AN EXPLORATORY DISCUSSION OF THE IMPACTS OF DRIVERLESS VEHICLE OPERATIONS ON THE MAN-MADE ENVIRONMENT

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Abstract: - This paper explores the impacts that driverless vehicles are likely to have on the man-made environment namely, the highway infrastructure, other (traditional) vehicles on the road, pedestrians, energy use, land use, safety of the driver and other passengers, and the general driving environment. The paper first briefly tracks the history of development of driverless vehicles. Then it discusses the developmental impacts in terms of vehicle weight reduction, change in land use, longer commute distances/times, increased need for parking infrastructure, and increase in vehicle trips. The effects of these developments are discussed in terms of the overall performance criteria, including energy use, safety, emissions, noise, and traffic volume. The report also discusses the intersection delay impacts, vehicle size impacts, impact on pedestrians and traditional vehicles in the traffic environment, and impacts on the physical driving environment (road infrastructure), and briefly touches on other impacts related to public transportation, security, and the economy.

Key-Words: - Driverless vehicles, self-driving vehicles, autonomous vehicles

1 Introduction
A driverless vehicle is referred to as a vehicle that can operate without the need for a driver. Synonyms include: robotic vehicles, autonomous (or automated) vehicles, and self-driving vehicles. Driverless vehicle operations involve sensor-based equipment that use cameras, artificial intelligence based image detection algorithms to develop (and interpret) in real time a three-dimensional characterization of the physical conditions around the vehicle. In the United States, the National Highway Traffic Safety Administration (NHTSA) has established an official classification system for defining different levels of autonomy: Level 0 – the driver completely controls the vehicle at all times; Level 1 – the individual vehicle controls (such as electronic stability control and automatic braking) are automated; Level 2 – at least two controls can be automated in unison, such as adaptive cruise control in combination with lane keeping; Level 3 – in certain conditions, the driver can fully cede to the vehicle, the control of all safety-critical functions; the vehicle can sense when conditions require the driver to retake control and provides a sufficiently comfortable transition time such transfer of control; and Level 4 – the vehicle performs all safety-critical functions for the entire trip including parking; the driver is not expected to control the vehicle at any time [1].

The concept of driverless automobiles was born in December 8, 1926 in Wisconsin when a driverless car was tested on a Milwaukee road. It is not certain whether that test was successful. Efforts towards driverless vehicle development slowed during the Second World War but were ramped up in the 1950’s through research experiments. Thirty years later, in 1984, the first self-driving car was developed, a result of the Autonomous Land Vehicle (ALV) project carried out by Carnegie Mellon University’s Robotics Institute Navigation Laboratory in Pennsylvania. This vehicle successfully completed several test runs. In 1987, Dr. Ernst Dickmanns at University of Bundeswehr, Munich, in collaboration with the Mercedes Benz automobile company, carried out a similar experiment successfully. Since then, other similar driverless-car prototypes have been developed by research institutions including Oxford University in UK, University of Parma I in Italy, and the Massachusetts Institute of Technology, and by companies including Mercedes-Benz, General Motors, Toyota, Google, Nissan, and Volvo.

The trends towards driverless vehicles has been (and will continue to be) evolution and incremental. At the current time, most vehicles
incorporate some advanced features that are part of this trend: automatic anti-lock braking systems, electronic stability control systems, rear-movement collision avoidance and warning systems, and lane-guidance systems. Over the next decade, it is expected that driving functions will increasingly become even more automated. It is expected that driverless operations on limited-access highways will soon be permitted for luxury vehicles that currently have or are expected to have such automated functions. According to a USDOT report, fully-automated driving, a driver is no longer needed to steer or adjust speed, could be commercially available within the next 20 years [2].

In response to these trends and expectations, governments in a number of countries have proactively supported or permitted the testing and use of driverless vehicles on public roads through policy and legislation. In Germany, Spain, and the Netherlands, the governments have granted permission for testing autonomous cars in real traffic. Also, a project funded by the European Union has selected five cities in UK, France, Italy, and Belgium for establishing systems to support driverless vehicles. In certain states of the United States (Nevada, Florida, California and Michigan), laws have been passed to permit the operations or testing of driverless vehicles on public roads; it is expected that by 2016, the governments of France and other European countries will allow the testing of autonomous cars on specific public roads in the country. In the United Kingdom, the government has recently given its blessings for a £19 million testing effort at Greenwich, Milton Keynes and Coventry, and Bristol [3]. In Ann Arbor, Michigan, a 32-acre spread has been dedicated to the testing of driverless vehicles, particularly, their software and sensors, through repeated real-life simulations of different scenarios. In Singapore, the MIT-Singapore Alliance for Research and Technology is currently testing a fleet of driverless vehicles in residential areas this year to gage public reaction, and Nanyang Technological University, JTC Corporation, and Induct Technologies are carrying out joint tests of driverless vehicles that shuttle passengers between the campus and research park.

As this paper seeks to examine the impact of driverless vehicles on the man-made environment, it is important to define what the man-made environment means, from the perspective of this paper. We define the man-made environment to include the highway infrastructure, buildings, other (traditional) vehicles on the road, pedestrians, energy use, land use, safety of the driver and other passengers, and the general driving environment.

2 The Expected Impacts of Driverless Vehicles on the Environment

The expected impacts of driverless vehicles on the environment can be illustrated using Figure 1. We now discuss each of these impacts. In the discussion, we duly recognize that driverless impacts may lead to disparate events that may have opposite effects in terms of some of the impact criteria, and that the net effect will depend on the individual contributions of each event.

![Figure 1. Expected Impacts of Driverless Vehicles](image)

**2.1 Safety Impacts**

In the United States, motor vehicle crashes are the leading cause of persons 1-34 years of age. The total societal cost of crashes exceeds $230 billion annually [4]. In 2012, over 33,000 people were killed, 2.3 million people sustained injuries, and property worth several billions of dollars was damaged in motor vehicle crashes [5]. For a vast majority of these crashes, human error has for a long time, been (and continues to be a contributory factor. As far back as the seventies, it was found that human factors were a probable cause in 92% of accidents [6]; in the eighties, it was reported that human actions are a sole or contributory factor in 90–95% of all accidents [7]; Other studies have reported that 45-75% of all crashes are caused by...
human (driver error) [8]; that the driver error contributes to as much as 75% of all roadway crashes [9]. These conclusions are similar to the findings by other researchers [10, 11]. As shown in Figure 2, the distribution of road accident causes in the United States is heavily skewed to the driver 5, [12]. In the figure, the share of crashes not attributable to any of these three factors can be considered to be 1%.

2.2 Effects of Vehicle Weight Reduction
The notion that driverless vehicles will lead to increased safety is reasonable and will incentivize auto makers to reduce the weight of their vehicles as there will be little need to continue arming the vehicle occupants from injurious crash impacts. This, however, is a double-edged sword: if there is a crash, however unlikely, due to in-vehicle computer error for example, the severity will be greater than the case for traditional vehicles due to the lack of armor. Other impacts of lighter vehicles (compared to traditional vehicles) include reduced emissions and noise, increased fuel efficiency, and reduced energy use. A number of studies have projected that the much lighter driverless vehicles would drastically increase energy efficiency of vehicles.

2.3 Change in Land Use
For the passengers of driverless vehicles, the time during the travel will be freed up to engage in some productive activity (such as reading or working on the way to work) or sleeping (on the way from work) while they are being driven. Therefore in-vehicle travel time will no longer be as great a burden as it is now. Thus, residential locations that are currently considered remote will make become more attractive and there will be a change in land use patterns as more agricultural or unused land far from the city centers are converted to residential use and other related land uses.

2.4 Longer commute distances/times
As noted in the section above, driverless vehicles will likely change where people live and the distances they are willing to travel. From this perspective specifically, there will be an increase in vehicle miles of travel, fuel consumption and emissions.

2.5 Increased Need for Parking Infrastructure
After dropping off their passengers at their destinations, driverless cars will likely not return to their bases (residences of their passengers) but will be programmed to seek parking until such time that their owner needs them again to return home or go to some other location. As a result, there will be increased need for parking infrastructure not necessarily in the vicinity of the destination (typically, their office) but at a reasonable distance away. Unlike the case of transitional vehicles, there will little or no desire to minimize the distance between their parking garage/lot and the passenger destination. The development of the parking
infrastructure can degrade or enhance the visual appeal of urban environment and landscape.

2.6 Increase in Vehicle Trips
A large percentage of vehicle trips are made by persons who do not derive direct personal benefits from the trip but undertake the trip so that others can benefit. Examples include drivers who drive children to school; and the infirm (elderly, sick or disabled persons) to hospitals or other activity centers. For example, 5-10 million people do not drive due to disabilities [2]. Such persons could be put in a driverless vehicle and sent to their destinations without a driver at the wheel. Thus, driverless vehicles are expected to lead to an increase in traffic volumes.

With increased traffic volume, there will be concomitant effects such as increases in fuel consumption, emissions and noise, congestion, and crash exposure. For each of these performance criteria, the net effect could be beneficial or adverse depending on the effects of other events in terms of these criteria.

The notion that driverless vehicles will cause a net increase in vehicle trips in a contentious one, as several proponents of the concept have made earnest efforts to link driverless vehicles with reduced traffic volumes in a bid to link driver vehicles with the virtues associated with traffic volume reduction. The fact is that driverless vehicles will cause decrease traffic volumes if it is implemented in sync with car sharing programs; but the same is true for traditional vehicles in the current situation: car sharing programs do (and will) reduce traffic volumes as has been demonstrated in past research.

On the other hand, if it can be shown that driverless vehicles plus car sharing programs lead to a greater reduction in traffic volume compared with traditional vehicles plus car sharing, then a better case can be made for driverless vehicles in this regard; at least one researcher seems to share the view that driverless cars could make car-sharing more popular and thus lead to fewer vehicles on the road [14, 15]. In other words, if driverless vehicles, by virtue of their features, are inherently more favorable for car sharing, then it can be expected that driverless vehicles will be associated with some degree of traffic volume reduction. However, the net effect of this decrease and traffic volume increase due to increased travel demand (as discussed in a section above) could be in either direction and is uncertain at this point.

2.7 Overall Impacts in Terms of Energy Use, Safety, Emissions, Noise, and Traffic Volume
The overall change in energy use will be a net effect of the opposing effects of lighter vehicles (will reduce consumption), longer commute distances/times (will increase consumption), and increased traffic volumes (will increase consumption).

The overall change in safety will be a net effect of the opposing effects of lighter vehicles (will cause increased crash severity if a crash occurs), increased traffic volumes (will cause increased exposure to crashes) and removal of the driver-error factor of crash (will cause reduced crash propensity).

The overall change in emissions and noise will be a net effect of the opposing effects of increased traffic volumes (will cause an increase in emissions and noise), lighter vehicles (will cause reduced emissions and noise).

Also, as noted in the section above, the overall change in traffic volume will be a net effect of the opposing effects of decreased traffic volume (due to car sharing, relative to car sharing with traditional vehicles) and increased traffic volumes due to increased travel demand (as persons not eligible for traditional vehicle driver licenses become empowered to undertake trips).

2.8 Intersection Delay Impacts
By removing the element of human behavior at urban intersections, it is expected that driverless will significantly reduce delay at such locations, resulting in decreases in fuel consumption and emissions. Researchers have used agent-based game theory modeling for driverless vehicles at intersections [16]; they controlled vehicle trajectories using Cooperative Adaptive Cruise Control (CACC) systems to avoid collisions and minimize intersection delay and carried out computer simulations to compare conventional signal control with CACC, and demonstrated potential 91% and 82% savings in delay and fuel consumption respectively, relative to conventional signal control.

2.9 Vehicle Size Impacts
As commute times become longer and the driving task is eliminated, it is expected that travelers will seek to undertake a wide range of activities in their vehicles as they drive from their residences to work or from their workplaces and other destinations to their residences. On the way to work, some may seek to utilize this time to have breakfast, listen to
the news, or get a head start on their activities for the day. On the way from work, some may seek to rest (take a nap), finish up their work for the day, or relax by having online visual chats. As such, travelers will seek to have a more conducive environment where these activities can be carried out. More comfortable and productive workspaces will be sought after in the vehicle, and the installation of coffee makers, kitchenettes, mini offices, communication equipment and screens, and entertainment consoles will become standard features in vehicles. As such, larger vehicles are expected to dominate the general driving environment, as earlier noted by at least one researcher [17].

2.10 Impact on Pedestrians and Traditional Vehicles in the Traffic Environment
Pedestrians are a critical component of the driving environment, as such a discussion of the impact of driverless vehicles on pedestrians is vital. In the current age of traditional vehicles, there are often informal gestures and non-verbal communication and cues between the drivers of traditional vehicles and pedestrians. The advent of driverless vehicles could diminish such communication and may render pedestrians less safe. On the other hand, because driverless vehicles are not subject to human driver error due to fatigue, stress, and other factors, they are inherently safer and are less likely to inadvertently crash with pedestrians.

2.11 Impacts on the Physical Driving Environment (Road Infrastructure)
The current highway infrastructure is designed for human drivers who can be subject to a variety of errors due to distraction, fatigue, inexperience and other factors; thus the infrastructure is designed, even if indirectly or implicitly, to accommodate such foibles of human nature. For example, carriageways and shoulders are assigned widths far beyond vehicle widths and safety features such as rumble strips, median cables, guardrails, and slowdown and other warning devices are provided in cognizance of the imprecise and often errant nature of human driving. Thus, driverless vehicles are expected to lead to a reduction of infrastructure capacity and elimination of certain features. However, it may also lead to addition of certain new infrastructure (such as roadway installed sensors) that will be more consistent with driverless vehicle operations.

2.12 Other Impacts
Researchers have stated that driverless vehicles will likely lead to less desirability of public transportation [18]. Related to this possibility, it has been cautioned that emphasis on planning solutions centered around driverless vehicles may serve as a disincentive to communities from implementing conventional but cost-effective initiatives including pedestrian and transit improvements, pricing reforms, and other demand management strategies [15].

Also, there will be a reduction in job opportunities for drivers. The increased safety offered by driverless vehicles may encourage their passengers to travel in conditions that may be unsafe, due to risk compensation behavior; if this happens, driverless vehicles could cause an overall net reduction in safety. A few researchers have also cited possible reduction in passenger security and privacy. Driverless vehicles may be attractive to malicious individuals who might view these vehicles as a non-traceable opportunity for carrying out criminal or terrorist activities including anonymous delivery of harmful devices or materials. Also, the mélange of computers aboard a driverless vehicle makes it an attractive target for persons who seek to acquire or abuse the information they contain.

Other issues related to the environmental and wider impacts of driverless vehicles include the liability for damage in case of crashes, reliability of in-vehicle software and sensors, the possibility that in situations of software/sensor failure, the passengers are unable or ineligible to take over the driving task from the vehicle, availability of high-quality and updated digital maps in the vehicle’s computer to make navigation more reliable.

3 Discussion and Concluding Remarks
This paper explored the impacts that driverless vehicles are likely to have on the man-made environment namely, the highway infrastructure, other (traditional) vehicles on the road, pedestrians, energy use, land use, safety of the driver and other passengers, and the general driving environment.

The paper first briefly tracks the history of development of driverless vehicles. Then it discusses the developmental impacts in terms of vehicle weight reduction, change in land use, longer commute distances/times, increased need for parking infrastructure, and increase in vehicle trips. The effects of these developments are discussed in terms of the overall performance criteria, including
energy use, safety, emissions, noise, and traffic volume. The report also discusses the intersection delay impacts, vehicle size impacts, impact on pedestrians and traditional vehicles in the traffic environment, and impacts on the physical driving environment (changes required in physical road infrastructure), and other impacts related to public transportation, security, and the economy (reduction in driving-related jobs).

The most significant impact of driverless vehicles is expected to be in the safety area. While it is true that the sensors and algorithms could function more efficiently than a human driver in a state of stress, distractedness, fatigue, and so on, the fact remains that there are certain qualities of the human brain that is still superior. Schumacher, as cited in the literature [19], stated that in perceiving the external environment, the human brain can “see” and “interpret” the vehicle’s surroundings in ways that are far beyond the capability of available sensors and artificial intelligence. Stating that “humans use a combination of stored memories and sensory input to interpret events as they occur and anticipate likely scenarios,” Schumacher offered one of many examples that characterize real-life vehicle operations: if a ball were to roll onto a road in front of a vehicle, the human driver will likely brake in expectation that a child is following the ball while artificial intelligence lacks such a level of inferential thinking, nor can it communicate in real time with the environment.

Overall, researchers have cautioned that driverless vehicle implementation does not fundamentally change how we define transport problems but rather tends to reinforce the existing automobile-oriented planning paradigm (Litman, 2015). Also, the changes that will accompany the impacts of driverless vehicle operations will be expected to have significant impacts from the perspective of the social, legal and financial environment.

References:
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