhtsa.gov/press-releases/traffic-fatalities-sharply-2015. Accessed: Mar. 13, 2017.
7. Volvo IntelliSafe. (2017). Autopilot. [Online}. http://www.volvocars.com/au/about/innovations/intellisafe/autopilot. Accessed: Mar. 15, 2017.
8. Ortman, J.M., Velkoff, V.A., and Hogan, H. (2014). An Aging Nation: The Older Population in the United States. *U.S. Department of Commerce, Economics and Statistics Administration.* U.S. Census Bureau. https://www.census.gov/prod/2014pubs/p25-1140.pdf. PDF File. Accessed Mar. 15, 2017.
9. Garber, N.J. and Srinivasan, R. (1991). Risk assessment of elderly drivers at intersections. *Transportation Research Record*, 1325, 17–22.
10. Mayhew, D.R., Simpson, H.M., and Ferguson, S.A. (2006). Ćollisions Involving Senior Drivers: High-Risk Conditions and Locations. *Traffic Injury Prevention*, 7(*2*), 117-124.
11. Cicchino, J.B., and McCartt, A.T. (2015). Critical older driver errors in a national sample of serious U.S. crashes. *Accident Analysis & Prevention, 80,* p. 211-219.
12. Fingas, J. (2017, Jan 9). Volvo is testing self-driving cars with real families. *Engadget.* Retrieved from https://www.engadget.com/2017/01/09/volvo-tests-self-driving-car-with-real-family/. Accessed: Mar. 15, 2017.
13. BI Intelligence. (2016, Jun. 15). 10 million self-driving cars will be on the road by 2020. *Business Insider.* Retrieved from http://www.businessinsider.com/report-10-million-self-driving-cars-will-be-on-the-road-by-2020-2015-5-6. Accessed: Mar. 15, 2017.
14. Mercer, C. (2017, Mar. 14). 11 companies working on driverless cars: Volvo, Google, Tesla and more are investing in autonomous vehicles. *Techworld.* Retrieved from http://www.techworld.com/picture-gallery/big-data/-companies-working-on-driverless-cars-3641537/. Accessed: Mar. 15, 2017.
15. Logan, B. (2015, Oct. 5). Mercedes-Benz's self-driving big-rig proves that autonomous vehicles are coming sooner than we think. *Business Insider.* Retrieved from http://www.businessinsider.com/mercedes-self-driving-big-rig-on-a-public-highway-2015-10. Accessed: Mar. 15, 2017.
16. Muoio, D. (2016, Aug. 18). These 19 companies are racing to put driverless cars on the road by 2020. *Business Insider.* Retrieved from http://www.businessinsider.com/companies-making-driverless-cars-by-2020-2016-8/#volvo-is-aiming-to-make-its-cars-deathproof-by-2020-by-rolling-out-semi-autonomous-features-in-its-cars-eventually-working-up-to-fully-driverless-ones-6. Accessed: Mar. 15, 2017.
17. National Center for Statistics and Analysis. (2017, February). *Summary of motor vehicle crashes (Early edition): 2015 data.* (Traffic Safety Facts. Report No. DOT HS 812 376). Washington, DC: National Highway Traffic Safety Administration.
18. Treat, J. R., Tumbas, N. S., McDonald, S. T., Shinar, D., Hume, R. D., Mayer, R. E., Stanisfer, R. L. and Castellan, N. J. (1977) Tri-level study of the causes of traffic accidents. *Report No. DOT-HS-034-3-535-77 (TAC).*
19. Freund, B. & Smith, P. (2011). Older Drivers. In B.E. Porter (Eds.), *Handbook of Traffic Psychology* (339-352). London, UK: Elsevier, Inc.
20. Mercedes-Benz. (2017). The Mercedes-Benz F 015 Luxury in Motion. Retrieved from https://www.mercedes-benz.com/en/mercedes-benz/innovation/research-vehicle-f-015-luxury-in-motion/. Accessed: Mar. 16, 2017.
21. Arseneau, B., Roy, S., Salazar, J., and J. Yang. (October, 2015). Autonomous and Connected Vehicles: Preparing for the Future of Surface Transportation. *HDR, Inc.* [PDF]. Accessed: Mar. 17, 2017.
22. Boudette, N. (2016, Jun. 4). 5 things that give self-driving cars headaches. [Online]. Retrieved from https://www.nytimes.com/interactive/2016/06/06/automobiles/autonomous-cars-problems.html. Accessed: Mar. 17, 2017.
23. NHTSA. (2017, Jan. 19). Automatic vehicle control systems. [Online]. Retrieved from https://static.nhtsa.gov/odi/inv/2016/INCLA-PE16007-7876.PDF. Accessed: Mar 17, 2017.
24. National Conference of State Legislatures. (2017, Feb. 21). Autonomous Vehicles/Self-Driving Vehicles Enacted Legislation. [Online]. Retrieved from http://www.ncsl.org/research/transportation/autonomous-vehicles-self-driving-vehicles-enacted-lNegislation.aspx. Accessed: Mar. 20, 2017.
25. Coates, C. (2017, Mar. 17). UK bill to set a precedent from autonomous car legislation. [Online]. Retrieved from https://www.dwf.law/news-events/legal-updates/2017/03/uk-bill-to-set-a-precedent-for-autonomous-car-legislation/. Accessed: Mar. 21, 2017.