Research on driverless car impact on energy and public safety

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Abstract. As urbanization progresses, cities are increasingly confronted with challenges such as escalating energy consumption, severe traffic congestion, and deteriorating air quality. Highly automated autonomous vehicles (Levels 4 and 5) have the potential to mitigate these issues by enhancing energy efficiency and improving traffic safety through optimized driving routes and speeds. However, the extensive deployment of these technologies also presents significant social challenges, including potential job displacement for drivers and a range of legal and ethical concerns. This study aims to critically evaluate the impact of autonomous driving technology on energy efficiency and social safety. It will investigate how these vehicles contribute to energy optimization by minimizing unnecessary variations in speed and delays, while also addressing potential negative consequences, such as increased social inequality and employment impacts. Furthermore, the study will examine the risks associated with social safety, including cybersecurity threats and ethical issues. By analyzing existing research and data, this study seeks to predict the impact of autonomous driving technology on future society, provide guidance for policymaking, and raise awareness of the potential issues associated with autonomous vehicles.

Keywords: Autonomous vehicles; energy efficiency; public safety; social crime risk.

1. Introduction

In recent years, as populations have grown and more people have chosen to live and work in urban areas, cities have been facing increasingly severe issues related to the environment, energy, and public safety, such as declining air quality, rising energy consumption, traffic congestion, and frequent accidents. The rapid pace of urbanization has directly contributed to a dramatic increase in traffic pressure, especially during peak hours, when roads and bridges often operate at full capacity. This situation not only wastes a significant amount of time but also significantly raises the risk of accidents. Moreover, prolonged traffic jams lead to unnecessary vehicle emissions, worsening air pollution. Research shows that motor vehicle emissions account for 31.1% of total local pollution, and in congested conditions, emissions are 50% higher than under normal traffic conditions [1]. By 2050, urban populations are expected to make up two-thirds of the world's population [2], further escalating urbanization and energy consumption. Studies indicate that a 1% increase in the average urbanization index can lead to a 0.495% increase in actual energy consumption, a 0.18% rise in optimal energy consumption, but a 0.201 percentage point decrease in energy efficiency [3]. This suggests that as urbanization advances, cities will face increasingly prominent energy challenges. Addressing these problems urgently requires effective solutions. Autonomous vehicles, by optimizing routes and driving speeds, offer a more scientific and rational approach to driving, potentially reducing energy consumption and enhancing traffic safety. This is seen as one of the effective strategies for addressing the challenges posed by urbanization. To mitigate these growing issues, innovative transportation solutions such as autonomous vehicles have gained attention for their potential to optimize energy use and enhance public safety.

Autonomous vehicles integrate a variety of sensors, including cameras, lidar, radar, GPS, odometers, and inertial measurement units (IMU), to form a comprehensive sensing system. This system relies on large datasets for backend analysis to automatically recognize, analyze, and make driving decisions based on the surrounding environment [4]. Significant progress has been made in the field of autonomous driving by several companies. For example, Waymo has conducted extensive testing in multiple U.S. cities; Tesla continues to refine its fully autonomous driving system; and Baidu’s Apollo project has been tested and promoted in several Chinese cities.

The Society of Automotive Engineers (SAE) has classified autonomous driving technology into six levels as Level 0 (No Automation), Level 1 (Driver Assistance), Level 2 (Partial Automation), Level 3 (Conditional Automation), Level 4 (High Automation), and Level 5 (Full Automation) [5]. Currently, most autonomous driving technology falls between Level 2 and Level 3, with some vehicles offering limited Level 4 capabilities.

However, despite the many benefits of autonomous vehicles, they still face numerous challenges. Particularly in complex urban traffic environments and under adverse weather conditions, the performance of autonomous vehicles remains uncertain. Additionally, the widespread adoption of autonomous driving technology could lead to significant job losses for drivers. Addressing the legal and ethical challenges associated with this technology is also a pressing issue.

As autonomous driving technology rapidly advances, particularly with the development of Level 4 and Level 5 vehicles, the future of transportation is set to be revolutionized. While these technologies promise significant improvements in traffic efficiency, reduction of human errors, and fewer accidents, they also raise critical concerns regarding energy consumption, cybersecurity, and societal impacts. Existing research has extensively explored the fundamentals and advantages of autonomous vehicles, but there is a noticeable gap in understanding how highly automated vehicles specifically influence energy efficiency and public safety. This paper aims to address this gap by analyzing the energy optimization strategies and public safety challenges posed by Level 4 and Level 5 autonomous vehicles, providing valuable insights for the future development of autonomous driving technologies and offering practical recommendations for policymakers.

2. Impact on energy

2.1. Energy Optimization Strategies in Autonomous Vehicles

Frequent variations in speed and unnecessary time delays during driving are significant contributors to energy consumption. In traffic congestion, the inability to maintain an appropriate distance from the vehicle ahead results in frequent transitions between low speeds and stops, which not only wastes time but also increases fuel and energy consumption. Additionally, the inability of drivers to accurately adjust their speed to accommodate traffic infrastructure, such as traffic lights and signs, leads to further fluctuations in speed. Furthermore, unfamiliarity with routes can cause additional detours and time delays, thereby exacerbating energy consumption.

Autonomous vehicles optimize energy consumption by generating eco-friendly routes and employing eco-driving strategies. By leveraging V2V (vehicle-to-vehicle) and V2I (vehicle-to-infrastructure) technologies, these vehicles can access data from neighboring vehicles (e.g., speed and route information) and infrastructure elements (e.g., digital maps and traffic signals). Integrating factors such as elevation profiles, traffic conditions, and energy recovery from electrified powertrains allows autonomous vehicles to plan routes that minimize energy usage and determine optimal speeds, thereby significantly reducing unnecessary time losses and speed fluctuations.[6]

At the same time, air resistance also significantly contributes to energy consumption. Therefore, reducing air resistance plays a crucial role in decreasing energy usage. According to research, factors such as vehicle shape, distance between vehicles, and vehicle order in a convoy are key variables that influence the reduction of drag. Since the benefits of convoy driving are more pronounced for vehicles in the middle of the convoy, the average fuel savings increase with the number of vehicles. For instance, when two cars are separated by 1 meter, the average drag is estimated to decrease by 10%. Additionally, when 15 cars are traveling with a gap of 6-8 meters, they may achieve optimal fuel savings within the convoy [7]. However, human-driven vehicles or lower-level autonomous vehicles find it challenging to maintain precise distances, which can lead to accidents. In contrast, higher-level autonomous vehicles can utilize V2V communication to safely and accurately reduce air resistance.

2.2. Date Center Consumption

The operation of autonomous vehicles undoubtedly necessitates substantial cloud computing resources to ensure safe driving. As a fundamental component of cloud computing infrastructure, data centers manage enormous volumes of data. Projections indicate that from 2018 to 2025, the volume of data stored by enterprises will increase by 61%, reaching 175 ZB, with the majority of this data being housed within data centers. Concurrently, the energy consumption of data centers has doubled over the past decade and is anticipated to increase three to four times over the next ten years. In 2017, data centers accounted for 2% of total energy consumption, a figure expected to rise to 5% by 2024. [8]. This increase in energy consumption not only escalates operational costs but also imposes significant environmental pressures, particularly in the context of reliance on fossil fuels, leading to a marked increase in carbon emissions.

In this context, the technological demands and challenges posed by autonomous vehicles, particularly Level 4 and Level 5 vehicles, become more pronounced. These vehicles, which possess fully or highly automated driving capabilities, depend on intricate algorithms, extensive sensor data, and real-time computational processing to ensure operational safety. Continuous communication with data centers is essential for obtaining real-time traffic information, performing map updates, and processing vehicle status data. As the adoption of autonomous driving technology expands, data centers will face an increased burden of managing and storing the substantial data generated by these vehicles, further exacerbating the rise in energy consumption.

3. Impact on public safety

3.1. Reduction of human errors

According to data from the World Health Organization (WHO), approximately 90% of traffic accidents worldwide are caused by human error. These errors include speeding, drunk driving, distracted driving, and violating traffic regulations. In contrast, autonomous vehicles appear to be much safer. Human drivers typically rely on their eyesight to observe obstacles ahead, which becomes more challenging in poor visibility conditions such as nighttime, fog, or rain. However, autonomous vehicles use radar, sensors, and other equipment to perceive their surroundings. For example, RADAR sensors detect the distance and speed of objects around the vehicle by emitting radio waves, offering functionalities like obstacle detection, blind spot monitoring, and rear collision warnings, even in adverse weather conditions [9].

Additionally, the reaction speed of autonomous vehicles is significantly faster than that of human drivers. The typical human reaction time is around 0.5 seconds [10], which includes perceiving danger, making decisions, and then taking appropriate action. In contrast, autonomous vehicles rely on sensors, radar, lidar, and cameras to perceive the environment, with data processing and decision-making occurring in milliseconds. This enables autonomous systems to react nearly ten times faster than humans, allowing them to respond to sudden situations and make decisions more quickly.

3.2. The Application of Autonomous Vehicles in Emergency Situations

In emergencies such as fires, medical rescues, or police operations, every second counts. Delays in response can severely jeopardize life safety, and faster response times often save more lives. The data in Table 1 [11] reveals critical insights into emergency response times across different types of housing. For instance, the median response time for single-family homes is 655 seconds, while for nursing homes, it is 390 seconds. This indicates that certain environments, such as single-family homes, may experience longer response times, Furthermore, the data in Table 1 shows that in nursing homes, reducing response time by one minute can save a life after 2,638 dispatches, whereas in single-family homes, it requires 3,719 dispatches. This highlights the varying potential of response time reduction technologies to save lives in different environments, particularly in settings where emergencies are more frequent.

Therefore, improving response speed is crucial for ensuring life safety. Autonomous driving technology, through vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication systems, provides emergency vehicles with priority access, thereby reducing response times. V2V systems allow vehicles to share real-time information about their locations and speeds, enabling emergency vehicles to navigate around other vehicles more quickly. Meanwhile, V2I systems interact with traffic infrastructure, such as priority control for traffic lights, to further optimize travel routes and ensure that emergency vehicles can reach their destinations swiftly. By leveraging these technologies, autonomous driving systems significantly reduce response times and enhance rescue efficiency, ultimately saving more lives in critical moments.

Table 1. Parameter Estimates OlS with Log (response time), Grouped Dependent Variable

Variable/Parameters	Blocks of flats	Summer/winter houses	Semi-detached/terraced houses	Detached houses	Nursing homes
Intercept (α's)	-0.00377	-0.00816	-0.00529	-0.00563	-0.00438
Ln response time (β's)	0.00235	0.00304	0.00261	0.00266	0.00244
R-squared	0.158	0.117	0.21	0.152	0.191
No. of observations	22376	1858	1510	20806	2101
No. of observations with fatalities (percent)	265 (1.13%)	22 (0.99%)	22 (1.39%)	254 (1.12%)	10 (0.45%)
Median response time, seconds	384	900	459	655	390
Marginal effect for 1 min change in response time, at median	0.000472	0.000199	0.000338	0.000241	0.000379
Turn-outs necessary to save one life if response time reduced by 1 min	1996	3567	2709	3719	2638

3.3. Cybersecurity risks

One of the most pressing concerns is cybersecurity. Firstly, there is the risk of hacking into wireless event data recorders. These systems store critical data, and unauthorized access or manipulation could result in significant security breaches. Another major threat is GPS signal interference. Malicious actors might jam the vehicle's GPS, causing it to lose its direction and making theft easier. Additionally, the modification of sensors and maps poses a serious risk. Autonomous vehicles rely on accurate sensor data and maps for safe navigation, and alterations to these can lead to dangerous misinterpretations. Finally, Denial of Service (DoS) attacks represent a significant threat. Such attacks could prevent the vehicle from receiving crucial information, potentially leading to system failures [12]. Given that Level 4 and Level 5 autonomous vehicles have high levels of autonomy, passengers may find it difficult to control the vehicle during such incidents, making these threats particularly impactful.

In addition to the aforementioned threats, vehicular communication technologies, such as Vehicle-to-Everything (V2X) and Vehicle-to-Vehicle (V2V) communication, can exacerbate cybersecurity risks. These technologies enable autonomous vehicles to rapidly exchange and process information with external systems, which helps prevent collisions and optimize travel routes and speeds. However, this increased connectivity also exposes the vehicle's movements and location to external networks, potentially allowing individuals to track AV users. Private data of users might be sold to third parties, and such data could be used for targeted marketing and advertising, or even for identity theft[13]. The concentration of information could lead to significant privacy violations, placing users at risk of various cyber threats.

3.4. The Link Between Autonomous Vehicles and Increased Social Crime Risk

The widespread adoption of autonomous vehicles (AVs) could have significant implications for employment, particularly in driving-related professions. According to Table 2 [14], approximately 2.9% of workers in the United States are employed in driving-related jobs. The implementation of AVs may lead to considerable social costs, with potential annual losses estimated at $180 billion for workers in driving professions, $120 billion for the insurance industry, and up to $6.4 billion for car repair centers. These figures suggest that the transition to autonomous driving technology could result in substantial unemployment within the driving and auto repair industries, highlighting a critical area for policy consideration and workforce planning.

Table 2. The full implementation of AVs can result in severe societal costs due to loss of jobs.

Stakeholder	Type	Current Benefit (US)	Potential Loss from AVs (US)
Workers in Driving Jobs	Income	$180 billion	-$180 billion
Insurance Industry	Income	$300 billion	-$120 billion
Car Repair Centers	Income	$71 billion	-$1.5 to -$4 billion

Fig.1 illustrates the social impacts of unemployment, divided into two groups [15]. The first group, represented by charts a and b, depicts the economic effects of unemployment on individuals, including declines in employment rates and labor income. The data reveals a significant reduction in employment rates and a sharp drop in labor income following job loss. Beyond these economic impacts, unemployment in driving-related professions could also strain social welfare systems and lead to higher public spending on crime prevention and law enforcement.

The second group, consisting of charts c through f, examines the effect of unemployment on various types of crime. The data shows an increase in the prosecution probability for all types of crimes after unemployment, with a particularly notable rise in economically motivated and violent crimes. Additionally, there is a rise in other types of crimes, including non-economically motivated and non-violent crimes. This indicates that unemployment not only deteriorates economic conditions but also contributes to higher crime rates, highlighting the extensive negative impact of unemployment on social order. To mitigate these effects, policymakers could consider implementing retraining programs for displaced workers and providing incentives for industries that can absorb the surplus labor.

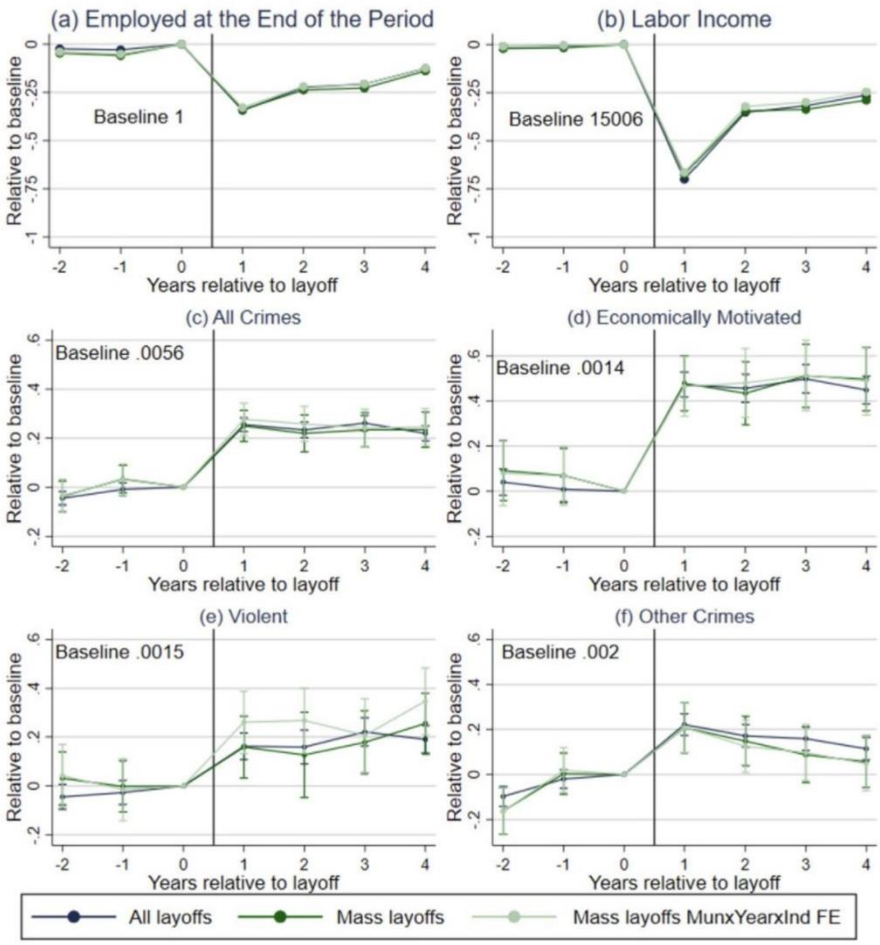

Fig 1. Effect of job loss on employment and criminal prosecution probabilities [15].

The widespread adoption of autonomous vehicles could have significant impacts on employment, particularly in driving-related professions. The introduction of AV technology may result in substantial economic losses and unemployment in these industries, leading to broader social repercussions. Unemployment can reduce individual employment rates and labor income, increase the burden on social welfare systems, and contribute to higher crime rates, including economically motivated and violent crimes. Therefore, policymakers need to consider implementing measures such as retraining programs and industry incentives to address these potential social and economic challenges.

4. Limitation

In this study, there are several limitations that need to be acknowledged. First, the availability of real-world data on highly automated autonomous vehicles (Level 4 and 5) is limited due to the relatively early stage of their implementation. Most of the conclusions are based on simulations and theoretical models, which may not fully capture the complexities of real-world environments. Additionally, the rapidly evolving nature of autonomous driving technology means that some of the findings might become outdated as new advancements are made. Furthermore, external factors such as infrastructure, climate conditions, and regional policies could influence the actual performance of autonomous vehicles, and these are not fully accounted for in the analysis. Future studies could address these limitations by incorporating more real-world data as autonomous vehicle deployment becomes more widespread.

5. Conclusion

In conclusion, this paper has explored the impact of highly automated autonomous vehicles (Level 4 and 5) on energy efficiency and public safety. The research shows that while these vehicles have the potential to significantly reduce human errors and optimize energy consumption through route planning and speed control, they also raise concerns related to increased overall energy consumption due to extended travel distances and the energy requirements of supporting data infrastructure. On the public safety side, the reduction in accidents due to human error is promising, yet cybersecurity risks and job displacement could introduce new social challenges. The findings highlight the need for balanced and thoughtful integration of autonomous vehicles into society. Policymakers, engineers, and urban planners should work together to mitigate the potential downsides while maximizing the benefits. Future research should focus on real-world testing and long-term impacts, particularly in areas such as cybersecurity, privacy concerns, and energy consumption optimization under various conditions. Continued innovation and collaboration across sectors will be critical to addressing these challenges and fully realizing the potential of autonomous vehicles.

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