Building on the Past to Help Prepare the Workforce for the Future with Automated Vehicles: A Systematic Review of Automated Passenger Vehicle Deployment Timelines

Shubham Agrawal*
Department of Psychology
Clemson University, Clemson, SC 29634, USA
Email: agrawa3@clemson.edu
ORCID: https://orcid.org/0000-0002-0990-9785

Amy M. Schuster
Department of Sociology, Anthropology and Criminal Justice
Clemson University, Clemson, SC 29634, USA
Email: amschus@clemson.edu
ORCID: https://orcid.org/0000-0002-4472-0283

Noah Britt
Department of Engineering, Computing and Applied Sciences
Clemson University, Clemson, SC 29634, USA
Email: nbritt@clemson.edu

Elizabeth A. Mack
Department of Geography, Environment, and Spatial Sciences
Michigan State University, East Lansing, MI 48824, USA
Email: emack@msu.edu
ORCID: https://orcid.org/0000-0002-1829-8787

Michael L. Tidwell
Department of Sociology, Anthropology and Criminal Justice
Clemson University, Clemson, SC 29634, USA
Email: mltidwe@clemson.edu

Shelia R. Cotten
Department of Sociology, Anthropology and Criminal Justice
Department of Communication
Clemson University, Clemson, SC 29634, USA
Email: scotten@clemson.edu
ORCID: https://orcid.org/0000-0002-8657-8262

* Corresponding author. Address: 319C Brackett Hall, Clemson, SC 29634, United States. Tel: +1 (765) 409-9067. Email: agrawa3@clemson.edu (S. Agrawal)

Abstract

A variety of stakeholders have put forth automated vehicle (AV) deployment timeline predictions over the past decade. To synthesize these predictions, we performed a systematic literature review of past and current AV deployment timeline predictions in the United States from different stakeholder groups, including private stakeholders, government organizations, and research organizations. Our analysis revealed that none of the AV mass deployment timelines from any stakeholder group have been met. It also shows discrepancies between timelines put forth by private and public stakeholders, with the private sector being more optimistic in their predictions. Accurate timelines are needed so regulators are able to create appropriate public policies and comprehensive budgets, and private stakeholders can make better informed decisions. More specifically, the mass deployment of AVs is anticipated to affect many transportation-related jobs which reinforces the importance of accurate AV deployment timelines to prepare the workers who may be displaced and for the development of workforce education and training initiatives.

Keywords: Automated vehicle; Mass deployment; Timeline prediction; Regulation; Industry

1. Introduction

Though media attention surrounding AVs has increased over the past decade, the idea of self-driving cars or AVs has fascinated the public for decades, and technologists have forecasted for quite some time that the age of driverless cars is just around the corner (Gammon, 2016; Stayton, 2015; Tennant & Stilgoe, 2021). At the 1939 exhibit entitled "Highways and Horizons," also known as "Futurama," General Motors presented a futuristic vision of sprawling highway systems where cars drove themselves (Coombs, 1971). This fascination with projecting the arrival of AVs prompted Jameson Wetmore, a technology researcher, to note: "At every point in the past 50 years, someone mentioned that autonomous vehicles were just 20 years in our future… That's what they said in the '60s, the '80s, and the late '90s" (Gammon, 2016, para. 1).

Research and demonstrations of AVs date back to 1925 ("Science: Radio Auto," 1925) and continue to the present day. Demonstrations of the latest AV technologies for passenger transportation are evident in companies ranging from automakers like General Motors (Hawkins, 2017) to technology companies like Google/Waymo (Sage, 2018). Several retail businesses like Walmart (Straight, 2021) and Domino's Pizza (Marakby, 2018) have also partnered with AV developers to test future driverless delivery options.

If we are to adequately prepare the workforce of tomorrow to meet the demands of the changing nature of work, we need to understand how jobs are expected to change over time. One of the challenges of understanding how jobs will change is having an accurate timeline for projected changes in specific industries. Changes due to automation in the transportation industry are one area that society must grasp if we are to prepare to meet the changing demands of the workforce of tomorrow. We conduct a systematic review of past and current automated vehicle (AV) deployment timeline predictions from different stakeholders, including private stakeholders, government organizations, and research organizations. We also delineate states that have passed laws surrounding AVs. A thorough and systematic review of these timeline predictions and state laws can help transportation, workforce, and education entities determine how timelines have evolved over time and what may be realistic moving forward as we seek to adequately prepare the workforce of tomorrow to meet the demands of automation. Examining different stakeholder groups also highlights which stakeholders are more optimistic or conservative in their predictions, which may suggest specific areas where outreach and education efforts are needed.

2. Background and Motivation

2.1. Factors affecting AV deployment timelines

The research community has devoted considerable attention to understanding AV perceptions (Bansal & Kockelman, 2017; Othman, 2021) and other factors that might facilitate or act as barriers to the deployment of AVs (Alfonzo, 2020; Brodsky, 2016), which could directly and/or indirectly impact AV timelines. Due to the lack of federal and state regulations to guide AV deployment (Cohen & Cavoli, 2019; Vincent, 2021), many in the automotive industry view regulatory hurdles as the largest barrier to mass AV deployment (Brodsky, 2016). The lack of regulations can also negatively affect the business ecosystem (Pütz et al., 2019). For example, a lack of equal access to AV data for insurance companies may lead to unfair and distorted market competition that can be monopolized by AV companies. Federal legislation pertaining to AVs remains minimal, providing only recommendations which are not enforceable (NHTSA, 2017). Laws on AV deployment are generally left to individual states, which vary across states (Brodsky, 2016; Geistfeld, 2017; Rodriguez & Isaac, 2017). For example, special AV license plates are required in Michigan but are not required in Virginia (Hubbard, 2018). Efforts to centralize the regulatory process have been attempted, but thus far have not yielded any results (Canis, 2018). The lack of centralization acts as a strong barrier to mass AV deployment, as inconsistencies and uncertainties in state-level policies hinder the automotive industry's ability to form concrete deployment timelines.

In the 1990s and earlier, technology development was considered a key barrier to AV deployment (Bender, 1991). However, with increasing real-world AV testing and pilot programs on public roads, valuable data exists to help AVs address safety-critical, edge-case scenarios (Widen & Koopman, 2022). Currently, the high cost of AV technologies is a barrier that hinders mass AV deployment (Nunes & Hernandez, 2019). In addition, the high costs of insurance, maintenance, and safety measures could offset the economic benefits of AVs (Compostella et al., 2020; Nunes & Hernandez, 2019) and pose a barrier to AV deployment for private stakeholders (developers and investors). AV developers and manufacturers deal with the high risks associated with technology innovation and commercialization such as concerns over intellectual property rights (Marshall & Davies, 2018), which can dissuade private stakeholders from government collaboration (Cheon, 2003b) and can potentially lead to discrepancies in deployment timeline predictions from public and private sectors.

The earliest efforts in developing AV deployment timelines noted the importance of infrastructure (Bender, 1991). Automated highway system (AHS) was seen as the most comprehensive way to address infrastructure needs for automated travel via the incorporation of intelligent technologies (e.g., traffic monitoring) into highway infrastructure (Federal Highway Administration, 1995). There has been a shift from infrastructure-controlled technologies to in-vehicle technologies (Cheon, 2003b), allowing the private sector to take the lead in developing AV technologies (Rouse et al., 2018). However, independently operating AVs on the road will still need infrastructure resources such as proper lane marking, and 5G networks (Leonard et al., 2020). The multi-year funding and planning efforts necessary to meet AV-specific infrastructure demands may pose a barrier to the development of accurate timelines and mass deployment of AVs, as the barrier may result from a lack of implementation pathways for AV technology rather than the development of the technology itself. Additionally, unlike private sector companies with shorter-term goals of achieving a return on their investments, local and state governments face longer-term hurdles to AV deployment that require substantial and consistent funding, such as the modification of infrastructure and development of effective workforce programs (Saghir & Sands, 2020). The cost of AV technology of updating infrastructure (Chajka-Cadin et al., 2020) and the shortage of workers with the necessary professional and technical skills to operate and maintain emerging vehicle technologies (Cheon, 2003a) have also been cited as barriers for AV deployment.

There is a shortage of workers with the necessary professional and technical skills to operate and maintain emerging vehicle technologies, particularly in state and local government transportation agencies (Cheon, 2003a). Studies have projected that driving-related jobs may be displaced (e.g., taxi and bus drivers) and vehicle-related service roles (e.g., patrol officers and insurance appraisers) could decrease or even be eliminated through the introduction of AVs (Groshen et al., 2018; Sohrabi et al., 2021; Yankelevich et al., 2018). This potential has resulted in a pushback against AV deployment from unions and organized workers such as the Upstate Transportation Association in New York, which called upon state legislators to ban Uber and Lyft from testing AVs in New York City (Hamilton, 2017). This resistance may become another barrier to deployment (Ryan, 2020). Generalized fear of technology as a barrier to AV adoption may actually be linked to how threatened Americans are by the prospect of unemployment and financial insecurity (McClure, 2018). Hence, policy responses also needed to support the deployment of AVs, such as leadership initiatives, and workforce education and training (Leonard et al., 2020).

The introduction of AVs will likely lead to a decrease in state revenues through reduced profitability of gas taxes, parking fines, and traffic infraction fees (Fox, 2020). This impact cannot be understated, as state gas taxes boast a cumulative revenue of almost $35 billion (about $110 per person) across the U.S. (Ratner, 2017). While some cities have considered placing a tax on the use of AVs (e.g., San Francisco, CA), testing and potential deployment of AVs is being incentivized as opposed to taxed by state legislatures at large (National Conference of State Legislatures [NCSL], n.d.). The introduction of AVs would also provide financial benefits to the government, for example, reduced healthcare spending because of the reduction of roadway accidents (Freedman et al., 2018). Most U.S. states have passed legislation paving the way for AV mass deployment (NCSL, n.d.) and would likely consider fast-tracking these programs if current funding was available without sacrificing longer term financial stability.

The public opinion of AV technology is one of hesitancy and mistrust (Fraade-Blanar et al., 2021; Jagst, 2020), especially by certain population subgroups like female consumers (Rice & Winter, 2019). Research has shown that trust is a major contributor to consumer's intention to use AVs (Dirsehan & Can, 2020). The industry, which has historically focused on developing trust with the public and their developers in order to avoid federal, state, and local regulatory interference, has ultimately created distrust and increased concerns over the lack of regulations and safety of emerging AVs (Widen & Koopman, 2022). This fear has increased with the number of reported accidents (Othman, 2021). While the public does see benefits to AVs, such as the ability to multitask while in the car (Ryan, 2020), the overall sentiment of public perception of the safety of AVs seems to be negative (Fagnant & Kockelman, 2015; Wang et al., 2020), and it may take some time to instill public faith in AV technology (Lavasani et al., 2016; Saghir & Sands, 2020). Previous research also suggested that the current standards of level of automation (e.g., SAE) are techno-centric and are not 'consumer-friendly,' which can lead to confusion (e.g., linear expectation of technology innovation or misinterpretation of AV capability) (Hopkins & Schwanen, 2021) and, thereby, hinder their deployment. From a socio-technical perspective, researchers have examined our attachment to the idea of AVs to better understand solutions that will need to be implemented for AVs to be widely deployed (Tennant & Stilgoe, 2021).

Situational factors may also affect AV deployment timelines. For example, COVID-19 presented economic barriers to private sector AV development as transportation companies were faced with decreased demand for ride-hailing services during lockdown periods (Hawkins, 2020;

Teale, 2020). In an effort to reduce high costs during the pandemic, both Uber and Lyft sold their AV divisions, which were acquired by Aurora and Toyota, respectively (Bursztynsky, 2020; Hawkins, 2021). The pandemic also presented opportunities for AV development and deployment. New delivery options to reduce human contact were shown to be more favorable for current virus-related circumstances, which may lead to quicker AV adoption (Kapser et al., 2021).

As detailed in this section, a myriad of factors are related to whether AVs are deployed in the U.S. Without a full understanding of how these factors are interrelated, it is unlikely that any entity could develop accurate AV timelines.

2.2. Study contributions

Accurate timelines of advancements in AV technologies and their commercial viability can help regulators to design timely and relevant public policies and create well-planned budgets. For example, since the mass deployment of AVs is likely to affect several transportation-related jobs (e.g., truck and taxi drivers) (Yankelevich et al., 2018), estimates of AV timelines can impact the workforce development policies and efforts toward specific workforce sectors (Hendrickson et al., 2014). It can also impact investment-heavy infrastructure plans such as AV-dedicated lanes (Guo et al., 2021; Seilabi et al., 2020) or 5G network connectivity infrastructure (Leonard et al., 2020). On the other hand, AV-related regulatory timelines can aid private stakeholders in making more informed business decisions. Timeline predictions from different sources can also affect workers' perceptions of the impacts of AVs on their jobs (McClure, 2018) as well as the public's trust in AVs and, thereby, their acceptance of AVs (Othman, 2021).

In the past, AV deployment timelines have been proposed by groups ranging from technology developers, industry experts, researchers, and government agencies (Faisal et al., 2021; Simons et al., 2018). However, to the best of our knowledge, none of the existing studies have systematically reviewed and analyzed AV timelines from different perspectives (including industry, government, and research communities); nor, have researchers examined whether AV timelines have been met. In this context, the purpose of the present study is to synthesize AV deployment timelines in the light-duty passenger vehicle sector to answer the following research questions. First, what are the timeline predictions put forth by different stakeholders (i.e., industry, government, and research community) and have they been met? Second, how do timeline predictions vary depending upon stakeholder groups?

3. Methods

For this systematic literature review, we analyzed AV deployment timeline predictions from three different sources (published research articles and reports, industry predictions, and AV legislation and executive orders) to achieve a detailed and comprehensive review of the various stakeholders (i.e., research organizations, private industries, and government organizations). This inclusive approach allowed us to compare timeline predictions put forth by the different stakeholders for accuracy and discrepancies. We focused our discussion on light-duty passenger vehicles, including privately-owned AVs and robotaxis (i.e., driverless taxis), given that different AV applications (e.g., trucking, delivery, transit, and passenger cars) will most likely have their own set of barriers and facilitators to deployment (Yankelevich et al., 2018). Further, we considered only U.S.-based or global timelines in our review, since the regulatory framework surrounding AVs varies across countries (Lee & Hess, 2020).

During our review, a challenge that emerged in the lack of consistent terminology denoting varying technological levels of automated vehicles as defined by SAE J3016 (SAE International, 2021). Therefore, if a reviewed source did not identify the SAE level of automation, we approximated based on the contextual information available to determine the automation level being discussed. Our study uses the following terminology for clarity and consistency: the term "automated vehicle" (AV) is used for SAE level 3 or greater systems; "self-driving vehicle" (SDV) to indicate SAE Levels 4 or 5 systems with a safety driver; and "driverless vehicle" (DV) to indicate SAE Levels 4 or 5 systems without a safety driver.

3.1. Published peer-reviewed research articles and reports

Timeline predictions from published research articles and reports were gathered following the PRISMA framework (Page et al., 2021). We searched three databases (ProQuest, EBSCOhost Multi-Database Search, and Web of Science Core Collection) for peer-reviewed literature published between January 1, 1990, and September 30, 2022, which yielded 2,030 articles. In addition, the Transport Research International Documentation (TRID) database was searched for published reports from various federal and state agencies in the U.S. and research organizations, which yielded 391 reports. The search terms and other search parameters are summarized in Table 1. After retrieving the articles from the four databases, we removed duplicate articles. Next, we screened the titles, keywords, and abstracts to exclude articles from unrelated domains (e.g., underwater vehicles), articles that focused on a specific engineering problem rather than deployment timeline or issues (e.g., vehicle control system, sensing equipment, trajectory planning), and articles with findings from regions outside of the U.S. (e.g., survey studies from Europe). Articles for which we could not find the full text were also excluded. We reviewed the full text of 633 articles and found 100 articles with AV timeline predictions for passenger vehicles in the U.S. or worldwide. However, most of these AV timeline predictions were cited from other sources (i.e., cross-cited articles) and not an original timeline prediction from the reviewed article. To address this issue, we expanded our review to include these cross-cited articles that were not included in our original search. We removed duplicate cross-cited articles and then reviewed the remaining articles for original timeline predictions. Our final sample for analysis includes 43 articles with original AV timeline predictions. The systematic review protocol that details the review process is illustrated in Figure 1.

Table 1. Search parameters for the systematic review

Search Query[1,2]	Database	Article Types	Language	Region[3]	Number of search results
TITLE = (“autonomous vehicle?” OR “automated vehicle?” OR “self-driving vehicle?” OR “driverless vehicle?” OR “autonomous car?” OR “automated car?” OR “self-driving car?” OR “driverless car?” OR “automated highway system?”) **AND** TERMS = (“forecast*” OR “deployment” OR “timeline?” OR “market penetration” OR “adoption” OR “commercially available”)	ProQuest	Peer-reviewed	English	None	588
	EBSCOhost	Peer-reviewed	English	None	1013
	Web of Science	Peer-reviewed	English	United States	429
	TRID	Reports, books, and collections	None	None	391
Total					**2421**

Notes.
[1] The field TERMS refers to “full text” for ProQuest, “all text fields” for EBSCOhost, “topic” for Web of Science, and “keywords” for TRID.
[2] “?” denotes a wildcard for single character and “*” denotes a wildcard for multiple characters. This allowed us to include plural of the search terms.
[3] The region filter was used only if all searched articles in the database had a region associated with them. Thus, we avoided excluding articles that may not have this metadata information available.

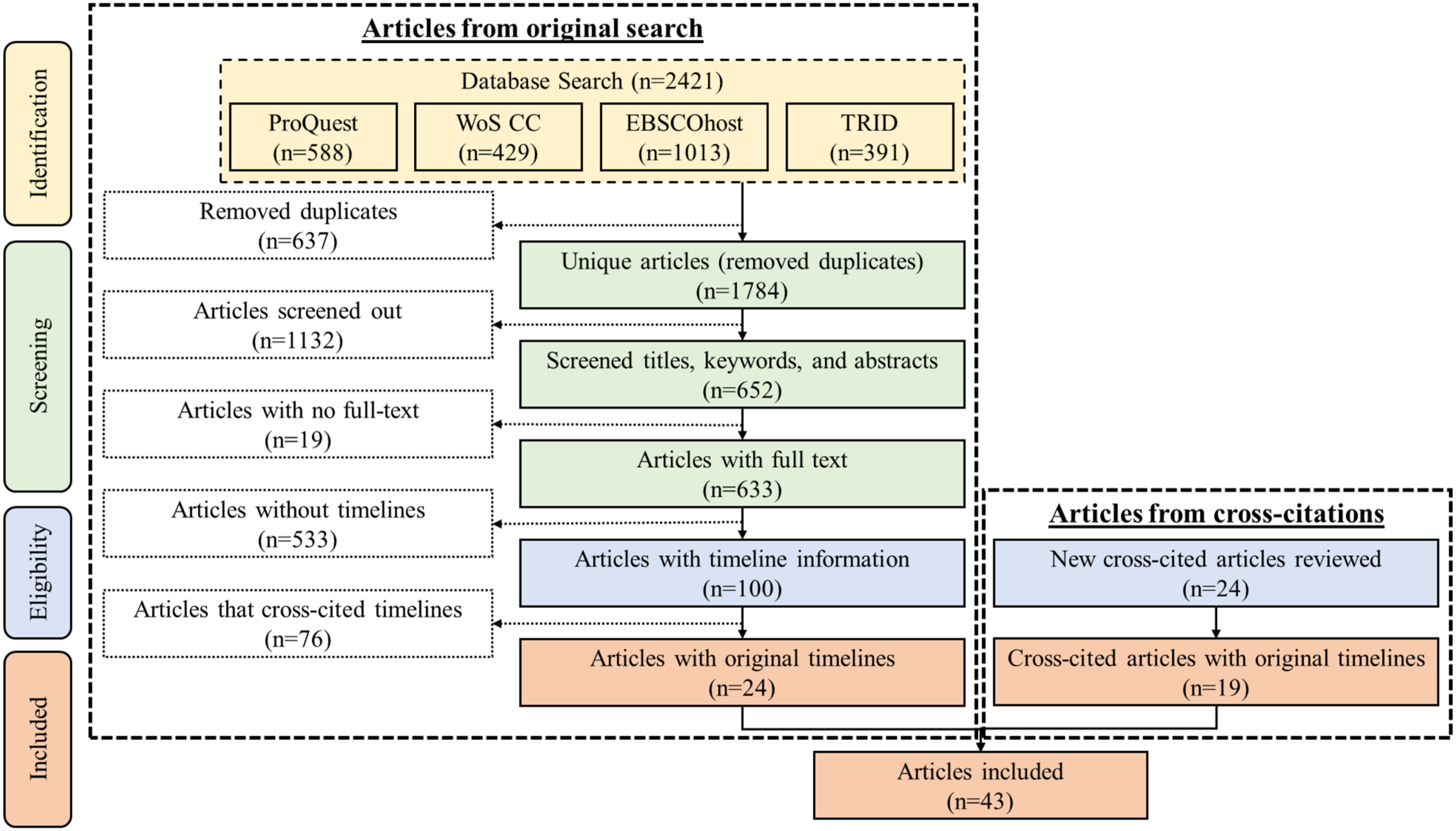

Figure 1. Systematic review protocol

3.2. Industry predictions

To capture AV deployment predictions from private stakeholders, we reviewed popular media sources. Given the overabundance of predicted AV deployment timelines from the private sector, it was impractical for us to perform a systematic review. Hence, we focused our efforts on obtaining an approximate representative sample by reviewing timelines from all major AV companies operating in the U.S. Since we did not do an exhaustive search, there may be some bias in our review of industry predictions. We searched for newspaper articles and company press releases on Google Search and several databases (including U.S. Major Dailies, Newswire, and Newspaper Source Plus) using the same search terms presented in Table 1. Given that the interest in the AV market was first sparked in early 2010s (Thrun, 2010), we reviewed popular media sources that were published between January 1, 2010, and September 30, 2022. We also included relevant major events (e.g., company partnerships, acquisitions, launches, and public tests) in the review.

3.3. AV legislation and executive orders

Legislative bills were found through the Autonomous Vehicles State Bill Tracking Database (NCSL, n.d.). At the time of this review (October 2022), the database contained all AV-related bills across all U.S. states and the District of Columbia up to July 20, 2022. These AV-related bills were then filtered to include only bills that had been enacted or adopted. Bills that were shut down, vetoed, or still in committee, were not included in the final selection. For executive orders, the website for each state governor was searched for AV-related executive orders. The text of each relevant bill and executive order was then analyzed and organized into six broad topics (i.e., taskforce, insurance/liability, funding, commercial use, testing, platoons) that were inspired by Hubbard (2018) (see Section 4.3 for more details).

4. Results and findings

We found AV timeline predictions focusing on multiple perspectives, including technological capability, commercial viability/availability, and market share. To assess the current path to AV deployment, we also reviewed relevant major AV-related events such as AV-related legislation, company partnerships and acquisitions, and public testing and launches.

4.1. Systematic literature review

We found 67 timelines from 43 different sources in our search. We classified AV timeline predictions into three categories: (i) when the AV technology will be ready ('technological capability'), (ii) when AVs will be available for consumers to use or purchase ('commercial availability'), and (iii) predictions of market share of AVs in terms of revenue, vehicle-miles traveled, or fleet size by specific years ('market share'). Some sources provided a prediction by a specific year, while others provided a range of years. We labeled the start and end year of the ranged prediction as 'optimistic prediction' and 'conservative prediction,' respectively.

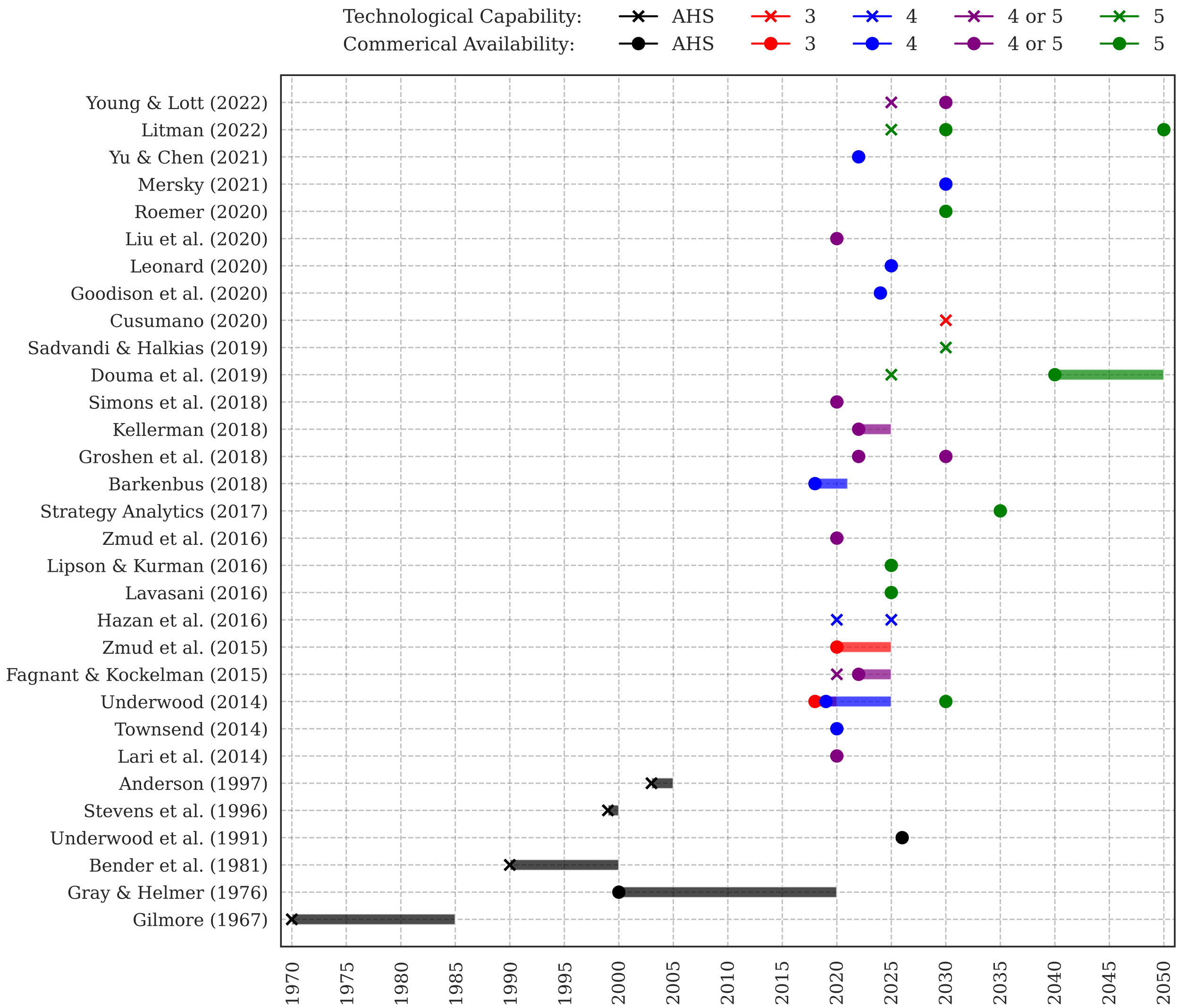

Figure 2. Timeline predictions for different levels of automation from the systematic literature review (N=41 timelines from 31 articles)

Figure 2 presents the predicted ranges of AV technological capability and commercial availability timelines from our systematic review. In the U.S., some of the earliest efforts related to AV deployment were made in the 1980s. They focused on vehicle-highway solutions, such as Automated Highway Systems (AHS). A key vision of AHS was having AVs (similar to current SAE level 4 on highways) operating with extremely smaller headways of 0.5 to 2 seconds (Bender et al., 1981). We found 6 timelines from 6 sources related to AHS published between 1967 and 1997 as illustrated in Figure 2. The results indicate that the technological capability of AHS was predicted to be ready within 10 years from the prediction year while the commercial availability was predicted to be ready between 24 and 35 years.

Gradually, the USDOT's focus shifted from AHS to intelligent vehicles with the Intelligent Vehicle Initiative in 1997 (Joint Program Office for Intelligent Transportation Systems, 1997). The next big steps toward AV development were the three grand challenges in 2004, 2005, and

2007 organized by the Defense Advanced Research Projects Agency (DARPA, 2014), which resulted in rapid AV technology development and increased business interest leading into the 2010's, both in the U.S. and globally. We found 8, 27, and 26 timelines from 38 articles related to technological capability, commercial availability, and market share, respectively, for AVs (not including AHS). Thirty-seven of these articles were published after 2010. For predictions regarding technological capability of AVs, the optimistic timeline predictions ranged from 3 to 11 years (n = 8, mean = 6.4 years, median = 5.5 years), while there were no conservative predictions. For predictions regarding commercial availability of AVs, the optimistic predictions ranged from 0 to 35 years (n = 27, mean = 7.9 years, median = 6 years) and conservative predictions ranged from 3 to 31 years (n = 7, mean = 11.1 years, median = 10 years). A summary of optimistic and conservative predictions for different levels of automation is presented in Table 2.

Table 2. Summary of timeline predictions from the systematic literature review

Level	Prediction Type	Optimistic Prediction (years)					Conservative Prediction (years)				
		n	mean	median	min	max	n	mean	median	min	max
AHS	Technological capability	4	7	7.5	3	10	4	14	13.5	4	25
	Commercial availability	2	29.5	29.5	24	35	1	44	44	44	44
3	Technological capability	1	10	10	10	10	0				
	Commercial availability	3	6	5	4	9	2	8	8	6	10
4	Technological capability	2	6.5	6.5	4	9	0				
	Commercial availability	7	4.29	5	0	9	2	7	7	3	11
4 or 5	Technological capability	2	4.00	4	3	5	0				
	Commercial availability	9	5.22	4	0	12	2	8.5	8.5	7	10
5	Technological capability	3	6.67	6	3	11	0				
	Commercial availability	8	14.88	13	8	28	1	31	31	31	31

Most market share timelines predicted AVs as a percentage of the total vehicle fleet size (n = 11). Although these predictions varied considerably, most of them agree that AVs would account for about 10-25% of the total vehicle fleet by 2030 and more than 50% by 2050. Other articles estimated the market share as the number of vehicles in the fleet (n =1), percentage of new vehicles sold (n = 3), usage share in terms of vehicle-miles traveled (n = 3), or the global economic market share (n = 2). Six predictions provided a more qualitative estimate by mentioning that AVs will reach a "critical mass," or will on the roads in "significant numbers," or make up for "most vehicles" on the road. Twenty-five out of 26 market share timelines were predicted for SAE Levels 4 or 5. More details on market share predictions are presented in Table 3.

Table 3. Market share predictions

Citation	Start Year	End Year	SAE Level	Prediction	Prediction Type	Private vehicle	Ride hailing
Underwood et al. (1991)	2011	2035	4		Most vehicles		
IEEE (2012)	2040		4 or 5	75%	Fleet size		
Lari et al. (2014)	2040	2050	4 or 5		Most vehicles		
Townsend (2014)	2030		4	25-35%	Fleet size	x	x

Citation	Start Year	End Year	SAE Level	Prediction	Prediction Type	Private vehicle	Ride hailing
Kyriakidis et al. (2015)	2050		5	50%	Fleet size	x	
Zmud et al. (2015)	2020	2035	3		Critical mass		
Zmud et al. (2015)	2035	2050	4		Significant numbers		
de Winter et al. (2015)	2030		5		Most vehicles	x	
Lavasani (2016)	2035	2050	5	8-84 million	Fleet size	x	x
Lipson & Kurman (2016)	2035	2050	5	10-100%	New vehicles		
Arbib & Seba (2017)	2031		5	95%	Usage share		
Strategy Analytics (2017)	2035	2050	5	$800 billion-$7 trillion	Global market	x	x
Strategy Analytics (2017)	2050		5	50%	New vehicles	x	x
Forsgren (2018)	2030	2040	4 or 5	2-50%	New vehicles		
Groshen et al. (2018)	2050		4 or 5	100%	Usage share	x	x
Simons et al. (2018)	2022	2050	4 or 5	10-80+%	Fleet size	x	x
Talebian & Mishra (2018)	2050		4 or 5	15-100%	Fleet size		
Yankelevich et al. (2018)	2028		4	20%	Fleet size	x	x
Zmud et al. (2018)	2038		4		Significant numbers		
Concas et al. (2019)	2030	2050	4 or 5	18.5-50+%	Fleet size		
Ksenofontov & Milyakin (2020)	2045		5	2-22%	Fleet size		
Liu et al. (2020)	2050		4 or 5	12.4-15.4 million	Fleet size		x
Roemer (2020)	2030	2035	5	$282-$558 billion	Global market	x	x
Statista (2020)	2030		4 or 5	10%	Fleet size		
Mishra et al. (2021)	2050		4	55-83%	Fleet size		
Yu & Chen (2021)	2067		4	85-95%	Usage share	x	

The mass deployment of AVs and predicted timelines are conditional on the advances in AV technology development and the state of AV-related regulatory framework (Bender, 1991; Bender et al., 1981; Fagnant & Kockelman, 2015). Thus, we discuss the timelines of major events and predictions of AV technology development and public road testing in the U.S. as well as existing AV-related regulations in the following subsections.

4.2. Industry predictions

In 2010, Google (now Waymo) revealed that they had been successfully testing SDV on public roads in California, albeit on specific routes (Thrun, 2010). Despite California not having any AV-related state legislation in place at that time, Google's testing was deemed legal per California's motor vehicle regulations as there was a safety driver present to override the automated driving system (Markoff, 2010). Soon after, Google expanded their SDV testing in the state of Nevada (Arthur, 2012), which required Google to have at least two people in the car at all times – one safety driver and another person monitoring the computer system of the vehicle. After these early efforts by Google, several companies started testing their AV technologies on public roads in the U.S., including SDVs (e.g., Mercedes-Benz (Cecotti & Groeneveld, 2013)) and DVs (e.g., Waymo (Fairfield, 2016), Cruise (Hawkins, 2017), and Motional (Motional, 2021)). More recently, some companies have also begun opening their robotaxi operations to the general public, both SDVs (e.g., AutoX and Pony.ai (Liao, 2019)) and DVs (e.g., Waymo (Krafcik, 2020; Sage, 2018) and Cruise (California Public Utilities Commission, 2021)).

Given growing efforts towards AV technology development and testing, several industry experts put forth predictions of when different levels of AV technology would be ready. For example, Tesla's CEO Elon Musk predicted in January 2016 that Tesla would have DVs that could drive from New York to Los Angeles ready by 2018 (King, 2016) and in 2016, Tesla began equipping all vehicles with the necessary hardware for a DV, preempting DV software development (Fagella, 2017). Ford's CEO Mark Fields predicted in 2015 that the industry would develop SDV technology within five years or 2020 (Su, 2015). Renault-Nissan's CEO Carlos Ghosn projected in 2016 that SDV technology would be ready by 2020 and DV technology by 2025 (Dillet, 2016). General Motors' CEO Mary Barra believes that GM will sell personal SDVs by 2030 (Korosec, 2021).

Moreover, in the early 2010s, most AV companies were trying to accomplish all tasks required to deploy AVs independently (e.g., developing different technologies and producing/retrofitting vehicles). More recently, companies have started seeking strategic partnerships with other companies and acquiring smaller companies to increase the size of consumer bases, improve production capacity, and acquire niche technologies. Table 4 summarizes the timeline of major events in the AV industry (i.e., 'business acquisitions and partnerships' and 'testing, launch, and permits') and 'timeline predictions' from U.S. industries. Further, our review revealed that several private stakeholders have a business interest in operating AV fleets to provide transportation services rather than selling them to consumers. Hence, we categorized our data further into three groups: 'private vehicles' (selling to consumers), 'ride-hailing, taxi, and delivery service' (operating a fleet to provide transportation services), and 'technology' (technological development irrespective of the business case).

Industry experts are often more ambitious with their predictions for the readiness and deployment of AV technology. For example, in 2014, Chris Urmson, an AV technology expert, predicted that his son would never need a driver's license because self-driving would be ubiquitous by the time his son reached driving age in 2019 (Gomes, 2014). However, in 2019, he more modestly stated that potentially thousands of AVs would be on the road by 2024 (Knapp, 2019).

On the other hand, some experts remained skeptical about the capabilities of AVs. In 2018, Waymo CEO John Krafcik commented that AVs that can drive in any condition without ever needing a human to intervene (i.e., SAE level 5 AV) would never exist (Tibken, 2018). Still, there is skepticism around these predictions, as they are often based on past trends of disruptive technologies such as digital cameras, smartphones, and personal computers. Additionally, those with financial stakes in the industry may be inclined to downplay the challenges to development and adoption of AVs (Litman, 2021).

Data in Table 4 shows that several major automakers like Ford and GM have recently established partnerships with companies like Lyft and Postmates to expand their business domain from primarily selling private vehicles to ride-hailing and delivery services. The table also shows strategic acquisitions and partnerships between AV technology developers (e.g., Uber) and sensing technology developers (e.g., Otto). Since 2016, several companies have started testing free SDV and DV taxi services, especially in California. These services are typically offered for free, primarily because of the existing regulatory framework that prohibits companies to charge passengers during the testing phase (California Public Utilities Commission, 2021). In 2021, companies like Waymo and Cruise requested permits from local government agencies that would allow them to offer paid robotaxi services in select areas (Jin & Dave, 2021); these requests were later granted, allowing Waymo and Cruise to charge for service in select regions of San Francisco and San Mateo counties (Descant, 2021).

The data shows that most timeline predictions for the SDV/DV technology readiness and commercial availability made by the private sector are within 10 years. None of the earlier predictions regarding commercial availability of SDVs and DVs (marked in the table) have been realized as of September 2022. And some – such as Ford and Argo.ai – are severing relationships and dropping plans to develop SDVs (Isidore et al., 2022).

In contrast to the AV deployment timeline predictions (excluding AHS) from public stakeholders that typically ranged from 0 to 35 years with a median and mean of around 6 years and 7.6 years respectively (as discussed in section 4.1), industry stakeholders' timeline predictions of AV technology readiness were more optimistic. In predicting when private vehicles will be market ready, industry stakeholders report a median time of 4.5 years (n = 20, mean = 5.2 years). Similarly in the ride-hailing, taxi, and delivery service industry, the reported median time to availability was 3.5 years (n = 10, mean = 4.6). In predicting the availability of technology for AVs, industry stakeholders reported a median time to availability of 1.5 year (n = 6, mean = 5.0); the mean time is heavily skewed by one outlier prediction that was 20 years out for availability (see Zoox in Table 4). If we disregard this outlier, the median and mean times are 1 year and 2 years (n = 5).

Table 4. Major events and timeline predictions by the AV industry

Event type	Sector	Source Year	Prediction	Company	Description
Acquisition and partnerships	Private vehicles	2016		BMW	Partnership with Intel and Mobileye (both technology) to begin AV (SAE Levels 3-5) production
		2018		Hyundai	Partnership with Aurora (technology) to commercialize AVs (SAE Level 4) in smart cities
	Ride-hailing, taxi, and delivery service	2016		Volvo	Partnership with Uber (market) to create and distribute AVs
		2016		Waymo	Launched by Google as a separate subsidiary of the parent company Alphabet
		2017		GM	Partnership with Lyft (market) to begin testing a fleet of EV/AV taxis
		2018		Ford	Partnership with Domino's Pizza, Postmates (market), and Argo.ai (software) to launch pilot delivery service
		2020		Motional	Partnership with Lyft (market) to launch AV taxi service in major US cities
		2020		Yandex	Partnership with Hyundai-Mobis (vehicle production) to add DV to MI fleet
		2021		Ford	Partnership with Argo.ai (software) to launch SDV delivery service in Miami, FL
		2021		Ford	Partnership with Argo.ai (software) and Lyft (market) to deploy SDV ride-hailing in Miami, FL and Austin, TX
		2021		May Mobility	Partnership with Toyota Mobility Foundation (vehicle production) to launch free to public SDV fleet in Indianapolis, IN and Fishers, IN
		2022		GM, Cruise	GM purchased a majority stake in Cruise
		2022		GM, Honda	Partnership to develop electric and autonomous vehicles
	Technology	2016		Uber	Acquired LiDAR sensor company Otto
		2019		Aurora	Acquired LiDAR sensor company Blackmore
		2021		Hyundai	Partnership with Motional (software) to release IONIQ 5 SDV taxi (SAE Level 4) EV
		2021		Pony.ai	Partnership with Luminar (LiDAR) to design new LiDAR sensing platform
Launch, testing, and permits	Private vehicles	2013		Audi	First Original Equipment Manufacturer (OEM) licensed to test AVs in NV
		2014		Audi	First OEM licensed to test AVs in CA and FL
		2016		Tesla	Technology capable of SAE Level 5 standard on all new Tesla Model 3 cars
	Ride-hailing, taxi, and delivery service	2016		Uber	Free SDV taxi service in Pittsburgh, PA, in partnership with Volvo (vehicle production)
		2017		Cruise	DV ride-share (limited) service for San Francisco, CA employees
		2018		AutoX	SDV grocery delivery in San Jose, CA
		2018		Drive.ai	Free SDV ride-share service on designated routes in two TX cities
		2019		AutoX	Free SDV taxi service in CA
		2019		Pony.ai	Free SDV taxi service in CA
		2020		Cruise	DV testing in San Francisco, CA
		2020		Waymo	DV taxi service in Phoenix, AZ for selected members
		2020		Yandex	DV testing in Ann Arbor, MI
		2021		Cruise	Permit request for paid DV rides in San Francisco, CA
		2021		May Mobility	Free-to-public SDV shuttle service in Ann Arbor, MI and Arlington, TX
		2021		Pony.ai	DV testing in three CA cities
		2021		Waymo	Permit request for paid SDV rides in San Francisco, CA

Event type	Sector	Source Year	Prediction	Company	Description
		2022		Waymo, Cruise	Permit granted to charge for rides in select regions of San Francisco and San Mateo counties
		2022		Lyft	Riders can hail a self-driving car (with two safety drivers) in Las Vegas
		2022		ArgoAI	Established safety board of external experts on development of AV software
		2022		Cruise	Launched in California and Arizona
		2022		Waymo	Permit to operate free-for-employee rides in San Francisco
	Technology	2012		Google	First SDV operations begin in NV with two occupants in the car
		2015		Google	First DV ride in Austin, TX
		2018		Tesla	Software released with enabled SDV mode
		2019		Tesla	Introduction of "smart summon feature" (DV capability)
		2020		Comma.ai	Released development kit for partial AV automation
Timeline predictions	Private vehicles	2012	before 2017[a]	Google	SDVs commercially available
		2012	2022	Intel	DVs commercially available
		2014	2019[a]	Google	SDVs will be ubiquitous
		2015	by 2020[a]	Ford	SDVs available in pre-defined areas, not necessarily by Ford
		2016	2021[a]	BMW	Start AV production (SAE Levels 3-5)
		2016	2025	Continental	AVs available on controlled-access highways
		2016	2020[a]	Nissan	SDVs available for urban conditions
		2016	2025	Nissan	Commercially available DV
		2016	2018[a]	Tesla	DVs commercially available
		2017	2021[a]	BMW	Partnership with Intel and Mobileye to have AV in production by 2021 (SAE Levels 3-5)
		2017	2020[a]	Honda	Mass AV production (SAE Level 3)
		2017	2025	Honda	"Production-ready" SDVs (SAE Level 4)
		2017	2021[a]	Volvo	SDVs available for "highways"
		2018	by 2030	Hyundai	SDVs available (SAE Level 4)
		2018	2020[a]	Mercedes-Benz	Certain car models to have "eyes off" autonomous drive technology (SAE Level 3)
		2018	2020[a]	Rivian	AVs for highway driving; delayed until potentially 2022
		2019	by 2021[a]	Hyundai	Partnership with Aurora to commercialize SDVs in smart cities (SAE Level 4)
		2020	2023	Motional	Plan to launch AV taxi service with Lyft (market) in major U.S. cities
		2021	2022[a]	BMW	AVs commercially available (SAE Level 3)
		2021	2030	GM	SDVs commercially available (SAE Levels 4-5)
	Ride-hailing, taxi, and delivery service	2015	2030	Uber	DV fleet available
		2016	2021[a]	Volvo	Create and distribute AVs with Uber (market)
		2017	by 2019[a]	Cruise	"Commercial launch at scale" SDV in urban environments
		2017	2021[a]	Ford, Argo.Ai	SAE Level 4 vehicles in production for ride-hailing application
		2017	2020	Renault-Nissan, Microsoft	SDV taxis available for "urban conditions"

Event type	Sector	Source Year	Prediction	Company	Description
		2017	2025	Renault-Nissan, Microsoft	DV taxis will be available
		2019	2024	Aurora	SDV taxis will be on the road
		2019	2020[a]	Tesla	DV taxi service run by Tesla owners
		2021	2022[a]	Ford	Commercialize SDV ride-hailing business with Argo.ai (software) and Lyft (market) in Austin, TX
		2021	2023	Pony.ai	Automotive-grade production of AV fleet
	Technology	2013	2020[a]	Nissan	Commercially available SDV features
		2016	2017[a]	Tesla	"Coast to coast" DV capability and demonstration
		2017	2019[a]	Tesla	"True" DV autonomy two years away (SAE Level 5)
		2019	2019[a]	Tesla	"Feature-complete" SDV by the end of the year
		2021	by 2021[a]	Tesla	DV technology ready by the end of the year (SAE Level 5)
		2022	2042	Zoox	Technology needed for AV deployment 20-30 years away

Note. The SAE levels in the description column have been indicated in parentheses when explicitly stated within the source.
[a] Prediction not realized as of September 2022

4.3. Regulatory timelines

The regulatory framework in the U.S. requires each state to pass laws in order for AVs to be tested on public roads and ultimately deployed. Hubbard (2018) summarized various AV-related laws across different U.S. states as of 2017. We present an updated timeline of U.S. states' AV-related laws passed up to July 2022 in Appendix B. In addition to state legislation, executive orders have also been used to spur regulation and incentives for AV testing and deployment. Twelve states, namely Arizona, Delaware, Florida, Hawaii, Idaho, Illinois, Massachusetts, Maine, Minnesota, Ohio, Washington, and Wisconsin, have passed executive orders relating to AVs. Most of these orders are used to create taskforces and other related committees on AV development, with two, Arizona and Ohio, including directives for insurance licensing and AV testing, respectively. These executive orders, though limited in scope, represent a unique path forward for AV regulation, as they can be implemented much faster without the delays generally experienced in state legislative committees. Interestingly, AVs were commercially allowed on public roads in Washington D.C., but a recent bill was proposed to regulate their introduction more strictly (*D.C. Law 23-156*, 2020).

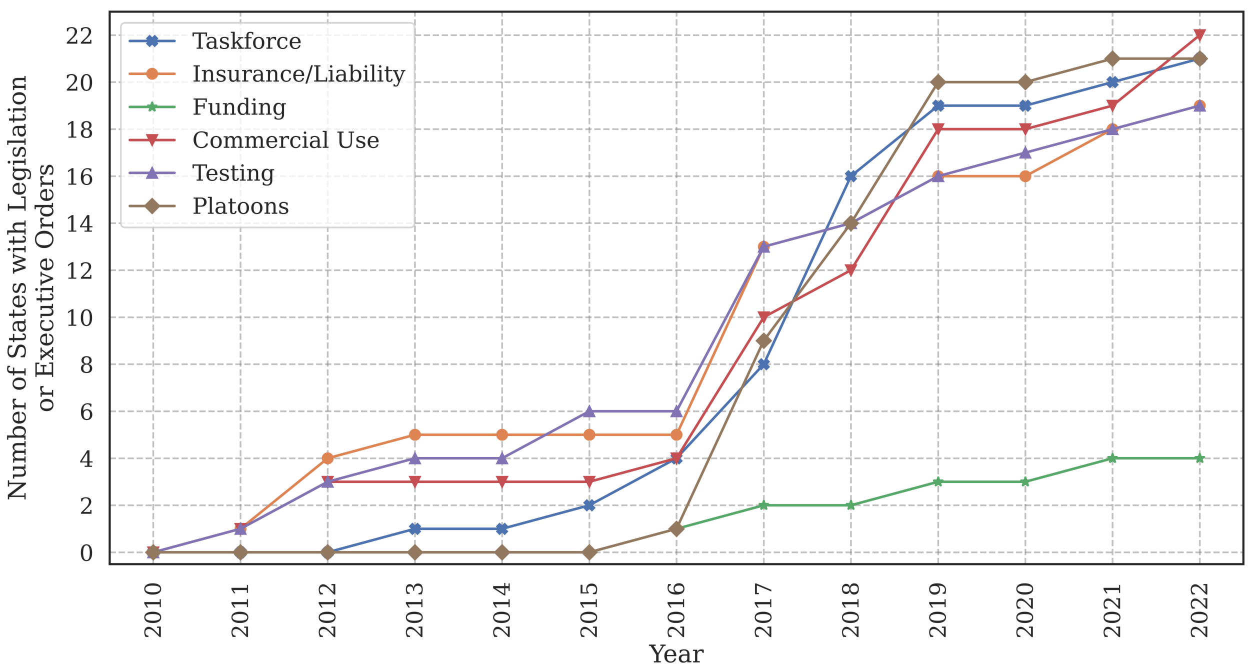

Figure 3. Cumulative number of U.S. states with AV legislation and executive order by AV topics

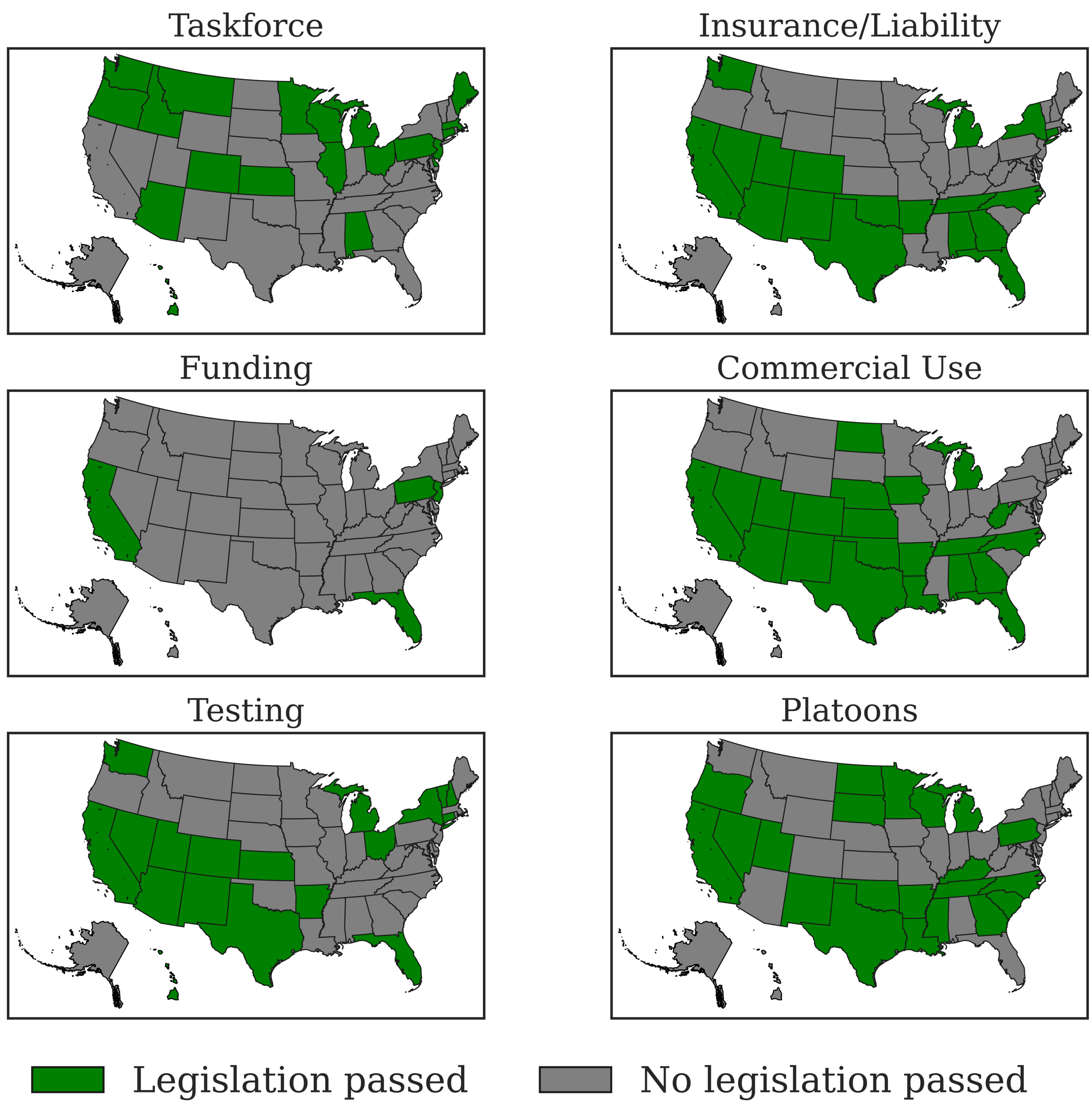

Figure 4. Map of U.S. States with AV legislation and executive orders by AV topics

Figure 3 illustrates the cumulative number of U.S. states that passed AV-related laws through legislation or executive order by categorizing them into six AV topics: Taskforce, Insurance/Liability, Funding, Commercial Use, Testing, and Platoons. *Taskforce* refers to an investigative body convened by state governors or legislatures to work towards advancing AV development, testing, and deployment in the state. These taskforces can range in scope and jurisdiction but are generally tasked with making recommendations for future regulations and procedures regarding the use of AVs. In many cases, these taskforces represent a forecast of more concrete legislation to come. For example, Michigan called for recommendations by a taskforce established in 2013 legislation that resulted in more comprehensive AV-related legislation three years later (*Public Act 231 of 2013*, 2013). *Insurance/Liability* includes legislation that establishes liability for AVs or specific insurance requirements for operating AVs (testing or deployment) in the state. This also includes qualifications that AVs must follow the same insurance laws as traditional vehicles, as in the case of Arizona's 2018 executive order (*Exec. Order No. 2018-04*, 2018). *Funding* includes legislation that allots a specific amount of funds to be directed towards AVs (e.g., investment in research, infrastructure, or pilot programs) or changes in tax codes to accommodate AVs. The state of Pennsylvania, for example, permitted up to $40 million towards intelligent transportation systems and AV technology in 2016 (*Act of Jul. 20, 2016, P.L. 861, No. 101*, 2016). *Commercial use* refers to legislation that outlines specific regulations for AV use by private companies or consumers on public roads, but not necessarily allowing them to use AVs commercially yet. *Testing* includes legislation pertaining to any form or level of testing of AV technology, whether on private or public roads. However, unlike Hubbard (2018), we do not include legislation that calls for future testing under this topic. Finally, *platoon* includes legislation that specifies regulations regarding the use of truck platoons or other connected vehicle systems. Although not directly related to light-duty passenger vehicles, this topic represents a case of exemptions being given to AV technology in other important application domains. Figure 4 shows the map of U.S. states that have passed legislation and executive orders related to the six AV topics.

Data in Appendix B show that the states of California, Florida, Michigan, Nevada, and the District of Columbia were the earliest to enact AV-related laws, mostly related to *insurance/liability*, *commercial use*, or *testing*. As of July 2022, other than seven states (Alaska, Indiana, Maryland, Missouri, Rhode Island, Virginia, and Wyoming), all other U.S. states have passed either legislation or an executive order relating to the six aforementioned AV topics. *Funding* was the least common type of legislation topic, which was passed by four states.

5. Discussion

This systematic review examined AV deployment timelines across stakeholder groups as well as how states vary in laws related to AVs which could affect AV deployments and timeline projections. Our analysis revealed that none of the AV deployment timelines had been met yet, regardless of whether they were put forth by private or public stakeholder groups. However, there have been successful developments in AV technology that have led to limited public testing and launches.

The systematic review also shows that although the mean of optimistic timeline prediction for commercial availability is higher, on average, than the technological capability, it is not the case for SAE levels 3 and 4. The most likely reason is that articles that predicted AV timelines for technological capability for relatively lower levels of AVs (i.e., 3 or 4) have a more conservative view towards the mass AV deployment. Hence, they avoided providing a timeline prediction for the commercial availability of AVs, which would naturally be after the technology is ready to be deployed. This indicates a possible optimistic bias in the predictions that provided timelines for commercial availability only, especially given that none of the deployment timelines have been met yet (see Table 4). The market share predictions are more in line with the predictions for commercial availability than technological capability, with most studies predicting a modest market share (10-25%) of AVs by 2030 followed by a period of rapid growth in the 2040s and 2050s.

A review of AV deployment timelines from different perspectives reveals clear differences between private (e.g., companies and investors) and public (e.g., policymakers, independent agencies, and researchers) stakeholders. Timeline predictions for AVs (excluding AHS) from published articles and reports (range = 0-35 years, mean = 7.6 years, median = 6.0 years), mostly provided by research organizations and government agencies, are more conservative compared to the predictions from the industry sector (range = 0-20 years, mean = 5.0, median = 4.0). These discrepancies between the predictions from the different stakeholders could be due to two key reasons. First, potential financial conflicts of interest may result in intended or unintended biases in private entities' predictions. Second, public stakeholders lack up-to-date data on technological progress and base their predictions on past trends of disruptive technologies, which may not hold for AVs.

The differences in AV timelines might also reflect varying perceptions a of different barriers and facilitators. For example, with regards to the factors that influence AV deployment, the most critical barrier seems to be the lack of a consistent and comprehensive regulatory framework, especially at the federal level (Vincent, 2021; Yankelevich et al., 2018). Industry innovations continue at a rapid pace, which results in a mismatch between technological capabilities and current regulations and standards. As our results showed, only 19 states had passed testing laws as of July 2022, resulting in over half of the states not having any type of testing permitted at that point in time. In addition, nuanced disparities between state driving laws also pose challenges in developing consistent state-level and federal-level regulations. This could impact the timeline of AV deployment for different industries. For example, while state-level laws may be sufficient for deploying AVs for robotaxis and local delivery services, private ownership of AVs may require federal regulations or may force states to accelerate their regulatory timelines.

The private sector has undertaken efforts to overcome the lack of regulation and standards barrier by forming consortiums such as the Automated Vehicle Safety Consortium (AVSC, n.d.) to discuss issues related to AV safety in a technology-neutral manner. Several industry partnerships and company acquisitions have also stemmed from efforts to consolidate technical expertise and expand commercial application domains, which may accelerate AV development and deployment. These efforts may accelerate AV deployment timelines, at least from the perspective of the industry sector.

From the public sector's perspective, concerns related to workforce impacts, equitable deployment, ethical algorithms, and data privacy need to be addressed for AV deployment. Public opinion and trust are also crucial for successful deployments (Dirsehan & Can, 2020). However, public opinion is negatively affected by crashes involving AVs (including lower levels of AV) (Othman, 2021). As exhibited by the COVID-19 pandemic, external and unpredictable factors may also play a critical role in determining the pathway to mass AV deployment. These factors may introduce more uncertainty in AV timelines, especially from the perspective of government agencies and research communities.

In this review, efforts were taken to be as comprehensive as possible. However, it is inevitable that some information related to the review topic may not have been included. Thus, the findings from this paper are limited to those covered by the present review, especially for industry predictions. We selected a particular time period for this review to strike a balance between coverage and the feasibility of the review. Further, this study focuses on timeline predictions that are relevant to the U.S. context, and our findings may not be directly transferable to other countries worldwide.

6. Conclusions

Given the variety of factors that affect AV deployments, varying state laws related to AVs, and the range of stakeholder timelines that have been put forth but not yet been realized, it may be a challenge to adequately prepare the transportation workforce for the future. AVs are expected to disrupt a range of jobs in the transportation industry in addition to creating new job opportunities in fields like data science, artificial intelligence, and cybersecurity (Yankelevich et al., 2018). The increased technological background needed for such positions, as well as investment into reskilling and upskilling of employees, however, will be needed upon introduction of new jobs and displacement of existing ones (Frey & Osborne, 2017). These investments in new jobs and the workforce will be challenged if AV timeline projections continue to vary as dramatically as this systematic review has articulated that prior projections have varied. It behooves industry, education, and governmental stakeholders to work closer together to better ascertain what are realistic timelines for AVs, given historical and current barriers to AV testing and deployment. Without more realistic AV timelines, it is unlikely that U.S. industry, government, and educational sectors will be able to implement policies and training programs to ensure that the workforce can meet the demands of an evolving transportation industry.

In sum, AV development and deployment timelines have evolved over time. Timelines will continue to evolve as policies, infrastructure, and technology developments are modified. Having a clear picture of prior timelines, as well as barriers and facilitators of AV development and adoption, may help researchers, technologists, government agencies, and private industry develop more accurate timeline predictions in the future. Without more accurate timelines, the U.S. transportation workforce will not be prepared as we move into a future with AVs.

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Appendix A: Systematic Review Predictions

Citation	Start Year	End Year	SAE Level	Technological Capability	Commercial Availability	Market Share	Private vehicle[1]	Ride hailing[1]
(Gilmore, 1967)	1970	1985	AHS	x			x	
(Gray & Helmer, 1976)	2000	2020	AHS		x			
(Bender et al., 1981)	1990	2000	AHS	x				
(Underwood et al., 1991)	2026		AHS		x			
(Stevens et al., 1996)	1999	2000	AHS	x				
(Anderson, 1997)	2003	2005	AHS	x				
(Underwood, 2014)	2018	2020	3		x			
(Zmud et al., 2015)	2020	2025	3		x			
(Zmud et al., 2015)	2020	2035	3			Critical mass		
(Cusumano, 2020)	2030		3	x				
(Mersky, 2021)	2030		3		x			
(Underwood et al., 1991)	2011	2035	4			Most vehicles		
(Underwood, 2014)	2019	2025	4		x			
(Townsend, 2014)	2020		4		x			x
(Townsend, 2014)	2030		4			25-35% (Fleet size)	x	x
(Zmud et al., 2015)	2035	2050	4			Significant numbers		
(Hazan et al., 2016)	2020		4	x				
(Hazan et al., 2016)	2025		4	x				
(Barkenbus, 2018)	2018	2021	4		x			x
(Yankelevich et al., 2018)	2028		4			20% (Fleet size)	x	x
(Zmud et al., 2018)	2038		4			Significant numbers		
(Goodison et al., 2020)	2024		4		x			x
(Leonard et al., 2020)	2025		4		x			x

Citation	Start Year	End Year	SAE Level	Technological Capability	Commercial Availability	Market Share	Private vehicle[1]	Ride hailing[1]
(Yu & Chen, 2021)	2022		4		x		x	
(Mersky, 2021)	2030		4		x			
(Mishra et al., 2021)	2050		4			55-83% (Fleet size)		
(Yu & Chen, 2021)	2067		4			85-95% (Usage share)	x	
(IEEE, 2012)	2040		4 or 5			75% (Fleet size)		
(Lari et al., 2014)	2020		4 or 5		x		x	x
(Lari et al., 2014)	2040	2050	4 or 5			Most vehicles		
(Fagnant & Kockelman, 2015)	2022	2025	4 or 5		x		x	
(Fagnant & Kockelman, 2015)	2020		4 or 5	x			x	
(Zmud et al., 2016)	2020		4 or 5		x			
(Groshen et al., 2018)	2022		4 or 5		x			x
(Groshen et al., 2018)	2030		4 or 5		x		x	
(Kellerman, 2018)	2022	2025	4 or 5		x			
(Simons et al., 2018)	2020		4 or 5		x		x	x
(Simons et al., 2018)	2022	2050	4 or 5			10-80+% (Fleet size)	x	x
(Talebian & Mishra, 2018)	2050		4 or 5			15-100% (Fleet size)		
(Forsgren et al., 2018)	2030	2040	4 or 5			2-50% (New vehicles)		
(Groshen et al., 2018)	2050		4 or 5			100% (Usage share)	x	x
(Concas et al., 2019)	2030	2050	4 or 5			18.5-50+% (Fleet size)		
(Liu et al., 2020)	2020		4 or 5		x			x
(Liu et al., 2020)	2050		4 or 5			12.4-15.4 million (Fleet size)		x
(Statista, 2020)	2030		4 or 5			10% (Fleet size)		
(Young & Lott, 2022)	2030		4 or 5		x			x
(Young & Lott, 2022)	2025		4 or 5	x				x
(Underwood, 2014)	2030		5		x			
(Kyriakidis et al., 2015)	2050		5			50% (Fleet size)	x	

Citation	Start Year	End Year	SAE Level	Technological Capability	Commercial Availability	Market Share	Private vehicle[1]	Ride hailing[1]
(de Winter et al., 2015)	2030		5			Most vehicles	x	
(Lipson & Kurman, 2016)	2025		5		x			
(Lipson & Kurman, 2016)	2035	2050	5			10-100% (New vehicles)		
(Lavasani et al., 2016)	2025		5		x		x	x
(Lavasani et al., 2016)	2035	2050	5			8-84 million (Fleet size)	x	x
(Strategy Analytics, 2017)	2035		5		x		x	x
(Strategy Analytics, 2017)	2035	2050	5			$800 billion-$7 trillion (Global market)	x	x
(Strategy Analytics, 2017)	2050		5			50% (New vehicles)	x	x
(Arbib & Seba, 2017)	2031		5			95% (Usage share)		
(Douma et al., 2019)	2025		5	x				
(Douma et al., 2019)	2040	2050	5		x			
(Sadvandi & Halkias, 2019)	2030		5	x			x	
(Roemer, 2020)	2030		5		x		x	x
(Roemer, 2020)	2030	2035	5			$282-$558 billion (Global market)	x	x
(Ksenofontov & Milyakin, 2020)	2045		5			2-22% (Fleet size)		
(Litman, 2022)	2025		5	x				
(Litman, 2022)	2030		5		x			
(Litman, 2022)	2050		5		x			

Note.

Citation	Start Year	End Year	SAE Level	Technological Capability	Commercial Availability	Market Share	Private vehicle[1]	Ride hailing[1]

Data are sorted by SAE Level and Publication Year.

[1] For rows with both Private vehicle and Ride hailing empty, the article did not clarify for which sector the timeline was predicted.

Appendix B: Timeline of AV Legislation and Executive Orders in the U.S.

	Law Type		AV Topic					
State	**Legislation**	**Executive Order**	**Taskforce**	**Insurance /Liability**	**Funding**	**Commercial Use**	**Testing**	**Platoons**
AL	✓		2016	2019		2019		
AK								
AZ	✓	✓	2015[a]	2018[a], 2021		2018[a], 2021	2015[a] 2018[a]	
AR	✓			2021		2019	2017	2017
CA	✓			2012	2017	2017, 2021	2012, 2016	2017
CO	✓		2019	2017		2017	2017	
CT	✓		2017	2017			2017	
DC	✓		2018	2012		2012	2020	
DE		✓	2017[a]					
FL	✓	✓		2012, 2016, 2019	2019	2012, 2016, 2019, 2021	2012, 2019[a]	
GA	✓			2017		2017, 2021		2017
HI	✓	✓	2019				2017[a], 2020	
ID		✓	2018[a]					
IL		✓	2018[a]					
IN								
IA	✓					2019		
KS	✓		2022			2022	2022	
KY	✓							2018
LA	✓					2019, 2022		2019
MA		✓	2016[a]					
MD								
ME		✓	2018[a]					
MI	✓		2013	2013		2016	2013	2016
MN	✓	✓	2018[a]					2019
MO								
MS	✓							2019
MT	✓		2021					
NC	✓			2017		2017, 2020		2017
ND	✓					2019		2019
NE	✓					2018		
NH	✓						2019	
NJ	✓		2019		2021			

	Law Type		AV Topic					
State	**Legislation**	**Executive Order**	**Taskforce**	**Insurance /Liability**	**Funding**	**Commercial Use**	**Testing**	**Platoons**
NV	✓			2011		2011, 2021	2011, 2013	2017
NM	✓			2021		2021	2021	2021
NY	✓			2017			2017	
OH		✓	2018[a] (Jan 22)				2018[a] (May 9)	
OK	✓			2022		2022		2019
OR	✓		2018					2018
PA	✓		2018		2016			2018
RI								
SC	✓							2017
SD	✓							2019
TN	✓			2017		2017		2017
TX	✓			2017, 2021		2017, 2021	2017	2017
UT	✓			2019		2019	2015	2018
VA								
VT	✓						2019	
WA	✓	✓	2017[a]	2017[a]			2017, 2020	
WV	✓					2022 (March 28), 2022 (March 30)		
WI	✓	✓	2017[a]					2018
WY								

Notes.
The date is mentioned in parentheses if multiple laws are passed in the same year.
[a] Indicates an executive order.