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Holistic Review of the Implications of Autonomous Vehicles

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ABSTRACT

We are at the advent of a fourth industrial revolution, where autonomous vehicles (AVs) are a major pillar brought by this new wave. We can already observe the impacts of AVs, especially in changing behavior in drivers, as highlighted by statistics on attentiveness by Tesla drivers. There are six levels of AVs, ranging from levels 0-5. Level 0 AVs have no autonomous features, while level 5 AVs can navigate without any human intervention. This paper will focus on the implications and impacts that level 4 or 5 AVs would have on different facets of society (e.g., mobility, environment, public health, infrastructure, economy, public behavior, and equity). Information reported in this paper was searched for via a four-step process broken down into finding keywords, searching for papers with such keywords in Google Scholar, filtering said papers and reports based on certain criteria, and finally reporting the found information. The paper includes a literature review that summarizes current predictions or patterns on the implications and impacts of AVs. Additionally, this paper provides suggestions for policies and planning for implementing high-level AVs into our current society, highlighting how to properly optimize the benefits AVs could bring and discussing social norms that could be a barrier to implementation.

Introduction

Throughout history, emerging technologies have always directed the development of society and humanity. Today, we still live through the effects of the First Industrial Revolution. For instance, infant mortality rates worldwide have been exponentially growing from the increased standard of living from the massive increase in productivity provided by automated factories [1]. We also still suffer from the environmental effects of the First Industrial Revolution. Compared to preindustrial surface temperatures, surface temperatures in 2015 have increased by 1°C. Additionally, the average global CO2 concentration was 120 ppm above preindustrial levels at 399.4 ppm.

Furthermore, the First Industrial Revolution spurred a massive increase in Earth's atmospheric nitrogen deposition [2]. We are living in the Fourth Industrial Revolution, where industrial and domestic devices worldwide are interconnected, allowing the instantaneous control and extraction of data [3]. Autonomous vehicles (AVs) are a significant part of this industrial revolution as they will replace conventional manual vehicles. Especially in the 2010s and later, major tech organizations have been developing and releasing their versions of AVs. Google began testing one of its AVs, a modified Lexus sport utility vehicle, in Austin, Texas, in the summer of 2015 [4]. As of October 2015, Tesla released the Autopilot feature to the general public in their Model S vehicles. Over time, Telsa implemented the software into other Tesla vehicles like the Model 3. Despite the relatively short time that Tesla's Autopilot software has been accessible to the general public, behavior in Tesla drivers has significantly changed after exposure to the self-driving ability provided. For example, with Autopilot engaged, Tesla drivers have a 36% proportion of off-road glances compared to a 24% of off-road glances without Autopilot engaged. Additionally, 33% of Tesla drivers do not grip the steering wheel while Autopilot is engaged [5]. As AVs develop even more and become ever popular, AVs will influence not only road behavior but other facets of society as mobility is tightly intertwined with the economy, environment, general health, etc.

AVs fall into six levels defined by the SAE International J3016 standard [6]. These levels range from 0 to 5, indicating an AV's autonomy. Level 0 vehicles have no AV features at all. There is a concern for levels 1 and 2 AVs with the vehicle's number of autonomous features (e.g., lane-keeping systems, adaptive cruise control). Level 1 autonomous vehicles only have one autonomous feature, while level 2 autonomous vehicles have two. From level 3 onwards, AVs are categorized by human interaction. Level 3 AVs can complete most driving tasks; however, in some cases require human interference. For instance, humans may need to control the vehicle themselves in unideal road conditions or navigation in rural areas. Level 4 AVs are fully autonomous, but humans can intervene with the vehicle's motion at their will. Finally, level 5 AVs are fully autonomous [7, 8].

Research Question and Overview

This paper reviews the implications that higher-level AVs, mainly level 5 AVs, could have on our current and future world. Following this introductory section is the methodology section, where a brief overview of this paper's research and writing process is presented. Next, the literature review is organized into sections based on AVs' impact (e.g., Mobility, Public Health, Environment). Then, there is the discussion section, which provides a holistic view of the impact of AVs and suggests policies and considerations that should be taken to implement higher-level AVs into society effectively. Finally, the Conclusion summarizes the study as a whole and points out several recommendations for future study.

Methodology

The methodology is structured into four steps - keywords, search, filter, and report. For the first step, keywords, a list of keywords that would later be used to search for papers and articles was created. This paper's scope is on the general impacts of AVs on society, including mobility, public health, environment, economy, people's rights and access to things, and infrastructure. Therefore, the keywords were "autonomous vehicles," "autonomous vehicles impacts," "autonomous vehicles impact on society," "autonomous vehicles impacts on economy," "autonomous vehicles impacts on environment," "autonomous vehicles impacts on health," etc. After a list of keywords was produced, in the search step, those keywords were used to search for papers on Google Scholar. Then, in the filter step, papers were selected for review if they were published during or after 2014 to keep relevance since the field of autonomous vehicles is ever evolving rapidly. The study or model locations in the filtered papers are not considered criteria because this paper covers the implications of AVs globally. Finally, in the report step, the selected papers were analyzed individually, and their results and models are reported in this review paper. During the writing of this paper, additional keywords had to be searched on Google Scholar for specific statistics or studies, repeating the four-step process.

Literature Review

Overview

This literature review will focus on the implications of AVs on broad individual scopes: environment, public health, economy, mobility, infrastructure, and social habits and equity. In addition, the implications reported in this paper refer to the implications of level 4-5 AVs projected in models and early testing of level 4-5 AVs.

Mobility

On-Demand Mobility

On-demand mobility (ODM) is on-demand transportation via shared vehicles. Companies specializing in ODM, like Uber and Lyft, are trying to integrate AVs with ODM, allowing almost every demographic to access cheap instant transportation [7]. Additionally, to promote a generally healthier traffic flow, the implementation of ridesharing, ODM with multiple passengers, with AVs has been considerably encouraged. Ridesharing has also become popularized as it is economically attractive since the passengers split the trip fare [11]. However, the general public has yet to accept ODM and AVs as the technology is dehumanizing and difficult to trust [33].

Traffic Flow

With AVs, private ownership seems attractive to consumers, and as for ODM, many consumers would prefer single-occupant commutes [34]. As a result, the fleet size would significantly increase, leading to more congestion, longer commute times, etc. [35]. Additionally, as passengers are not required to drive anymore with AV technology, trips will become longer, increasing vehicle miles traveled (VMT) [36]. Since ODM with AVs will likely be cheaper than current ODM as passengers do not have to compensate the driver financially, ODM may potentially convert commuters who own private vehicles to habitual ODM consumers. Despite the financial incentive brought on by ridesharing, the privacy of single-passenger ODM will be significantly preferred [37]. However, if appropriately implemented, ridesharing has the potential to become more attractive. With ridesharing, the fleet size is reduced by 9-11 vehicles per shared vehicle, but VMTs increase by 10% [12, 40]. Other models project that ridesharing will decrease the total fleet size by 90% [41]. Singapore has implemented level 4+ AVs into its road systems since 2015, leading to a 15% reduction in vehicle ownership in 3 years, bolstering traffic flow [42]. Automated parking from shared vehicles for ODM being on standby or AV owners leaving their vehicles to park as they engage in other activities will increase VMTs and congestion in parking lots and urban areas [38, 39]. Parking in large urban areas will also become increasingly difficult from a larger fleet size, increasing congestion. However, optimistically, it is projected that with ridesharing, up to 8 parking spaces will be saved with a single shared AV, significantly improving congestion in urban areas and minimizing land and infrastructure for parking [40]. Finally, with the smooth driving of AVs combined with automated platooning, fewer accidents are prone to happen on freeways, greatly reducing commute time. As a result, freeway capacity would increase by 30% [43]. However, as mentioned in the introduction, driver behavior will change, resulting in careless driving from human drivers. Additionally, AVs in unfamiliar conditions like extreme weather, rural roads, and complex urban areas may struggle, inducing more accidents and longer commute times in these conditions, ultimately leading to clogs in traffic flow.

Environment

Exhaust Emissions

Major AV developers (e.g., Tesla, Waymo, etc.) are developing their AVs as electric vehicles (EVs). Relying on these vehicles will lead to an overall decrease in air pollution and the release of CO_2 and black carbon emissions that contribute to climate change [9]. Including emissions from vehicle production, compared to gasoline vehicles, assuming a vehicle lifetime of 200,000 kilometers, EVs have a 27-29% decrease in global warming potential [10]. Along with a low-carbon electricity grid, ridesharing with electric AVs is estimated to reduce per-mile greenhouse gas emissions by up to 90% [11]. Moreover, AV usage cuts the resultant emissions from cold starts by 85-95% [12, 13]. Additionally, if coupled correctly with PT, along with ridesharing, AVs have the potential to further reduce the release of exhaust emissions by further decreasing fleet size and reducing traffic congestion and accidents.

Non-Exhaust Emissions

Despite a net reduction in the rate of air pollution from the adoption of electric or alternative fuel AVs, non-exhaust emissions must be factored in to evaluate the environmental implications of AVs. Particles resulting from non-exhaust emissions have higher oxidative potentials than other emissions from traffic. Non-exhaust emissions include but are not limited to tire residue, road dust, and brake wear [14]. Furthermore, compared to conventional combustion engine cars, EVs are heavier, which results in more friction between the vehicle and the road, producing more non-exhaust emissions [15]. Additionally, suppose private AVs are popularized over ridesharing. In that case, the rate of non-exhaust emissions release may drastically increase as VMTs increase, especially with possibilities such as self-parking and longer commutes.

Energy Consumption

With the longer commute times encouraged by AVs, energy consumption could increase even more, especially with empty miles driven [16]. However, this scenario only considers private AVs. Therefore, with ridesharing and autonomous PT, with the reduction of fleet size, the overall energy consumed from traffic will likely decrease. The increased collision avoidance associated with AVs also decreases energy consumption as accidents increase congestion and travel time. With automated platooning, collision avoidance is heightened, and the resultant smooth driving could decrease energy consumption by 15-20% [17].

Moreover, smoother accelerations and decelerations with AVs can save 4-10% of the energy consumed [18]. Along with changes in infrastructure and traffic laws to support optimized traffic flow alongside AVs, energy consumption decreases even further. Additionally, young people are less inclined to drive, potentially reducing future energy consumption rates [7]. The charging of AVs should be considered when discussing energy consumption. There would be a great energy and electricity demand during peak charging times when 53% of the global fleet is charging [19]. Furthermore, with fast charging options provided by AV consumers by companies like Tesla, even more energy per vehicle may be demanded.

EV Production

As previously discussed, AV production is steered towards using electric engines over combustion engines. Although EVs with low-carbon electricity sources reduce greenhouse gas emissions and release air pollutants, emissions during the production of EVs must also be consider to evaluate their environmental impact fully [10]. The production process of EVs brings the potential for increases in human toxicity, freshwater toxicity and eutrophication, and metal depletion [10]. However, environmental implications vary based on vehicle lifetime, electricity source, and energy consumption assumptions.

Public Health

Emissions

Unclean air is one of the leaders of mortality in the 21st century [20]. According to the World Health Organization's guideline for healthy air, 95% of the world exceeds safe levels of air pollution [9]. With electric AVs, the release of air pollution through exhaust emissions will decrease due to cuts in fleet size, safer and more efficient driving, and of course, reliance on electric engines instead of conventional combustion engines. However, as AVs become more predominant, the mass production of EVs will release harmful particles into local ecosystems and freshwater [10]. Additionally, pollution from non-exhaust emissions will increase from more VMTs. However, ridesharing must also be considered when evaluating the extent of non-exhaust emissions as fleet size will be cut drastically.

Physical Activity

With ODM, lower-income households could afford quick transportation, lowering the need for transportation that requires physical activity (e.g., biking, walking, etc.). Not only does physical activity allow for healthier lifestyles, but it also helps in reducing air pollution, traffic noise, and congestion [21]. Even worse, ride sharing can provide less incentive for physical means of transportation as ride costs are split between passengers, making the overall cost of travel lower [9]. Furthermore, with ODM, urban sprawl may be spurred by a smaller demand for lower-income households to live closer to their workplaces, reducing physical activity [22].

Electromagnetic Fields

AVs utilize different ranges of electromagnetic fields (EMFs) for navigation and sensing their environment. EMFs of low-mid frequency are safe as they are in the nonionizing radiation section of the electromagnetic spectrum [23]. On the other hand, prolonged exposure to EMFs of these levels is speculated to potentially cause cancer [24]. However, it is still too early to see the health risks imposed by the EMFs used by AVs.

Substance Abuse

According to the 2018 National Survey on Drug Use and Health, about 20.5 million people 16 years old and above drove under the influence of alcohol, and 12.6 million people in the same age range drove under the influence of illegal drugs [25]. With AVs, accidents will sharply decline, and traffic flow will significantly improve as drivers under the influence are automatically guided home. However, policies must address substance abuse regarding AVs as passengers can indulge in substance abuse during commutes [7, 9].

Pandemics

With AVs, during pandemics, essential workers would not have to endanger their health as AVs have the potential to transport and deliver items on demand, replacing human workers. For example, during the current COVID-19 pandemic, AVs are used in China to deliver food, allowing all demographics in urban areas to access food and control the spread of the disease [26]. Additionally, AVs are currently used to transport COVID-19 testing samples, bolstering research speeds [27]. Furthermore, AVs can detect infections with technologies like Vayyar to assess the cleanliness of the vehicle [7].

Infrastructure

Land Usage

Current policies and planning are considering creating separate lanes and infrastructure for AVs [6, 30]. However, policymakers will likely seek to integrate humans and AVs into mixed roads. If implemented into road systems with human drivers, AVs have the potential to cut down the number of lanes per roadway due to the aforementioned potential reduction of fleet size [46]. Additionally, given the reduction of fleet size, less parking and infrastructure will be required to be used on parking. Despite this, if not encouraged correctly, ridesharing and public transport (PT) can be seen as unattractive, encouraging usage of private AVs and significantly increasing the amount of infrastructure and land needed for parking space [28]. If PT is unpopular and ultimately replaced by ODM and AVs, infrastructure and land required for PT can be cleared up for alternative purposes. In order to support specific operating functions and features of AVs (e.g., cameras, sensors, radar, lidar, etc.), infrastructure, especially in rural areas, may need to be built [47, 48]. The new infrastructure includes signs and road markings, bridges and tunnels, structures to support connections from afar, service and charging stations, etc. [49]. Overall, the land usage from AVs may be unpredictable, relying primarily on the success of ridesharing and the associated reduction of the fleet size it brings.

Developing Countries

By 2030, traffic accidents will be the fifth most common source of mortality in developing countries [44]. Along with rapid industrialization and dependence on diesel-powered vehicles, emissions will spur additional deaths [45]. Therefore, AV technology must be adequately implemented in such areas as soon as possible. However, despite the overall willingness to adopt AVs by citizens of developing countries from several global surveys, the lack of proper traffic management, and a steady signal, developing countries provide a barrier to implementing AVs [7].

Economy

Productivity and Employment

Without the need to drive any longer, passengers in AVs can do whatever they please. More work-related tasks could be done during the workplace commute [9]. Therefore, with growing urban sprawl, commute times get longer but will not drop overall productivity. Additionally, as AVs generally replace cargo truck drivers or freight delivery drivers, products can be delivered from distant locations faster as there will be less time dedicated to rest periods and other delays [50]. Industries will readily adopt AV technology because of these cuts, increased production rates, and potential for all scopes. For instance, Amazon has recently released Proteus, making the warehouse processes much more efficient by quickly moving heavy cargo en masse. Additionally, delivery drones have drastically cut the shipping time for e-commerce [51]. Finally, with the production and commerce of AVs, there will be a new AV market in the economy and an amplified ODM market, potentially providing new work opportunities. However, there will be a considerable loss in driver-related jobs. Even worse, for the new jobs created by AV opportunities, most will likely require education and certification in technology-related fields like cybersecurity.

Social Habits and Equity

Accessibility

With ODM with AVs, people from almost all demographics would have access to transportation without the need for intermediate stops or delays. Along with ridesharing, ODM, but with multiple passengers traveling in the same shared vehicle, transportation becomes even cheaper and more accessible as the costs of trips are split [8]. Furthermore, without a driver, ODM becomes even cheaper as no tips and compensations have to be made for a driver [28]. ODM also provides transportation for people with physical or mental disabilities that would usually not allow them to drive. Although many jobs involving drivers will be eliminated from adopting AV technology, new jobs involving cybersecurity, data science, and other jobs involving AVs will be created [29]. However, these jobs mostly require a technical background, which many people of lower-income demographics cannot afford to pay for the required education.

Public Behavior

The public needs to feel safe about driving alongside AVs on urban systems and freeways to adopt AVs. Currently, different demographics have mixed reactions to integrating AVs onto our roads. For example, older people tend to be more skeptical and against using AVs than younger people [30]. In order to ease tensions regarding AVs, measures like separate lanes and fast charging times can be implemented. However, if not appropriately handled, PT may become even more undesirable as ODM allows for more privacy and personalization for travel [8, 9, 28].

ODM may spur urban sprawl as lower-income households no longer have to depend on PT or physical means of transportation to urban areas. Additionally, without the need for driving, other leisurely or work-related activities can be done in AVs, encouraging passengers to accept longer commute times [31]. AVs may also contribute to people not commuting for shopping or eating out as AVs can provide on-demand deliveries and services. Despite the reduction in fleet size induced by AVs and the other mobility-related implications reported earlier, over-dependence on private and personalized AV services may actually not serve to decrease traffic congestion [32].

Discussion

Optimization

Many policymakers are considering adding separate lanes for AVs to prevent issues with traffic flow alongside humans [7]. However, introducing a separate lane is unnecessary if policies are made so AVs can thrive alongside humans. In addition, separate lanes provide many negative impacts. For example, AVs take up land that could be used for other infrastructure, and they would cost millions, even billions, of dollars to implement, increase overall fleet size, etc.

Despite the positive benefits AVs can provide from a smaller fleet size, these impacts are only realized if ridesharing is correctly implemented. First, commuters, through public means, prefer their method of travel over private travel alternatives because of the financial attractiveness and commute time [28]. Therefore, due to the lack of drivers, ridesharing prices must be cut despite the already low price to compensate for the sacrifice of privacy as passengers split the fares. Moreover, ODM companies must devise a system to keep several shared AVs on standby in urban areas to optimize waiting and commute time. Shared AVs must also be luxurious and accessible to passengers. Finally, AVs must have an interactive and easy-to-understand UI and common maintenance by vehicle owners.

Autonomous PT must also be adequately advertised to the public as ridesharing can provide unnecessary congestion as shared AVs must be on standby for users. Even worse, auto-parking of shared AVs may prove a challenge as cramped urban areas will have a high demand for ridesharing if done properly. Therefore, PT must be even more economically attractive than ridesharing. Additionally, the interior of the vehicles must be clean, spacious, and provide a decent level of privacy - more than cramped shared AVs and comparable to a private vehicle. Also, autonomous PT must be implemented along with a convenient system to minimize waiting time from overlay, transfers, and initial boarding.

Differing Social Norms

Currently, different regions around the world have yet to legalize testing in urban areas. Singapore has already integrated AVs into its roads for a few years, reducing vehicle ownership and fleet size [42]. However, local conditions (e.g., physical condition, demographics, wealth, internet access) vary from location to location. Of these local conditions, when integrating AVs alongside people, the social norms of people of different cultures must be the largest factor considered when deploying AVs as drivers of different cultures differ in speed, customs, and habits [52]. Additionally, public behavior needs to sway toward accepting AVs as a strong negative stigma can cause a commotion, protest, and property damage towards AVs. Urban areas with a large population of low-income households must be cautious as AVs replacing many blue-collar jobs can provide a powerful motivation against AVs. Perhaps to mitigate uproar against job loss, autonomous PT and ODM can have drivers present to control the vehicle if road conditions are unideal.

Limitations

As a high school researcher, many journals were inaccessible due to a lack of journal subscriptions. Several articles considered were up to $40 to view during the search. Perhaps this paper would go more in-depth or take another perspective in specific fields in the discussion and literature review if given access to those previous papers. Additionally, much of the information in this paper may become outdated as AV technology is evolving at an ever-faster pace. Moreover, much of the findings and data reported in this paper rely on models. As AVs are tested, new results may occur.

Future Research

Future research can be conducted by testing AVs to confirm or reject the models' findings. Furthermore, environmental and health impacts of AVs are fields that can be further expanded in the future as AVs are a new technology, and most of their implications will be seen decades later. Furthermore, public behavior toward AVs is ever-changing as more robots are replacing traditional processes like delivery, especially during the current COVID-19 pandemic; therefore, attitudes toward AVs can be further researched as dependence on them grows. Moreover, greater dependence on AVs fosters innovation and development as demand grows, which means short-term impacts will be observable sooner.

Conclusion

The development of high-level AVs is still in its early stages. However, the evolution of AVs is ever-quickening. For example, from the inception of Tesla in 2013 to September 2020, when full self-driving software is being beta tested, their Autopilot has been rapidly updating to provide more features and reliability. Despite only having direct impacts on mobility, in our age, transportation has become so integral to society that it affects all facets of life. With a smaller fleet size, safer and smoother driving, and free space, AVs have the potential to benefit the environment and public health significantly. Additionally, social and economic patterns may change as urban sprawl is encouraged, travel habits change, and productivity rises. However, these benefits cannot be realized without a sustainable and guiding framework that promotes ridesharing. If private AVs are encouraged, fleet size increases, thus increasing congestion. As congestion increases, emissions increase, leading to worse environmental and health conditions. Furthermore, new infrastructure may need to be introduced to combat the slow traffic flow. Most imperative, policies must carefully consider and address the possibility of AVs replacing human workers.

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