Safety and Operations of Automated Delivery Vehicles: A Scoping Review

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Abstract

With the new revolution of e-commerce growth, the need for delivery service and light delivery vehicles have increased significantly in the last few years. The National Highway Traffic Safety Administration (NHTSA) recently permitted the deployment of automated delivery vehicles (ADVs) with low-speed thresholds. Unlike conventional low-speed vehicles, these ADVs are designed to have no human occupants and they operate exclusively using an automated driving for delivery purpose. ADVs can reduce costs of delivery, release less harmful emissions, improve time efficiency, and increase traffic safety and congestion. This is due to their automated system, dynamic route planning, and sensors that allow a better understanding of the environment. With the increasing demand for delivery services and cost-effective delivery options, there has been increases in research, company manufacturing, and usage of ADVs. Although there are many safety concerns due to the frequent stops on driveway prone residential localities, safety-related issues of these vehicles have not been explored. Additional concerns pertaining to ADVs include network performance demands, privacy issues, and trust of the public. This study performed a comprehensive scoping review on the safety and operational aspects of ADVs by looking at important topics related to ADVs and identifying the key aspects of prominent studies.

Introduction

The deployment of automated vehicles (AVs) has seen a rapid growth in recent years. According to the National Motor Vehicle Crash Causation Survey, human error is the critical error for 93% of crashes [1]. A study by Morando et. al showed that AVs can reduce the number of conflicts at signalised intersections by 20% to 65% [2]. AVs do not need the presence of human drivers thus, these vehicles have enormous potential in reducing the number of crashes by removing the human error component completely. AV's are able to map their surroundings using sensors as well as communicate with each other to further increase safety. Once the majority of vehicles operating on roadways are AVs, the transportation system will become safer, more environmentally friendly, and more efficient. However, before the mass deployment of AVs for passenger transportation, it is expected that in the early stage, AVs will be widely used in cargo delivery or other light delivery efforts first in the near future. This includes automated delivery vehicles (ADVs) or robots (ADRs) and automated delivery trucks (ADTs). DHL introduced in its online report saying that the logistic industry will have a chance to adopt AVs faster than any other industry due to the fact that logistics is less complicated and liability is less pressing since AVs are delivering goods rather than human beings [3]. The report mentioned four application areas of AVs in the logistic industry including warehouse operations, outdoor logistic operations, line haul transportation, and last-mile delivery.

ADVs have positive effects, but before they are more widespread and manufactured in bulk, there are some concerns regarding ADVs that are yet to be explored more. A primary concern in this area is road safety and pedestrian safety. It has already been shown that AVs have the potential to increase traffic safety, but evaluating the safety of pedestrians, interactions with common neighborhood surroundings, and overall safety impact is still a large issue. Many studies in this area use simulations to evaluate the safety impacts, but come with limitations. This remains a major challenge due to the limited real world data available as the deployment of ADVs is still done on a small scale. Nuro, a company that designs ADVs has recently become the first company approved to operate a driverless delivery business in California. Nuro's vehicles operate exclusively on public roads, and they partner with companies to make deliveries. Nuro recently funded and supported a study by the Virginia Tech Transportation Institute to understand how the increasing number of Occupantless Vehicles (OVs) influence crash risk and associated injuries [4]. They used a dataset consisting of crashes with other vehicles, motorcycles, and non-vehicles and used the Nuro vehicles characteristics in place of the vehicle causing the accident to assess how much of the crash and fatalities could have been avoided. The results for non-motorist were that using OVs would improve pedestrian protection by 23% versus light trucks and 3% versus passenger cars at 25mph. It was estimated that a full scale market of OVs would reduce fatalities by 58.2% and 61.8% of the injuries would be reduced. However, these results still have limitations as speeds can vary, the place of impact with the vehicle can vary, and the results are based on modeling rather than physical crash tests. We believe that as the market for ADV's increases, further safety studies will be done and physical accidents will be observed as well.

ADVs will be mostly applied in last-mile delivery. The traffic environment of last-mile delivery is ideal for AVs because the traffic involved in this situation is usually low speed which gives AVs more time to make decisions when an emergency happens. The National Highway Traffic Safety Administration (NHTSA) recently permitted the deployment of the low-speed maintained ADVs. Unlike other traditional low-speed vehicles, the ADVs have an enormous benefit of removing human occupants completely in the whole delivery process. With the revolutionized growth of e-commerce, the need for light delivery services such as ADVs has increased drastically. Additionally, the ongoing pandemic COVID-19 clearly shows the urgent need for a humanless light delivery system. To make ADVs more common on the residential areas and low-speed roadways, there is an urgent need for performing a rigorous investigation on the ADV associated key issues such as safety and operations. Many researchers conducted a variety of studies related to AVs in general. However, literature related to ADVs is still limited. We conducted a scoping review on this important topic. This study can be considered as a starting point in addressing this specific issue.

Literature Review

We used two prominent citation indexing servers (web of science or WOS, and Scopus) to identify the relevant studies. The studies range from design to operation, deployment, and safety. The current scoping review is limited to the following critical topics:

- ADV Design
- ADV Network and System Operation Design

- Crash Prevention and Safety
- Potential Impacts and Challenges of ADV
- Emission Reduction of ADV
- Public Acceptance of ADV
- Policy-making for ADV

Several existing studies have reviewed the development and strategies of ADVs. Flämig comprehensively introduced strategies to apply AVs to road freight transportation systems on public facilities [5]. This study investigates to what extent can AVs be applied to road logistic system. The study provides a historical understanding of in-house logistic which helps to understand why companies choose to use AVs in logistic system. Moreover, it also introduces the navigation, safety, and control requirement for ADVs. Paddeu and Parkhurst explored the developments in ADVs and presented a thorough review by focusing on its current and future development state [6]. Research gaps regarding the identification of the advantages of ADVs in terms of the economic benefits and the development cost still exist. Moreover, they indicated that practice and policy barriers remain. Table 1 summarizes these two studies and Figure 1 presents the ADVs of four different companies. Discussion on seven critical topics is provided in the following sections.

Author	Research Problem	Method	Key Findings
Flämig (2016) [5]	Overview of the current application and development history	Review Paper	• Introduced how AV can be applied to road freight transportation system on public facilities.
Paddeu and Parkhurst [6]	Offers an overview of emerging new technologies	Review Paper	• Explored the developments in both surface and aerial ADV. • A thorough review of automated urban freight transport systems. • Research gaps regarding the economic benefits of ADV and the developments cost still exist. • Barriers between practice and policy remain.

Table 1. AV related general studies

ADV Design

ADV design is broad and often tailored to specific tasks or environments. In general, AVs for passenger transportation can be directly used for cargo delivery. However, in many situations, ADVs require many different features than passenger AVs. For example, the level of inside safety protection of ADVs does not need to be as high as that of passenger AVs. While it requires more outside safety standard to protect surrounding pedestrians. Moreover, ADV should be lighter and smaller than passenger AV which makes ADV easy to operate in neighbourhood with high population density. Some types of ADVs also need specially designed docking procedures to load and unload goods. Thus, designing ADV for specific needs is very important for the operation effectiveness and safety of ADVs.

Clarembaux et al. presented a solution for future urban freight transportation built upon 100% electrical vehicles [7]. They addressed the onboard intelligence units and improved the visualization and control units for parking and docking process. Mathisen et al. proposed an ADV concept which focuses on dropping a UAV freely to the desired spot [8]. This concept includes a proposal for dynamic release state measurements with appropriate re-optimization frequency regarding the wind speed and current UAV

Fig 1. Automated Delivery Vehicles: (a) Nuro ADV; (b) Udelv ADV; (c) Amazon Prime Scout ADR; and (d) Gatik ADV.

status. Buchegger et al. studied the gap between indoor and outdoor transport robots and they transferred ideas generally applied in indoor robots to outdoor ADVs and presented a self-driving vehicle that is capable of operating in urban area reliably and distributing packages effectively [9]. They also proposed a flexible and robust navigation and mapping process to form the ADVs' capabilities. Yoo and Chankov introduced a revolutionary drone supply model which incorporates drone cargo delivery and automated mobility to satisfy the requirement of (1) high delivery demand; (2) fast supply times; and (3) complicated traffic delay situations [10] . This model has been seen to be more practical in high demand seasons as an alternative delivery form. These studies on ADV design are also summarized in Table 2.

Author	Research Problem	Method	Key Findings
Clarembaux et al. [7]	Focus on onboard intelligent units to improve the perception and control systems	Control Design	• A solution for future urban freight transportation build upon 100% electrical vehicles. • Addressed the on-board intelligent units and improved the visualization and control units for parking and docking process.
Mathisen et al. [8]	Focus on releasing objects from UAV and let them drop to landing location	Control Design	• UAV that can be dropped freely to the desired spot. • Dynamic release state measurements with appropriate re-optimization frequency regarding the wind speed and current UAV status.
Buchegger et al. [9]	Propose scalable and robust mapping and navigation process for ADV	Design Technology	• Transferred ideas of indoor robots to outdoor ADV. • Proposed an AV capable to operate in urban areas and distribute packages effectively. • Proposed a flexible and robust navigation and mapping process for ADV.
Yoo and Chankov [10]	Innovative delivery concept called Drone-delivery using automated Mobility (DDAM)	Design Science	• Introduced a revolutionary drone supply model to satisfy high delivery demand, fast supply times, and complicated traffic delay situations. • Found that drone-delivery Using automated Mobility (DDAM) is more practical in high demand seasons.

Table 2. Studies focusing on ADV design

ADV Network and System Operation Design

ADV network and system design is the core of ADV transportation. Since ADV transportation network does not involve human drivers, a reliable network and system operation design becomes even more important. A good network and system operation design can ensure goods being delivery on time and more importantly, it can also significantly reduce crashes during operation. Currently, the majority research works related to ADV are about ADV network and system operation design. Many studies have investigated the network and system operation design of ADVs and these studies are summarized in Table 3.

Haas and Friedrich proposed an urban cargo supply system based on the use of self-connected platoons [11]. The results showed a correlation between platoon arrangement and travel time, especially delays in intersections and the wait time during platoon switching. Scherr et al. proposed a Mixed Integer Linear Programming (MILP) formulation to design service networks for AVs in platoons (SNDAVP) and demonstrated how platooning can be integrated into this strategic planning problem [12]. Boysen et al. explored the idea of self-driving delivery vehicles releasing from trucks and established scheduling systems that minimize the weighted number of late deliveries to customers [13].

Scherr et al. proposed a service network design problem in an SAE level 4 environment to address strategic planning for package delivery [14]. Their findings suggested that platooning fleet coordination strategies should be dependent on the infrastructure, demand, and fleet configuration. Ulmer and Streng evaluated the potential for integrating pick-up stations with self-driving vehicles in same-day delivery [15]. They presented a policy function approximation (PFA) to determine where to send a vehicle and where to load the goods. Sonneberg et al. proposed an MILP optimization model to apply ADVs in urban last-mile shipments delivery problem [16]. The object of the model is to minimize the delivery cost using ADVs. The model selects the best locations form some existing stations for ADVs routing and positioning.

Yu suggested an AV logistic system (AVLS) optimization problem to address time schedule problems for queries allocation, vehicle routing, and battery recharging [17]. In terms of total travel distance and the use of renewable energy, the proposed problem is proven to increases AVLS performance . Jun et al. solved the pickup and delivery problem by considering ADV features [18]. A novel mathematical model was introduced to minimize the overall tardiness of transportation queries (including both partial and complete recharging strategies) and compared the proposed algorithm with others by experimental simulations under various battery levels.

Scherr et al. introduced a service network design problem in a city logistics system for the strategic planning of a package delivery system [19]. They developed an integer programming model to evaluate the fleet mix and operation schedule. They also proposed an algorithm based on the dynamic discretization discovery scheme to solve vehicle platooning. To gain better understanding of the application of a mixed self-driving vehicles fleet in a heterogeneous infrastructure system, a case study on a real network was investigated. Yu et al. presented a two-echelon urban delivery problem. A mixed-integer programming model was introduced to address the proposed vehicle routing problem [20]. A sensitivity analysis showed that there are limited cost effects of increasing ADV operation speed and they recommended keeping ADV speed low for a pedestrian friendly environment.

Crash Prevention and Safety

Crash prevention is important for ADV as safety related issues are always the most important public concern of a new technology. Since ADVs operate in neighbourhood with high population density for most of the time, safety becomes the major concern of ADV operation especially the safe interaction between ADVs and pedestrians. As Nuro introduced in their safety report, the company especially emphasize on reducing physical harm when ADVs strike pedestrians [21]. Moreover, the NHTSA has identified 12 autonomous driving system safety elements [22]. Nuro has also introduced how they work to respond these safety elements in their safety report. One major benefit of ADV is that it can significantly reduce occupant related fatalities and injuries since most ADVs are occupantless vehicles. The study conducted by Witcher et al. shows that with full market penetration rate of occupantless vehicles, fatalities can be reduced by 58.2% and injuries can be reduced by 61.8% [4]. RethinkX suggested that there will be a at least 90% decrease in the accidents involved AVs compared with conventional vehicles based on current safety data [23]. Tesla's crash rate dropped 40% after autopilot was introduced in 2015 [24]. However, there are critics believe that a 90% decrease in accidents is too optimistic and AVs will also bring other risks that can potentially jeopardize traffic safety. Mueller et al. suggested that AVs can decrease up to 34% of traffic accidents and this number will be more if technology can eliminate all traffic violations [25]. Groves and Kalra developed an online tool to show how many fatalities can the deployment of AVs reduce under different scenarios while non of them can reach a 90% decrease [26].

Currently, studies directly related to ADV safety impact are few. However, some of the safety features of ADVs are similar with that of general AVs. In this section, several papers related to AV safety are reviewed. Morando et al. applied a simulation-based surrogate safety measure approach to study the safety impacts of AVs [2]. They found that under a high market penetration rate, AVs can substantially improve the overall

Table 3. Studies focusing on ADV operational design

Author	Research Problem	Method	Key Findings
Haas and Friedrich [11]	Present a urban freight delivery system based on AV platoon	Traffic Microsimulation	• Proposed a platoon based cargo supply system using AV. • Travel time is related with platoon arrangement especially intersection delay and platoon switching wait time.
Scherr et al. [12]	Design a service network with mixed delivery fleet	Mixed Integer Linear Programming	• Applied MILP to solve service network design for AVs in platoon • Traditional manual vehicles are set as platoon leaders in the proposed model.
Boysen et al. [13]	Design a delivery system based on ADRs released from trucks	Mixed Integer Linear Programming	• Suggested a goods delivery system with ADRs being released from trucks • Established scheduling systems to minimize the weighted number of late delivery to customers.
Scherr et al. [14]	Design service network with mixed AVs fleet	Liner Integer Programming	• Proposed a design problem of service networks to address package delivery planning problem. • Proposed the concept of a heterogeneous infrastructure system. • Platooning fleet coordination strategies are dependent on the infrastructure, demand and fleet configuration.
Ulmer and Streng [15]	Study the potential of deploying pickup stations and ADV for same-day delivery	Policy Function Approximation (PFA)	• Evaluated the potential for integrating pick-up stations with self-driving vehicles. • Presented a policy function approximation (PFA) to determine where to send a vehicle and the goods to be loaded. • Each car can finish up to 100 fast deliveries per day.
Sonneberg et al. [16]	Optimize ADVs routing and positioning in urban last-mile delivery problem	Mixed Integer Linear Programming	• Proposed an MILP optimization model to apply ADVs in urban last-mile shipments delivery problem. • Minimize the delivery cost using ADVs. • Selected the best locations for ADVs routing and positioning.
Yu [17]	Solve a two-stage request scheduling problem for ADV logistic system	Mixed Integer Non-Linear Programming	• Proposed an AV logistic system (AVLS) optimization problem. • Formulated a mixed integer non-linear programming model. • Developed a two-stage scheduling technique to get the best solutions.
Jun et al. [18]	Address pickup and delivery problem with recharging strategies	Memetic Algorithm Mixed Integer Programming	• Solved the pickup and delivery issue. • Introduced a novel mathematical model to minimize the overall tardiness of transportation queries. • Proposed two constructive heuristic algorithms. • Developed a memetic algorithm to find near-optimal solutions within a reasonable time.
Scherr et al. [19]	Plan parcel delivery network design in a city logistics setting	Integer Programming Dynamic Discretization Discovery Scheme	• Proposed a service network design problem for the planning of package delivery system. • Introduced an integer programming model to make evaluation. • Generated an algorithm to solve vehicle platooning.
Yu et al. [20]	Introduce a two-echelon urban delivery problem	Mixed Integer Programming	• Solved a two-echelon urban delivery problem. • Proposed a mixed-integer programming to address the proposed vehicle routing problem.

safety level although AVs tend to operate with smaller headway to improve roadway capacity. Ye and Yamamoto applied the heterogeneous flow model to investigate the impact of connected autonomous vehicles (CAVs) on traffic safety [27]. The results indicate that the increase in market penetration rate can bring extra benefit to traffic safety. Moreover, more cautious car following strategy can further improve safety. Papadoulis et al. developed a decision-making CAV control algorithm using VISSIM [28]. The Surrogate Safety Assessment Model (SSAM) is implemented to evaluate the safety effects of the algorithm. The result show that even at low market penetration rate, CAVs can significantly reduce traffic conflicts. Katrakazas et al. developed a novel risk assessment approach under the framework of interaction-aware motion models and

Dynamic Bayesian Networks (DBN) which combines a network-level collision estimate with a real time vehicle-based risk estimate [29]. Findings revealed that there is an improvement of up to 10 percent in the interaction-conscious model, if traffic conditions are categorized as collision-prone. Summaries of these studies can be found in Table 4.

Table 4. Studies focusing on crash Prevention and safety

Author	Research Problem	Method	Key Findings
Morando et al. [2]	Investigate the safety impact of AVs	Simulation-based surrogate safety measure approach	• AVs can significantly improve safety level under high penetration rate. • At signalized intersection, AVs reduce conflicts number by 20% to 65% with penetration rate between 50% and 100%. • At roundabout, AVs reduce conflicts number by 29% to 64% with 100% penetration rate.
Ye and Yamamoto [27]	Investigate the impact of connected AVs on traffic safety	Heterogeneous Flow Model	• Applied heterogeneous flow model to investigate the safety impact of connected AVs. • More cautious car following strategy can further improve safety.
Papadoulis et al. [28]	Developed a decision-making CAV control algorithm using VISSIM	Surrogate Safety Assessment Model	• Surrogate Safety Assessment Model (SSAM) is implemented to evaluate the safety effects of the algorithm. • Even at lower market penetration rate, the introduction of CAVs can still significantly reduce traffic conflicts.
Katrakazas et al. [29]	Develop real-time risk assessment method for AVs	• Interaction-Aware Motion Models • DBN	• Developed a novel risk assessment approach. • There is an improvement of up to 10 percent in the interaction-conscious model, if traffic conditions were considered collision-prone.

Potential Impacts and Challenges of ADV

The mass deployment of ADVs is expected to make delivery become more efficient and safer. Different types of ADV delivery networks have different impacts on efficiency and safety. However, the deployment of ADVs will also bring challenges. In the report by Marks, he introduced the risks and benefits of deploying ADVs for last-mile delivery and especially compare the risks and benefits of sidewalk ADVs with other forms [30]. Currently, the impacts and challenges of ADV are still unclear because there is no mass deployment of ADV yet. Modelling and simulation techniques should be applied to investigate the potential impacts of ADVs.

There are several studies have investigated the potential impact and challenges of ADVs. In the study conducted by Jennings and Figliozzi, they investigated the restrictions set by current legislation in the US and the time/cost reductions and efficiencies that Sidewalk ADRs gain within current legislation and abilities [31]. The results indicate that Sidewalk ADRs will have considerable expense and time savings in certain cases. Additionally, they determined Sidewalk ADRs will minimize road travel per shipped box. Bellet et al. introduced a human-machine transition (HMT) solution as a standard modeling paradigm by considering human-machine interaction (HMI) roles and ethical problems together in order to solve the problem facing highly automated vehicles [32]. The study describes problems related to handover and takeover and possible implications on insurance firms. Schlenther et al. investigated the potential impact of using personal AVs for parcel delivery [33]. They proposed a technique for simulating and evaluating the efficiency of vehicles in the urban traffic environment, both for passenger and cargo transport. The result revealed that the vehicle miles driven for freight purposes improved because of extra access and egress trips. If the supplier considers further reductions in fleet ownership, maintenance costs will further decrease. Jennings and Figliozzi analyzed the characteristics and regulation of Road ADRs in the U.S. [34]. The study notes that Road ADRs would save a considerable amount of costs in certain scenarios at the price of much higher vehicle miles per customer serve. These studies are summarized in Table 5.

Table 5. Studies focusing on impacts and challenges

Author	Research Problem	Method	Key Findings
Jennings and Figliozzi [31]	Study the potential of sidewalk ADRs on freight efficiency	Continuous Approximations	• Investigated the restrictions by current US legislation. • Discussed current Sidewalk ADRs' technological capacities. • Examined the time/cost reductions and efficiencies that Sidewalk ADRs can gain. • Sidewalk ADRs will have considerable expense and time savings in certain cases. • Sidewalk ADRs will minimize road travel per shipped box.
Bellet et al. [32]	Analyze the potential impact during the transformation from semi to fully AVs	Human-Machine Transition (HMT) Approach	• Introduced a human-machine transition (MMT) solution to solve the problem of highly automated vehicles by considering human-machine interaction (HMI).
Schlenther et al. [33]	Investigate the potential impact of using personal AV for parcel delivery	Multi-Agent Transportation Simulation	• Proposed a technique to simulate and evaluate vehicle efficiency in urban area. • Studied the consequences of the decreasing in fleet ownership. • The vehicle miles for freight purposes improved because of extra access and egress trips. • Further decrease in fleet ownership can further decrease maintenance costs.
Jennings and Figliozzi [34]	Study the potential of roadway ADR on freight efficiency	Continuous Approximations	• Analyzed the characteristics and regulation of Road ADRs in the U.S. • Investigated the relatively effective travel, time and expense of the Road ADRs. • Road ADRs would save a considerable amount of costs in certain scenarios. • Road ADRs can contribute substantially for additional car miles per customer served.

Emission Reduction via ADV

The majority of ADVs nowadays are electric vehicles. Even though some ADVs might still use gasoline as their power source, AV operation and control system make these vehicles become more environmental friendly compared with human driven vehicles. Thus, one significant benefit of the application of ADV is emission reduction. Some researchers have conducted studies related to this topic. Nasri et al. tackled the question of improving ADT speeds to reduce pollution rates, fuel consumption, and trip times by applying two-stage stochastic programming formulations [35]. The results demonstrate that stochastic modelling has added value over a deterministic method and the quantified advantages of speed optimization. Figliozzi and Jennings presented a model and reviewed multiple scenarios to better understand ADRs energies and carbon reductions in the future [36]. Findings showed that ADRs could substantially reduce energy usage and CO2 in urban areas. Figliozzi investigated efficiencies in vehicle-miles, oil usage, and CO2 pollution associated with both air and ground delivery vehicles, including AVs [37]. They developed a function (including factors such as the size of the order and the types of vehicles a self-pickup customer may drive) to evaluate the tradeoff between self-pickup and automated delivery. Detailed information of these studies are summarized in Table 6.

Public Acceptance of ADV

Another important topic of ADV is the public acceptance. Since ADV delivery is a emerging technology, consumers still have many doubts and uncertainties toward ADVs. In order to deploy ADV service more effectively, it is necessary to understand what

Table 6. Studies focusing on emission reduction

Author	Research Problem	Method	Key Findings
Nasri et al. [35]	Reduce emission by optimize speed and route for ADTs	Two-Stage Stochastic Programming Formulations	• Applied two-stage stochastic programming formulations to improve ADTs speeds to reduce pollution. • Stochastic modeling has added value over a deterministic method.
Figliozzi and Jennings [36]	Investigate the impact of ADR on energy consumption and emission	Continuous Approximations	• Presented a model to understand future ADRs energies and carbon reductions. • ADRs could significantly reduce CO2 emission in urban areas.
Figliozzi [37]	Study the carbon emission reductions by air and ground ADV	Continuous Approximations	• Developed a function including the size of order and vehicle types consumers drive to evaluate the tradeoff between self-pickup and automated delivery.

factors affect public's decision to accept ADV as a new delivery form and companies can use the findings to address people's concerns accordingly. Pani et al. analyzed the public acceptance of the ADVs and conducted a thorough review of public feedback using the representative sample of 483 Portland customer desires, faith, attitudes and willingness to pay (WTP) [38]. This study offers realistic guidelines for promoting the mass adoption of carbon-friendly delivery vehicles by defining the latent class WTP determinants. Kapser and Abdelrahman suggested that ADVs may be a resource drain if ADVs are not generally embraced as an alternative to be produced [39]. A structural equation modeling has been carried out using quantitative data obtained via an online survey methodology (n=501), they found that price sensitivity is the best indicator of consumer adoption, followed by performance expectancy, hedonic motivations, potential risk, social factors, and facilitating polices. However, no effects of effort expectation could be identified. Kapser et al. investigate the difference between the ADV acceptance of men and women during the COVID-19 pandemic [40]. They extended Unified Theory of Acceptance and Use of Technology (UTAUT2) by including gender as a moderator. Then structural equation modelling was applied to analyze the data collected from questionnaire. The findings conclude that price sensitivity is an important factor of consumers' ADV acceptance in Germany and perceived risk plays a decisive role of the ADV acceptance among female consumers in Germany. Detailed information of these studies are summarized in Table 7.

Table 7. Studies focusing on public perception

Author	Research Problem	Method	Key Findings
Pani et al. [38]	Evaluate public acceptance of ADR during COVID-19 pandemic	Latent Class Analysis (LCA)	• Analyzed the public acceptance of the ADRs and carried out a thorough review using the representative sample of 483 Portland customers. • Offered realistic guidelines for promoting the mass adoption of carbon-friendly delivery vehicles.
Kapser and Abdelrahman [39]	Investigate user acceptance of ADVs in Germany	Structural Equation Modelling (SEM)	• Used an expanded UTAUT2 (Unified Theory of Acceptance and Use of Tech) to research the public acceptance of ADVs among users in Germany. • Carried out structural equation modeling using quantitative data obtained via an online survey. • Price sensitivity has been found to be the best indicator of consumer adoption, followed by performance expectancy, hedonic motivations, potential risk, social factors and facilitating polices.
Kapser et al. [40]	Investigate the difference between ADV acceptance of male and female in Germany	Structural Equation Modelling (SEM)	• Used an expanded UTAUT2 (Unified Theory of Acceptance and Use of Tech) with gender as a moderator. • Carried out structural equation modeling using quantitative data obtained via questionnaire. • Price sensitivity has been found to be the best indicator of consumer adoption and perceived risk is a decisive factor for female consumers.

Policymaking for ADV

In terms of policymaking for ADV in road freight networks, the studies on this topic are limited. Most of the studies are related to policymaking for passenger AVs. Policymaking is crucial for the efficient deployment of ADVs. Marks provided a thorough review on the current local, state, and federal laws which regulate ADVs operation [30]. It also summarized the law and federal agencies that regulate UAVs, AVs, ADVs, and ADRs.

Crayton and Meier studied the public health implication brought by mass deployment of AVs which includes the benefit and harm to individual and population health [41]. They investigated how these implications can be considered when making AV related transportation policy. Monios and Bergqvist designed an electric and automated vehicles transport geography and set a research strategy for road freight transport by identifying outstanding problems [42]. A list of study questions on this emerging mode of transport was presented to provide guidance to policymakers. Faisal et al. conducted a literature review on AV pre-deployment policymaking [43]. Three topics are identified in this study: (1) Testing and Deployment; (2) Privacy and Cybersecurity; (3) Liability and Insurance. Detailed information of these studies are also summarized Table 8.

Table 8. Studies focusing on policy related issues

Author	Research Problem	Method	Key Findings
Crayton and Meier [41]	Consider the health implication of AV when making AV related transportation policy	Review Paper	• Considered the health implication (both benefits and harms) of AV when making AV policy. • Concluded that public health research agenda can provide n AV policy that can better support public heath.
Monios and Bergqvist [42]	Elaborate the transport geography of electric and automated vehicles for road freight transport	Analytical Framework	• Designed the electric and automated vehicle transport geography. • Set a research strategy for road freight transport. • Used an intermodal transport research system to explore the evolving EAV geography. • Decided how intermodal transport features, threats, business models and policy ramifications would assist decision-makers to prepare for the evolving EAV network growth.
Faisal et al. [43]	Review pre-deployment policymaking for AV	Review Paper	• Identify three topics that are crucial to AV pre-deployment policymaking.

Major Findings

This research identify seven critical ADV related topics. The major findings are listed as followed:

- Past studies have not focused much on ADVs. It is important to note that ADVs are usually deployed on low-speed roadways with an enormous number of potential conflict points due to the presence of driveways and non-motorists. There is a need for additional studies to address the safety and operational issues of ADVs.
- Among the ADV related studies reviewed in this paper, a large amount of studies are associated with ADV network and system operation design. This is reasonable because right now there is still no mass deployment of ADVs. Researchers are more interested in designing efficient and safe ADV network and operation system to prepare for the mass deployment of ADV in the future.
- Studies related to the safety issues of ADVs are very limited. The existing studies on this topic is only about the safety feature of passenger AVs. Although

passenger AV and ADV share some similar safety features, the operation environment between these two are different. Thus, more studies are needed to investigate the safety aspects of ADVs specifically.

- Very few studies focused on the potential impacts and challenges of ADVs. The relevant studies are mostly based on modelling and simulation. It is also due to the less deployment in the real-world scenarios. Once mass deployment of AV becomes reality in the future, more studies on this topic will emerge.

- The studies on the public acceptance of ADV are also limited. This is a very important topic because companies and practitioners can rely on the findings to deploy ADV service more effectively based on what consumers concern the most.

- Very few studies conducted studies on policy related issues associated with ADVs. Policymaking is very crucial for an emerging or disruptive technology. It can ensure the effective development of ADVs in the future. Thus, more studies related to ADV policymaking are needed.

Conclusion

In this study, we conducted a scoping review of ADVs. Our analysis focused on seven general safety and operation related sub-topics: (1) ADV Design; (2) ADV Network and System Operation Design; (3) Crash Prevention and Safety; (4) Potential Impact and Challenges of ADV; (5) Emission Reduction via ADV; (6) Public Acceptance of ADV; (7) Policymaking for ADV. We found that ADV network and operation design had the most studies likely due to wanting to lay the foundations of a larger production in the future. Despite Public Acceptance, Policymaking, Crash Prevention and Safety, and Potential Impact and Challenges being important topics, there are a limited number of studies. ADVs are still new and are yet to be widespread and manufactured on a larger scale. We believe that in the future we can expect ADVs to be increasingly influential on society, and expect more studies to occur in these areas. To the best of our knowledge, this is the first study that has conducted a scoping review on the safety and operational issues of ADVs. We provided a brief overview based on the available studies and this work can be extended with the inclusion of new studies on this topic.

This study can be considered a generalized scoping review on ADVs. The studies and the discussion on the ADV related studies can help policymakers and practitioners to better understand ADV in general. This study has limitations due to the limited number of available studies on ADVs. We included some studies that are broadly related to ADVs. Future studies can mitigate the current limitations by considering more studies related to this topic.

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