OVERVIEW OF AUTONOMOUS VEHICLES RESEARCH: PRESENT, PAST AND FUTURE

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ABSTRACT

Autonomous Vehicles (AV) research is increasing at a fast speed. Many manufacturing companies have already launched several models of self-driving vehicles. Simulation and neural network models are being used to simulate and predict AV behavior and challenges. Several ethical, social, and financial issues are related with AV research. This paper provides an overview of the present research which are carried out for getting better designs of AVs. This paper also provides a comparison between the timelines of AV research (present, past, and future). Several studies have made an assumption that self-driving vehicles will be available in the market by 2050. The challenges associated with market penetration, initial cost, and other relevant aspects will be among future research topics in this context. AV behavior in mixed traffic will be a matter of concern and several studies are focusing on the identification, integration, and pattern of AVs in the mixed traffic. This study will also illustrate some future research scopes based on the research gaps of previously-published research articles. A flow chart containing overview of the timeline will also be shown in this paper.

Keywords: *Autonomous Vehicles, Market penetration, Identification, Flow chart, Overview*

1. INTRODUCTION

Technological advancement has made life easier and more comfortable than ever before. Transportation engineering sector is also experiencing new types of advancement in traffic planning, transportation modes, roadway infrastructure, and so on. Conventional Human-driven Vehicles (HVs) have served the travel demand of the people for decades. But transportation sector needs to cope up with the pace of advancement and hence the idea of AVs came into consideration.

Human errors are responsible for most of the accidents. A 2013 NHTSA analysis stated that nine (9) deaths per day on American highways were attributable to distracted driving, out of 90 traffic crash deaths. 94% of all traffic crashes in the US are caused by human behavioral factors, making it difficult to determine the causes of such crashes and come up with solutions (Bhavsar et al., 2017). On the other hand, AVs can minimize the risks of accidents and also results in savings of money which were lost by numerous crushes. According to a study by Fagnant and Kockelman (2015), driverless cars may save over 4 million crashes and save over 21,000 lives annually if they were to reach 90% of the market. These technologies have been developed and tested by academic researchers and automotive corporations in an effort to increase the efficiency and safety of surface transportation systems. AVs have the potential to significantly alter present land use practices by decreasing parking spaces and possibly substituting vehicle windshield advertisements for billboards (Bhavsar et al., 2017).

There a number of different parts of a self-driving vehicle. Vehicle Piloting System (VPS), Vehicle Control System (VCS), Visual Guidance System (VGS), and Robust Communications System (RCS) are the components of an AV (Sanaullah et al., 2017). These parts provide a complete advantage package over HVs. According to this study, the benefits of autonomous transportation systems include increased parking and road capacity, enhanced safety, smoother traffic flow, less traffic congestion, and increased fuel efficiency. Due to their tiny size, AVs can travel on roadways with narrower spaces between them, increasing the capacity of the road by up to 30%. If the AVs move in platoons, the capacity on the highways can grow by 3-8 times. If the space is finally decreased with the ideal connected gadget, cars may even travel bumper to bumper at top speed. Connected Autonomous Vehicles (CAVs) are effective in terms of congestion mitigation and safety improvement. However, implementation of CAVs in the existing road network needs some considerations. A study led by Malikopoulos et al. (2018) found out the solution to the issue of controlling CAVs crossing an urban intersection optimally. This study found that the solution regarding throughput maximization problem depends exclusively on the strict safety limits placed on CAVs, and its design allows for the formulation of a decentralized optimum control problem for the reduction of energy consumption. Zhang & Cassandras (2019) analyzed the integration of CAVs into the existing road network with conventional vehicles as 100% CAV penetration is not possible. The study findings indicate that increases in the rate of CAV penetration lead to a greater improvement in energy efficiency; however, lower levels of traffic mean less significance.

Based on extant research, AVs have the potential to yield several safety advantages, such as the prevention of collisions and fatalities. It is estimated that human error accounts for between 90-95% of all car accidents (Bartneck et al., 2021). As a result, AVs have gained popularity and large manufacturing steps started. Over the past 10 years, research on numerous AV-related topics has become more and more prominent. While automakers have invested heavily in making the technology more practical, economical, and safe, research has focused on topics including infrastructure design, environmental effects, travel behavior, safety, congestion, and traffic operations (Talebian & Mishra, 2018).

The concept of autonomous cars has been around for decades, but large-scale manufacturing has been hampered by the prohibitive costs. Nevertheless, in the past 10 years, there has been a surge in the research and development work to realize the concept of the AV. For instance, the introduction of the Google vehicle raised awareness of AVs. Furthermore, the global automotive sector invests approximately €77 billion in research and development to foster innovation and maintain its competitive edge (Bagloee et al., 2016). Moreover, the research works are moving at a fast speed by additional funding opportunities.

The objective of this study is to summarize all relevant scientific studies and create an overall outlook of how far the AV research has reached and what can be achieved in future. This study provides a timeline of the past and present research and creates a pathway to the future scopes.

2. METHODOLOGY

This paper follows several processes of a literature review. The following review questions are followed:

- Why overview of AV research is necessary?
- What previous works have been done on the AV research?
- What are the future scopes of AV research?

This paper gives an overview of the previously-published research articles on AV research. The contradictions which lie between different published papers are highlighted in this paper. This paper also provides the future scopes of research which can be conducted in this field.

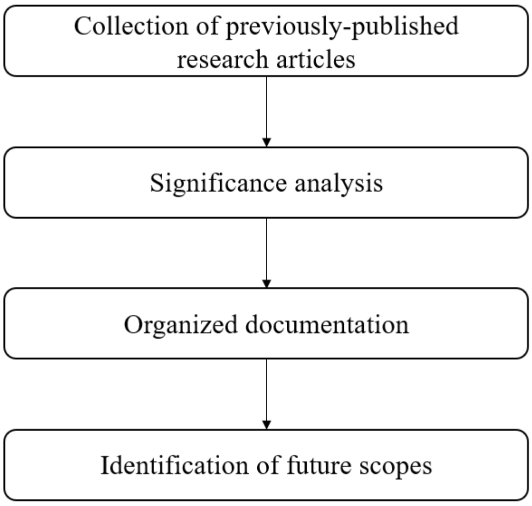

Figure 1: Flow chart of methodology

3. OVERVIEW OF PRESENT AV RESEARCH

A detailed and insightful overview of AV research will help the policymakers to visualize the history of AV research and relate its continuity with the works that are ongoing in the present time. Past and present timelines of AV research will dictate the path for the possible and feasible research works in future in this research context and help the relevant authorities and policymakers to focus on the possibilities and outcomes of the works that have the potential to have greater impacts in our daily lives.

VisLab Intercontinental Autonomous Challenge, often known as VIAC, was one of the main competitions that improved the testing and analysis of AVs due to the advancements in autonomous technology (Bimbraw, 2015). At present, several renowned automobile companies like Tesla Inc., Nvidia, Waymo, and Zoox, are manufacturing their AV models in the market. Due to the initial progress in AV technology, the future market of AVs will expand further. But due to the inclusion of AVs in the conventional roadway network, several concerns arise which are being researched by the scholars and scientists in this sector. Some of them includes compatibility of AVs in the existing roadway infrastructure, identification of AVs in mixed traffic network, performance of AVs in comparison to HVs, future market prediction analysis, motion features of AVs, impacts of AVs in socio-demographic sectors, attitudes and concerns on AVs from the roadway users, and so on.

Olia et al. (2018) conducted a study on traffic capacity implications of AVs in mixed traffic, which found that if every car is driven in a co-operative automated manner, it is possible to reach a maximum lane capacity of 6,450 vph per lane. This possible capacity appears to be highly insensitive to market penetration when it comes to the integration of AVs into the traffic stream. Traffic stream consists mainly of HVs and it becomes a concern to identify AVs in that stream. This issue can be resolved by the inclusion of learning-based Artificial Intelligence (AI) models. In a study with the 4 car-following trajectory datasets (historical dataset from a previous study led by (Yao & Li, 2020), Vanderbilt ACC dataset, CATS Lab ACC dataset, and Open ACC dataset), 2 AI models, namely Artificial Neural Network (ANN) and Long Short-Term Memory Network (LSTM), correctly identified 98.17% of AVs and 94.14% of HVs (Li et al., 2021). Identification of AVs like this study can facilitate traffic safety enhancement, roadway capacity elevation, and AV management assistance. However, with the inclusion of AVs in the existing roadway network can arise some safety concerns. Inclusion of AVs in the conventional roadway system also asks for market validation. A study has showed that Connected and Fully Automated Vehicles (CAVs) would have economic impacts of $1.2 trillion or $3,800 per American per year if they capture a large share of the automotive market (Clements & Kockelman, 2017).

Also, from the socio-demographic perspective, it is very important to know the attitudes and behavior of the transportation mode users for the demand analysis of AVs. In a survey in La Rochelle city of France, the respondents gave positive feedback on the AV implementation in urban areas. Among them, more than 50% showed interests towards using AVs upon being available; 75% in owning AVs and 25% in sharing AVs through car-pooling and car-sharing approach (Piao et al., 2016).

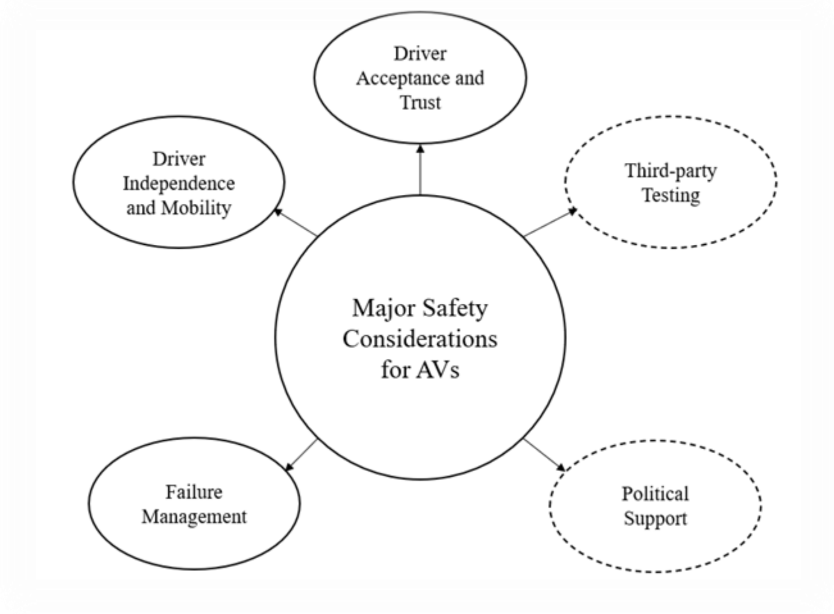

Figure 2: Driver (solid circle) and regulatory (dashed circle) safety considerations for AVs (Hancock et al., 2020)

The usage of Autonomous Goods Vehicles (AGVs) for commercial purposes has drawn increasing interest from the industry and policymakers as the underlying technology has advanced. Sindi & Woodman (2021) assessed the aspect of the implementation of commercial autonomous road haulage for the purpose of freight operations from the industry perspective. The key findings from this study revealed that the primary benefits of commercializing autonomous road haulage are lower overall maintenance costs because of reduced wear and tear and lower operating costs as vehicles can run for longer distances. Furthermore, short-term obstacles like public acceptance and transition costs are expected to be overcome by gains in usage and efficiency. On this context, Freight Urban RoBOTic vehicle (FURBOT), a complete drive-by-wire vehicle is expected to perform autonomously in an urban setting. The FP7-Transport European project, which concluded in December 2015, provided funding for the European Green Vehicles Initiative (EGVI), which included this vehicle. Though it was intended to be an AV, it was finished as a drive-by-wire vehicle. A higher level of autonomy for the vehicle will require resolving issues brought up by this upgrading, such as the licensing or legal framework that must be addressed in order for the vehicle to be insured and legally drive on public roads, as well as the modifications and upgrades the vehicle must undergo in order to become a fully autonomous freight handling vehicle (Masood et al., 2021).

4. COMPARISONS AMONG THE TIMELINES OF AV RESEARCH

At the 1939 World Fair in New York city, the automated highway concept in General Motors' Futurama vision was the first concept of automobiles that does not require constant driver's input, supervision, and monitoring. This idea was pitched by Norman Bel Geddes, who imagined what the world would look like after 20 years from the fair date. Although there was not much work done on automating civilian cars during World War II, General Motors (GM) and Radio Corporation of America (RCA) worked together to create scale models of automated roadways during the 1950s. The term "Automated Highway System," or "AHS," was coined in 1950 as a result of these and other activities. This indicated that, in contrast to modern efforts to integrate as much automation and control technology on-board the vehicle, a sizable portion of the technology back then consisted of roadside infrastructure and control architecture. In the early period of '90s, U.S. Federal Highway Administration (FHWA) established the National Automated Highway System Consortium (NAHSC). Later in 1995, Carnegie Mellon University (CMU) showed a demonstration called 'No Hands Across America' in a 4,500 km pathway from Pittsburgh to Los Angeles (LA) that 98.2% automated lateral control was achieved with the provision of camera and laser vision systems fused with neural network control concept. In the beginning of 21st century, U.S. Defense Advanced Research Project Agency (DARPA) initiated competitions called 'Grand Challenge' (in 2004 and 2005) and 'Urban Challenge' (in 2007) to inspire and motivate the participants to achieve control over unmanned vehicle-driving field. Automotive companies from Germany and Japan came to Stanford University for AV research collaboration due to the university's commendable success in those challenges. With the entry of Google in this field, the number of worldwide research and various development projects skyrocketed (Beiker, 2014).

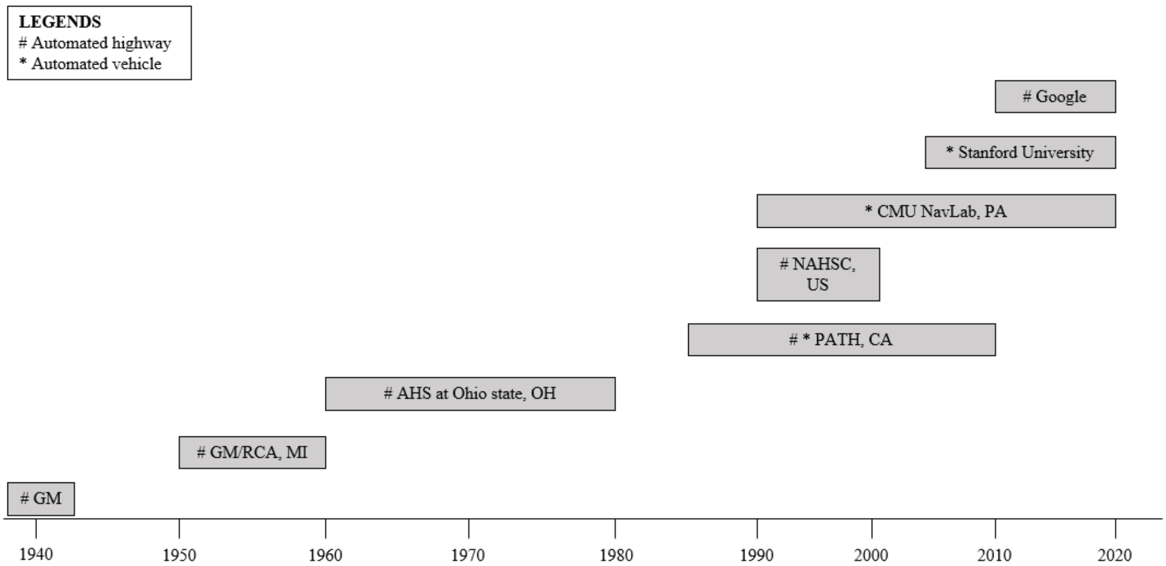

Figure 3: Overview of AV research timeline in USA (Beiker, 2014)

5. CHALLENGES

5.1 Market Penetration

There arise many challenges before the full-scale implementation of AVs. Market penetration is one of those challenges and hence the assessment and evaluation of AVs in this context is vital. Song et al. (2021) conducted a simulation-based study on this and found that CAVs equipped with CACC (Co-operative Adaptive Cruise Control) system perform better than AVs equipped with ACC (Adaptive Cruise Control) or IDM (Intelligent Driving Model) systems in low and high demand circumstances and they can cut average delays by 49% to 96%. While notable decreases could only be seen after 60% and 80% MPRs (Market Penetration Rates) for AVs with the ACC/IDM system, CAVs with the CACC system could also significantly reduce average delay with a 20% MPR. Another simulation-based study in Al-Madinah city of Saudi Arabia revealed that estimated vehicle delays decreased by 26%, 34.4%, 63.7%, and 74.2% for 25%, 50%, 75%, and 100% AV penetration rates, respectively (Abdeen et al., 2022).

5.2 Cost Constraint

Although AVs are gaining a lot of attention now-a-days, its cost can be a concern for the people who are interested in owning AVs. Due to the adverse economic condition of a region, provision of relatively high rate of taxation for AVs can demotivate this interest to a significant level, as only the people of high economic class will then be able to afford an AV for their day-to-day usage.

5.3 AV Behavior in Mixed Traffic

Calvert et al. (2017) found that the initial impact of low-level AVs on mixed traffic will be moderately adverse to road capacity and traffic flow. This study also demonstrated that traffic flow will only improve at penetration rates higher than 70%. Additionally, the capacity reduction seemed to be marginally larger when low-level AVs were present. But the paradigm shift from HVs to AVs can have vulnerabilities on the topic of cyber-security due to its unmanned driving approach which can cause discrepancies in a stable traffic flow.

5.4 AV Infrastructure

Steyn & Maina (2019) analyzed the impacts of AVs on pavement infrastructure upon the application of relevant Accelerated Pavement Testing (APT) data. In that study, it was found that AV implementation on the existing road pavement infrastructure show such responses that differ from the conventional and non-AVs and inclusion of rich APT datasets would improve the analysis procedure further for the development of AV infrastructure. Another case study that was conducted in Melbourne, Australia by Manivasakan et al. (2021) focused on infrastructure requirements for AV implementation in the existing road network, which is one of the less-talked aspects of AVs. It provides guidelines for infrastructure transformation and an assessment system to put safety, effectiveness, and accessibility first when integrating AVs with traditional vehicles and multi-modal users like pedestrians and commuters on public transportation. The key findings of this study demonstrate that different arrangements and trade-offs can be made for different types of regions, such as a regional Central Business District (CBD) street in a multi-modal and spatially constrained area and a regional commercial and transportation center in a residential neighborhood. On the context of infrastructure preparedness assessment of AVs, (Gouda et al., 2021) suggested combining voxelated LiDAR data and raycasting approach to test AVs in a virtual environment. Road features and AV are used to map sight distances and speed limits. When compared to the suggested method, a different algorithm was found to yield results that agreed by 1.94%. It was discovered that some AV scenarios might put AVs in dangerous driving situations.

5.5 Government Standard

Though the inclusion of AVs in the transportation sector might be fruitful for the economic development of a region or country, there is no specific or particular standard on AV implementation in the world set by the government or relevant authorities or regulatory bodies. US, the pioneer country in AV research, has not yet set standards on this regard. US is currently working on the development of the federal standards on AV implementation on the roads.

6. FUTURE RESEARCH SCOPES

It is evident that AVs will outnumber HVs in the days to come due to their significant advantages over the later one. Traffic and roadway network planning for AVs around the globe can be a major scope in the future. Development in CAV-related research field has been significantly prominent, such as inter-CAV communication, CAV security, intersection control for CAVs, collision-free navigation of CAVs, and pedestrian detection and prediction (Elliott et al., 2019). Addition and modification of the AV features can also be potential research scopes.

AV freights can be deployed on the road with considerably greater ease if the vehicle is purposefully designed to fit into an already-existing vehicle category. Due to the requirement for costly sensors and off-the-shelf software, changing hardware or software for autonomy can be quite costly. Therefore, during autonomy upgrading, budgeting and sensor identification should be given the topmost priority.

Furthermore, social science studies can play a major role to elevate the impression of the people towards the implementation of AVs to a significant level. In this context, a study was conducted which was a product of a workshop in London (2018) that analyzed the constructive role of social science in AV development on the basis of 8 themes, namely single versus multiple futures, public(s), distributional impacts, safety, physical infrastructure, data, environment, and governance and power (Cohen et al., 2020). Studies like this will further pave the way for an effective and efficient implementation of AVs worldwide.

7. CONCLUSIONS

This study focused on the AV research timelines and the summarization of the key findings. In doing so, it was able to answer the aforementioned research questions and give a detailed brief on them. The key findings from this study indicate that most of the research works are focusing on Machine Learning (ML) and Deep Learning (DL) to analyze several relevant datasets and identifying different features of AVs. In mixed traffic condition, AV identification could bring numerous benefits in the AV design, modification, and optimization sectors. The findings will help the relevant authorities and policymakers to have a glimpse on the existing AV research and the challenges that AVs will face upon the implementation, which will lead the development of AV implementation standards along with a well-planned and structured framework. However, extensive AV research is limited to mostly developed countries. Developing and under-developed countries are yet to enter into this research field including Bangladesh. Government-set standards in various developed countries need to be implemented that will help the inclusion of AVs in the existing roadway network. As US are working on it that has been mentioned previously in this study, the developed standards will help policymakers from other developed countries to give a consideration in this context which will pave the way for the AV implementation in developing and under-developed countries and ensure more efficient transportation network worldwide. In future, AV brands, features, and malfunctions could be identified using DL, image processing, and Artificial Neural Network (ANN) models. To recapitulate, integration of ML and DL-based models, techniques, and modifications will be included in the future timeline of AV research.

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