CENTER FOR AUTOMOTIVE RESEARCH

State of ADAS, Automation, and Connectivity

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ABOUT THE AUTHORS

The Center for Automotive Research is an independent non-profit that produces industry-driven research and fosters dialogue on critical issues facing the automotive industry and its impact on the U.S. economy and society. CAR researchers closely track current and future global automotive industry and technology trends and assess their impacts. CAR researchers also study international collaborations and stay abreast of changes in international trade and regulatory environments, the development of technology standards, and the deployment of new vehicle technologies.

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CENTER FOR AUTOMOTIVE RESEARCH

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CAR's mission is to produce independent research, convene stakeholders, and analyze critical issues facing the mobility industry and its impact on the economy and society.

Introduction

Vehicles are currently in a new stage of evolution that includes advanced driver assist, connectivity, and automation. Due to the evolving nature of the technology and shifting consumer preferences, the timing and pathway for implementation of these technologies is still uncertain. While these new technologies are still evolving, an understanding of the current automotive landscape may help provide a view to future developments.

The Center for Automotive Research is committed to informing the public about the current state of vehicle technologies. In 2017, 2019, and 2020, CAR published roadmaps describing the current and likely future state of vehicle technologies. To ensure the information forecasted by CAR remained current and reflected the latest in vehicle technologies, trends, and expectations, CAR conducted ongoing research and moderated industry roundtables. Industry roundtable experts included auto manufacturers, parts suppliers, technology providers, data providers, autonomous platforms providers, and technology investors. Following the roundtables, CAR developed an updated roadmap and report reflecting industry trends and expectations. This paper summarizes critical issues involving the development and deployment of technology in advanced driver assistance systems (ADAS), autonomous vehicles (AV), and vehicle connectivity.

Advanced Driver Assist Systems (ADAS)

Overview

Advanced driver assistance systems (ADAS) have the potential to reduce crashes and minimize traffic inefficiencies by eliminating human error and providing real-time data about traffic conditions. The technologies included in ADAS include automatic emergency braking, adaptive cruise control, lane-keeping assist, self-park, and varying automatic emergency braking systems.

There is little dispute about the potential benefits of ADAS. Eliminating human error and simplifying driving make ADAS an attractive vision for the future state of automotive technology. However, ADAS are still in their developmental stage, and a handful of highly publicized - and sometimes fatal - crashes have raised concerns about the safety of the technology.

There is a general lack of data and information to draw robust conclusions about the nature and cause of these crashes, but nevertheless, the negative headlines have tempered enthusiasm for this technology.

ADAS technologies, popular for the last two decades, have advanced in four distinct waves: aid features, warn features, driver assist features, and automated driving features.

1. Aid features are technologies that enhance driver vision through cameras and lights. Popularized in the early 2000's, aid features have since become commonplace.
2. Warn features include alert systems that utilize sensors and sounds to warn drivers of hazards. These features are regaining focus as they help shape driver monitoring.
3. Driver assist features are technologies that help situationally control the vehicle. These technologies have been around for decades but advanced significantly in the late 1990s. Since then, new features have consistently been introduced to provide a sophisticated level of driver assistance. Which may serve as the bridge to automated driving features.
4. Automated driving features serve as a more advanced driver assist, which takes responsibility and helps drive the vehicle in specific circumstances.

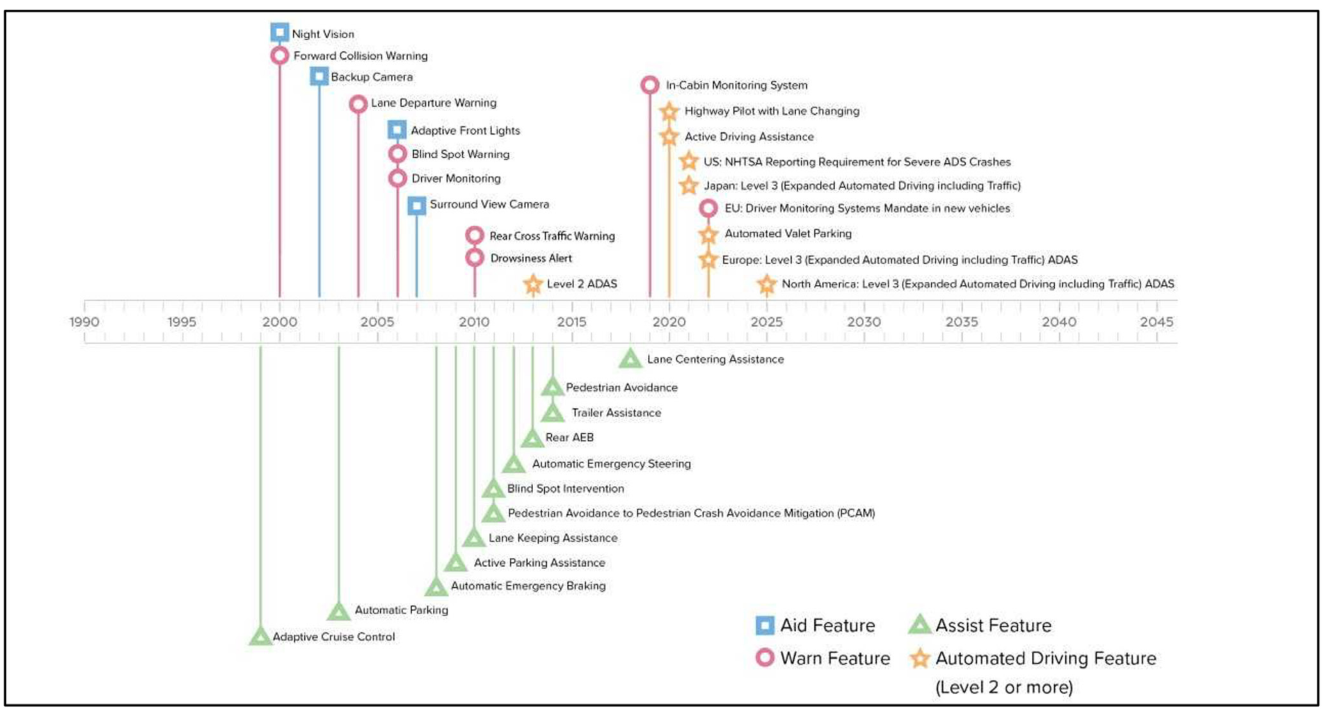

Figure 1: Driver Assist Technology Evolution

Crash Reduction and Safety

ADAS and automated technologies are touted as solutions for crashes and roadway safety because their advanced technology can eliminate human error. The National Highway Traffic Safety Administration (NHTSA) has reported that "94% of serious crashes are due to human error," supporting the inherent promise of automated and assisted driving (NHTSA, 2016). Statistics like this are central to the vision promoting full-scale deployment of automation and driverless vehicles.

However, the statistics provided by NHTSA that are core to ADAS adoption are, in some ways, an oversimplified narrative (Mueller et al., 2020). Issues that may arise from ADAS include technology failures, hacking, overreliance on technology to perform beyond intended use (human error), unreliable platooning technology that leads to more severe crashes, an inability to detect vulnerable road users, and decreasing level of investments in ADAS technologies.

Despite these potential technological shortcomings, recent studies predict that ADAS technology could reduce up to 34 percent of crashes. Some studies suggest this percentage could be even higher if the technology could eliminate traffic violations (Mueller, 2020). Reducing auto crashes by just 10% would reduce traffic fatalities by thousands.

A trend to consider further is the potential for ADAS to increase travel demand, even if proportionally lowering crash rates, while raising the number of aggregate crashes due to the increased demand from fleets.

Regulation

While there has been no congressional action governing ADAS technology in automobiles, NHTSA, whose regulatory framework remains primarily weighted toward driver-focused safety standards, has started amending its standards and issuing general orders to regulate ADAS. A standing general order was issued by NHTSA that required companies to report a crash if Level 2 ADAS technology was in "use at any time within 30 seconds of a crash and the crash involved a vulnerable road user or resulted in a fatality, a vehicle tow-away, an airbag deployment, or any individual being transported to a hospital for medical treatment" (NHTSA, 2021). The standing order aims to evaluate vehicle technologies and serves as a measure of ADAS assessment absent in current FMVSS and NCAP.

ADAS Naming Conventions

There are currently no federally mandated standards to ensure consistent use of terminology for referencing ADAS features like adaptive cruise control, highway pilot, and automated parking. ADAS technology has largely been promoted and described in varying ways by the companies that develop and adopt the technology in their vehicles (Williams, 2022).

Without universally accepted nomenclature, companies may promote their ADAS features and technologies using terminology that may not accurately describe the technology suite in their vehicles and may not be commonly understood by consumers. Tesla, for example, refers to its ADAS as "Full Self-Driving," yet it only lands on the second level of the SAEs five automation levels. This lack of consensus has led to a level of consumer misunderstanding and false expectations of the technology's true capability.

AAA led a working group to standardize ADAS features and technologies to "clear confusion" surrounding ADAS technology (AAA, 2022). The working group sought to provide industry-wide definitions of ADAS technology suites to improve understanding and transferability of terminology. While there was not uniform agreement on the importance of adopting a standardized nomenclature, the prevailing view is that standardization will be a critical factor in promoting and understanding ADAS technologies. Standardization will also be an important factor in driver education and technology knowledge transferability.

Driver Education

Educating drivers on the proper use of ADAS technologies is an essential step in fully realizing the benefits of ADAS. Misuse and human error may cause crashes that were otherwise preventable through ADAS technology. Without a proper understanding of when and where technology can be deployed, human error can lead to ADAS failures. A training program to advance the understanding of the ADAS technology used within a vehicle can reduce misunderstanding and misuse of ADAS.

Some companies implement training standards for drivers before they are provided access to certain ADAS features (Mayhew & Robertson, 2021). These mandatory instructional standards ensure that drivers better understand the capabilities and limitations of the technology in their vehicle. For example, a driver trained on Tesla's ADAS suite would learn that "Full Self-Driving" requires driver engagement and is not fully automated. However, few companies mandate this type of education (Stafford, 2022).

Despite the potential benefit of training programs, consumers appear unwilling to spend time learning how to use ADAS. Additionally, the low degree of transferability between manufacturers of technology suites means an investment in learning one manufacturer's technology may not be particularly helpful for a different manufacturer.

Driver Monitoring

Driver monitoring is another mechanism that can mitigate the risks associated with misusing ADAS by ensuring drivers are more fully engaged while driving.

There are varying degrees of driver monitoring ranging from periodic alerts to required engagement (Barry, 2022). The problem with a strict driver monitoring mandate is that it may remove the incentive to fully embrace the technology. If drivers feel monitoring requirements overly restrict their autonomy, they may find little benefit and value in the ADAS. Assuring focus through driver monitoring is a balancing act that companies and governing bodies are currently attempting to manage. Both are trying to ensure appropriate customer use of ADAS while not annoying the driver. Higher-end driver monitoring may result in backlash from consumers over a perceived invasive view and increased potential for cyber threats.

Additionally, false positive alerts generated by the driver monitoring system may create a technological challenge that discourages companies from entering this market (Mehmed et al., 2020). A recurring false positive rate could fuel consumer mistrust and misunderstanding of the vehicle which can negatively affect consumer adoption and willingness to buy.

Roundtable discussions on monitoring systems also highlighted the complexity of monitoring consumer distraction in light of advancements with in-vehicle features presented through phone connectivity.

The European New Car Assessment Programme (Euro NCAP) is currently the leader in evaluating driver monitoring standards through a series of orders (McManus, 2022). Euro NCAP standards have been instrumental in establishing driver monitoring standards. In time, more jurisdictions will implement similar standards.

Business Case and Consumer Acceptance

The business case for ADAS is currently unclear due to low consumption levels. Pricing models are difficult to establish as many consumers remain skeptical and unwilling to pay for the technology (Stigloe et al., 2022). A better understanding of how many consumers shut off the ADAS features in their vehicles is needed to appropriately model the business case for pricey subscription models.

As efficiency of these technologies improves overall, adoption rates are expected to increase (Heineke et al., 2022). There is a belief within the industry that as these technologies gain access to more information and data, their capabilities will vastly improve. In turn, the business cases for situations like long drives, and consumers looking for relief in arduous commutes will improve. However, standardization, lower prices, and technological improvements will likely be necessary for ADAS to overcome consumer uncertainty.

Going Forward

ADAS technologies' penetration of several markets proves there is a solid near-term business case. However, consumers will require near-term, pronounced improvements in ADAS for continued market penetration.

When implemented correctly, ADAS can provide an attractive incentive to consumers. However, adoption of ADAS will not solely come from the excitement surrounding the technology. Consumers will need to believe in the practical benefits of ADAS.

Safety is a pivotal selling point, but ADAS must also prove it can make the driving experience more manageable and less burdensome. That proof can only occur when consumers properly understand the benefits, which means clearly understood and consistent naming conventions for ADAS technologies. Unfortunately, standardization in naming conventions is likely unrealistic in the near term, but names more reflective of the respective technology's ability may enhance the consumer's ability to understand.

Driver education can bridge the gap. If companies are willing to help consumers correctly learn their vehicle's capabilities, ADAS use could become more commonplace, and less of a feature consumers forget to use (or intentionally turn off).

Driver monitoring will be an essential piece of regulation to limit the misuse of ADAS. Still, if driver monitoring regulation requires a focus similar to that of driving a traditional vehicle, there's little incentive to use ADAS features.

Higher ADAS adoption will likely be limited to conditions and speeds that pose less of a threat when the driver is disengaged. Even if ADAS projects to be limited in its on-road applications, companies will still introduce these technologies. If the costs of ADAS remain high, consumers still have a choice in their vehicle technologies, and the applications remain limited, the market will be narrow. Alternatively, if costs drop and applications increase, standardization is possible by the end of the decade.

Automated Vehicles (AV)

Overview

Vehicle automation, defined as SAE Level 4 and Level 5 technology, is the next phase of automotive driving technologies (SAE, 2021). While ADAS represents technologies that partially remove driver responsibility, AVs represent the complete shift in control from driver to vehicle. The rationale for focusing on Levels 4 and 5 as distinctly autonomous is that AVs remove the driver.

In the mid-2010's numerous forecasts predicted that Level 5 would arrive sometime this decade. But as the years have passed, few, if any companies or studies are projecting full autonomy and unrestricted operational design domains (ODD).

Similar to ADAS, AVs have been touted as a solution for safety. Numerous companies and studies have also listed AVs as a solution for lower emissions, reduced travel costs, increased productivity, and decreased congestion. While varying degrees of automation are available, high automation for widespread commercial use is currently unavailable.

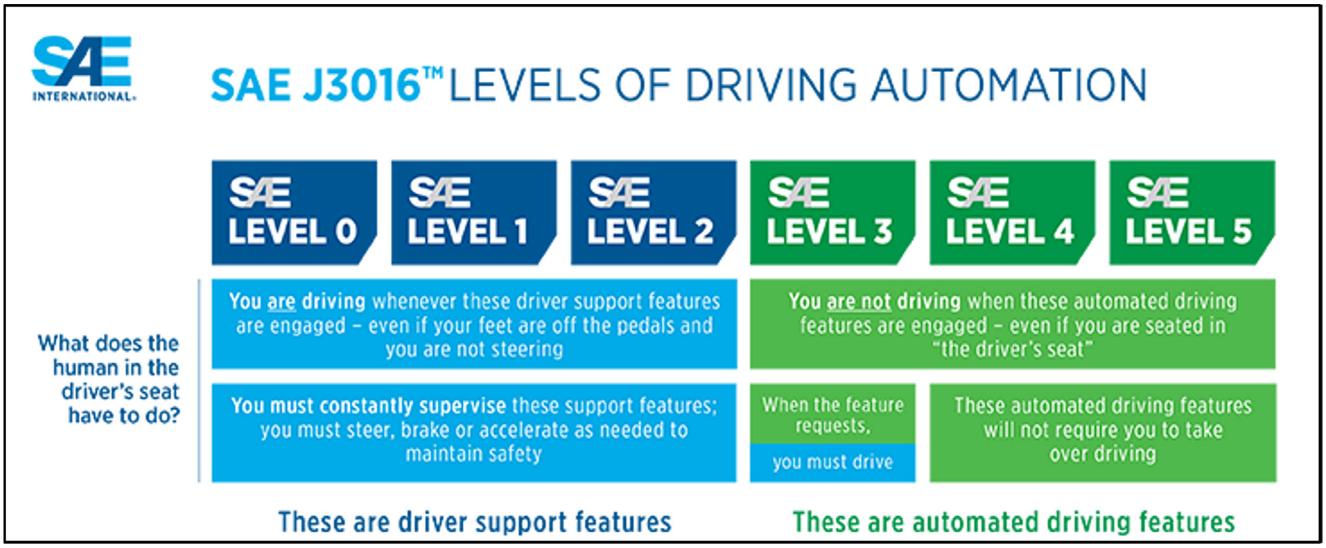

Figure 2: SAE Levels **Source:** SAE. (2021, May 3)

Timeline Evolution

Differing projections from consultants, industry stakeholders, and academia were reflected in CAR's last two iterations of the Technology Roadmap, but since then, all timelines and projections have shifted.

Around 2017, when funding for AV was at an all-time high, many consultants, researchers, and industry stakeholders projected AV deployment and market penetration by 2020 (Hawkins, 2021). In hindsight, these projections were bullish, and many missed the mark. Reports with projections are now rare, and currently, most consultant reports refer to technological barriers and breakthroughs, with few dates and deadlines. OEMs, technology companies, suppliers, and other stakeholders are projecting milestones in the near term, many of which are incremental and achievable.

While academic research was more conservative than consultants and industry stakeholders, they also missed some of their projections and forecasts. Consequently, projections have become less frequent and focused primarily on barriers to deployment.

All of these projections differ in their levels of automation, base year, rate of market penetration, and ODD capability. Due to these discrepancies, the aggregation of forecasts is now less straightforward than it had been in the past. While timelines may be difficult to project, a summary of the issues can provide a roadmap for deployment, and the barriers standing in the way.

Industry stakeholders at the roundtable acknowledged these missed projections and gave insight into the most realistic current use cases. With these insights and the aggregation of current studies, it is easier to understand the AV deployment roadmap and obstacles.

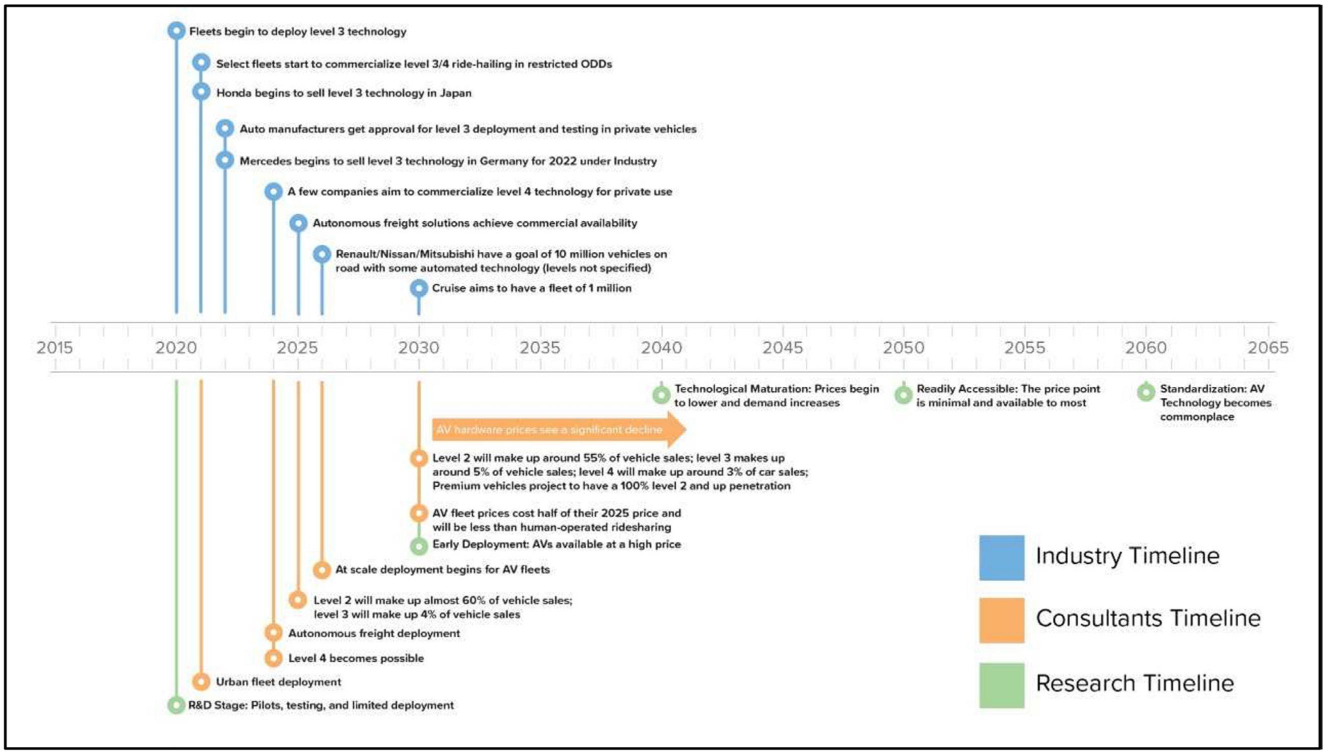

Figure 3: Aggregate AV Projections

From ADAS to AV: Skipping a Step

When AV optimism was at its peak, many companies pledged to go from Level 2 to Level 4, skipping Level 3 (Stathousis, 2020). However, skipping Level 3 has proven to be difficult, in part because in the real world, scaling is the best training.

A handful of companies have stuck to that scaling model. Over the last two years, Mercedes-Benz and Honda have introduced Level 3 technologies in their home countries (Sigal, 2022). These companies are considered industry leaders, and the first to offer a higher level of ADAS and AV technology to their consumers for private use.

These early innovators of Level 3 technology could trigger widespread offerings of Level 3 (as noted by industry participants at the roundtable), or they could remain outliers if companies are unwilling to assume liability.

Others in the industry point to a ten-year transition to Level 3, and the issues that may arise along the way. Level 3 has also been considered much more costly to develop, even at a lower rate, making consumer adoption much less likely. The experts on the panel pushed against the idea that Level 3 will be hard to achieve, but noted that barriers like the costs of additional computing and sensor technology must be overcome. For these reasons the prevailing sentiment is that Level 2 still has the strongest business case.

Key Issues Holding Back Deployment

Issue	Examples
Consumer Acceptance: Adoption and Risk Tolerance	The public sees ADAS crashes and remains unsold on its ability to promote safety
Business Case	Level 4 (broad term) implementation in the near term as a more practical model
Modality	A projection assumes private ownership as the AV business case but fleets are the predominant form in the following decades
ODD	A company reaches level 4 in sunny weather states like Arizona and Texas but is still years out from snowy and rainy states
Scaling	Argo testing vs Waymo launching a pilot vs Cruise launching a commercial operation
Infrastructure	The technology is held back by a lack of road repairs and smart infrastructure retrofitting
Policy and regulation	A lack of policy prevents AV implementation in specific localities
Liability	Opting to stay at level 2 to keep the liability on the driver
Technology: Hardware and Software	A metaphorical wall being hit for deep learning
Cyber/Data	Companies failing to implement V2V tech out of concern for cyber breaches
Maintenance	Cleaning costs every few rides for a fleet vehicle

Figure 4: Deployment Barriers

Consumer: Adoption and Risk Tolerance

Consumer skepticism toward AVs is high. The industry must address safety issues before consumers consider them a viable solution (Stigloe et al., 2022). While crash rates may not be higher than a traditional vehicle, consumer mistrust of AVs, stoked by publicized crashes and misuse of the technology, has remained consistently high over the years. Consumers need to understand and believe AVs are safe before any significant adoption can occur.

However, it is unrealistic to think of AVs as infallible and 100 percent safe, so consumers will eventually have to accept some level of risk and understand the limitations of their vehicle (Litman, 2022). At this point, it is uncertain what level of safety is needed (e.g., 10 percent fewer crashes? 1,000 fewer crashes per mile driven?) before consumers and regulators are convinced that the risks associated with AVs are justified and acceptable.

Business Case

Safety is not necessarily the sole sales pitch for AVs. They are also touted as a way to reduce congestion, lower costs, maximize efficiency, and increase productivity (Litman, 2022).

Maximizing efficiency faces an uphill battle as long as AVs have to share the road with traditional vehicles. An all-AV scenario would likely operate efficiently, but the reality is that they will need to perform with traditional vehicles for the foreseeable future.

In the early stages of AV development, there was optimism that AVs would relieve traffic congestion. However, further analysis of modality, demand, and vehicle miles traveled (VMT) projections now challenge this vision (Litman, 2022). If increased adoption of AVs results in more vehicles being on the road, congestion could actually increase. For example, a private or fleet vehicle may opt to continue driving between drop-off points instead of parking to await the next transaction. Vehicle stalling without a rider is another potential issue that could lead to congestion.

A selling point for AVs is their applications in ridesharing which could create lower costs compared to private vehicle ownership (Heineke et al., 2022). AV ride-sharing should also be cheaper than a traditional taxi because of the lower operating costs.

Another selling point of AVs comes from consumers' ability to focus on other tasks. Freed from the responsibility of driving, they can now use their phones, eat, or partake in other tasks while traveling.

Roundtable participants also noted that trucks and fleets in a geofenced area may now be the most attractive use case for AVs.

While AVs hold the possibility of providing convenience and efficiency benefits, it remains to be seen whether these anticipated benefits sufficiently outweigh initial safety concerns in influencing consumer adoption.

Modality

Various projections of AVs have been presented as ridesharing vs. private ownership. However, forecasts regarding these consumer patterns have been difficult to quantify with a reasonable degree of certainty. Variables influencing a consumer shift from ownership to ridesharing are complicated. Vehicle ownership is culturally ingrained in the U.S., making models like ridesharing a more complex selling point (Mohammadzadeh, 2021).

While many projections for AV pricing suggest AVs will be more costly than traditional vehicles and sold at price points outside the price range of comparable consumer segments, there are questions about consumers' willingness to ditch ownership of AVs and share vehicles. Since the pandemic, a decrease in the use of ridesharing suggests that it still faces some adoption challenges. However, if the price is sufficiently enticing, potential users of ridesharing services may be more inclined to use such a service. The low operating costs associated with using an AV for ridesharing may lead to more favorable pricing, shifting consumer preferences toward ridesharing and away from private ownership.

Operational Design Domains Condition

As AV testing has progressed, it has become clear that AVs' capabilities will be affected by the domain in which they operate. Operational Design Domains (ODDs) limit the conditions that a specific type of AV technology can be used (Berman, 2019). Technology can be fully autonomous in an ODD but prohibited from operating in certain, outside conditions or environments. The difference between limited ODDs (Level 4) and unlimited ODDs (Level 5) is that limited ODDs prescribes a specific geographical boundary or a set of weather conditions for AV technology operation, while unlimited ODDs has no such constraints - geographical or otherwise.

Due to this variability in ODDs, companies may discover that prime conditions for operating an AV are limited to conditions in very specific locations. For this reason, many companies are no longer forecasting Level 5. Waymo, Cruise, and other companies are deploying AVs only in Arizona, California, and Texas because they have far few weather-related ODD barriers like significant rain, snow, and clouds (Bellan & Korosec, 2022).

Roundtable participants shared their insight on the projections and explained that Level 4 is not ready for mixed-use unless the AV is contained in a geofenced area with limited weather hazards. In these narrowly defined ODDs, Level 4 may be within reach for a commercial fleet model, making it a more likely target for deployments.

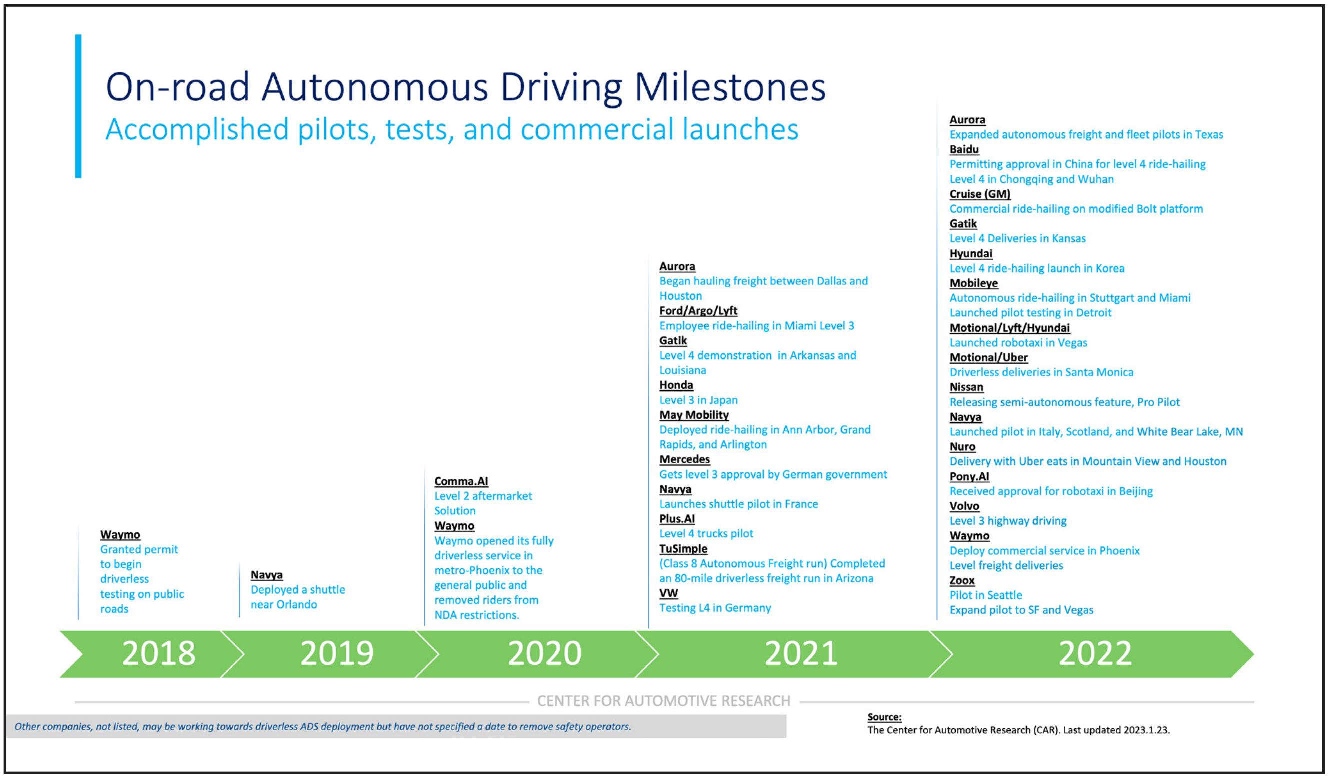

Figure 5: Accomplishments in Deployment

Scaling Toward Automation: Testing vs Pilots vs Launches

Progress toward AV rollouts typically occurs through a scaled process and is sometimes measured against complete automation (though there are suitable business cases for lower levels of automation). Due to the variety of methodologies and scaling objectives, it is difficult to assess progress and compare projections. For instance, a company can operate a test operation, a pilot operation, and a commercial operation and each operation may have a certain level of automation in a select ODD, but their scales may differ. Scaling for a pilot differs from Level 4 commercial availability, is different from Level 4 market penetration. These three markers could be years apart because they represent distinctly different milestones.

Level 4 in restrictive ODDs has already undergone testing, pilots, and commercial launches. These business models range from freight hauling to food delivery service to last-mile deliveries. Promoting business cases suitable for similar contexts would yield more immediate returns than scaling towards Level 5 in an unlimited ODD with an exceptionally distant timeline.

Additional business cases have recently undergone pilot launches with automation in trucking and small robotic deliveries in specific ODDs. These business cases have the potential to work under an operation center with human monitoring (which may blur the line between Level 3 and Level 4). Nevertheless, such use cases have greater potential for immediate commercial viability than that realized through higher-level automation with unlimited ODDs.

Infrastructure

AV potential is most significant when operated with other fully autonomous connected vehicles on smart highways. However, more realistic adoption patterns suggest that AVs must operate within the existing infrastructure and share roadways alongside traditional vehicles in the short term.

While smart infrastructure will help AVs operate more effectively, advanced infrastructure is not required to effectively operate at certain technology levels (Litman, 2022). With near term upgrades, existing infrastructure limitations can be overcome to provide an effective AV technology platform.

Augmenting sensor technology will likely generate more immediate benefits than developing new technology that relies on connectivity or a smart infrastructure.

Even if AVs do not require substantial smart infrastructure investments, many forms of AV technology will benefit from minor infrastructure upgrades to improve lane visibility and standardization of markings and maps (Canis, 2021). Reducing nonstandard and unclear road markings and irregular construction zone variabilities can, for example, improve the effectiveness of AV technologies.

Dedicated lanes for trucks and platooning are other examples of infrastructure upgrades that can yield benefits without developing smart highway technology.

Additionally, space currently used for parking can be repurposed as drop-off zones for ridesharing AVs.

The balance between AV development and infrastructure enhancements requires planning and collaboration between state and private stakeholders.

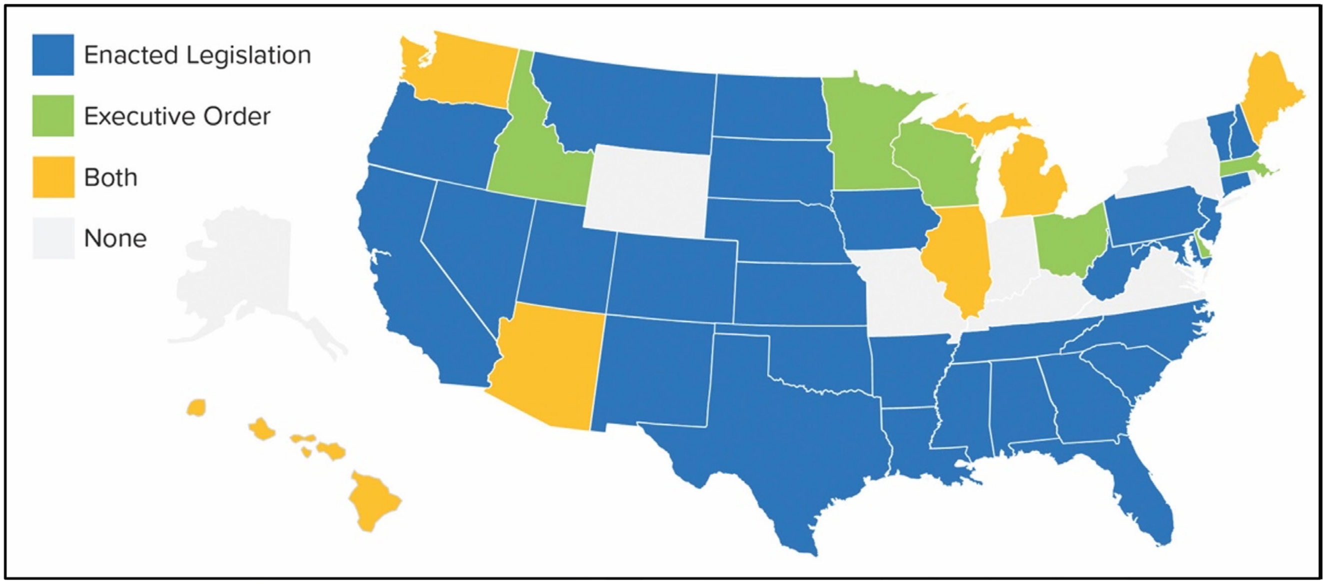

Figure 6: State AV Legislative Action

Policy and Regulation

Because the federal government has ceded regulatory power to the states, regulation of AVs has primarily occurred at the local level (Canis, 2021). However, NHTSA used its guiding documents to help foster state regulation and will continue to work with states to support new regulations (NHTSA, 2020). NHTSA is reevaluating conventional statutes from the Federal Motor Vehicle Safety Standards (FMVSS) that do not apply to automated driving technologies.

In the Automated Driving System Framework for Safety Standards, NHTSA sought to utilize the New Car Assessment Program (NCAP) to evaluate the AV capabilities of a given vehicle (NHTSA, 2020). Because AV technologies do not fit neatly within the FMVSS compliance framework, they issued a limited number of exemptions that allow a company to operate up to 2,500 automated vehicles per year, per company that petitions for use (NHTSA, 2022).

AVs are mainly deployed at the municipal level, requiring local coordination between companies and local governments. The burden falls on local communities to decide how to equitably implement this emerging technology. There are already examples of AV companies working with a municipality to allow their service to complement transit (Neef, 2021).

Some regulatory initiatives will ultimately guide the implementation of AVs, which may come in the form of a Vehicle Miles Traveled Tax, driver monitoring mandate, or policy for crash and traffic decisions.

Various organizations assist NHTSA in developing standards to support guidelines that govern automation. For example, NHTSA relied on SAE's levels of automation to define the ADAS technologies used in rulemaking documents and has used these levels to describe the state of the industry in its guiding documents (NHTSA, 2022). Additionally, NHTSA used the International Organization for Standardization (ISO) and Underwriters Laboratories (UL) to evaluate ongoing standards in the industry as a foundation for rulemaking.

Liability

Level 4, and possibly some Level 3 AV technology may shift responsibility and liability from the vehicle owner or driver to the vehicle manufacturer. On the other hand, liability associated with ADAS technology, typically limited to technology that assists the driver, will likely remain with the vehicle owner or driver. In the United Kingdom, highly automated vehicles and their manufacturers are liable, which creates a problem for the producers when deploying vehicles (Bellan, 2022).

To avoid liability, companies may continue a trend of deploying Level 2 or Level 2+ technology for their private vehicles. Currently there is ambiguity in assigning liability between the consumer or the provider when the technology lies between Level 2 and Level 4. At this point, the standards should make the consumers liable in Level 2 vehicles and the providers liable in Level 4 vehicles, while Level 3 is difficult to evaluate.

Insurance companies are struggling to gather the data necessary to accurately assess liability and there is currently not enough policy guidance or legal precedence to predict likely outcomes. Some companies opt to self-insure, which has made the insurance and liability pathways less clear for an autonomous future (Hall, 2022).

Technology: Hardware and Software

There is no consensus on technologies needed to best support AV development. AEB, LiDAR, sensors, cameras, ultrasonic, mapping, localization, computational platform, deep-learning, and IMU are examples of technologies used in AVs today.

To lower costs, Tesla is already developing a LiDAR-free pathway (Dickson, 2021). Other companies are moving away from deep learning due to the difficulty in unpacking the learning data – i.e., it is hard to standardize the foundational pieces and the learning methods.

Furthermore, without transparency into how deep learning or the hardware is implemented, it is hard to determine the root cause of a failure.

NHTSA's crash investigation strategy attempts to evaluate these technologies and software mishaps but likely will not paint the complete picture.

Cyber/Data

Cybersecurity of autonomous vehicles is a crucial issue as critical data can become vulnerable. Hacking is a looming threat, and policy protections for the data are integral to make safeguarding standards. For this reason, some companies are moving away from relying on communication with the local environment. Software updates may be pushed to vehicles without owner approval to ensure safe systems. However, such accessibility to vehicles poses a potential data privacy threat (Canis, 2021).

Data is valuable to all, but no definitive legislation determines whether consumers, automakers, tech companies, urban planners, law enforcement, or insurance has the right to access it (Canis, 2021). Presently, rules of data ownership seem to favor automakers, although they acknowledge the difficulty in gathering and using vehicle data - even when doing so can benefit them. Such difficulty demonstrates the limits of data collection and monetization.

Maintenance

The costs of maintaining an AV are significantly higher than a traditional vehicle because the associated hardware and software requires additional maintenance and regular updates (Heineke et al., 2022).

A crash or repair may cost more for an AV than a traditional vehicle, which could alter insurance costs. Furthermore, uncertainty surrounding the lifespan of certain technology suites in AVs complicates long-term vehicle cost projections. For example, the lifespan of a sensor may be shorter than other parts of the vehicle, but if the repair costs are too high, a private owner may decide to not repair the vehicle. Fleets, too, will have to take these additional repair costs into account over time (Litman, 2022).

Unlike private vehicle owners, fleets will also have to account for the costs of cleaning their vehicles. Ridesharing services that own AV fleets can no longer depend on drivers to be responsible for a clean and operable vehicle, which means they will have to factor in additional costs that are absent in traditional ridesharing services like Uber and Lyft.

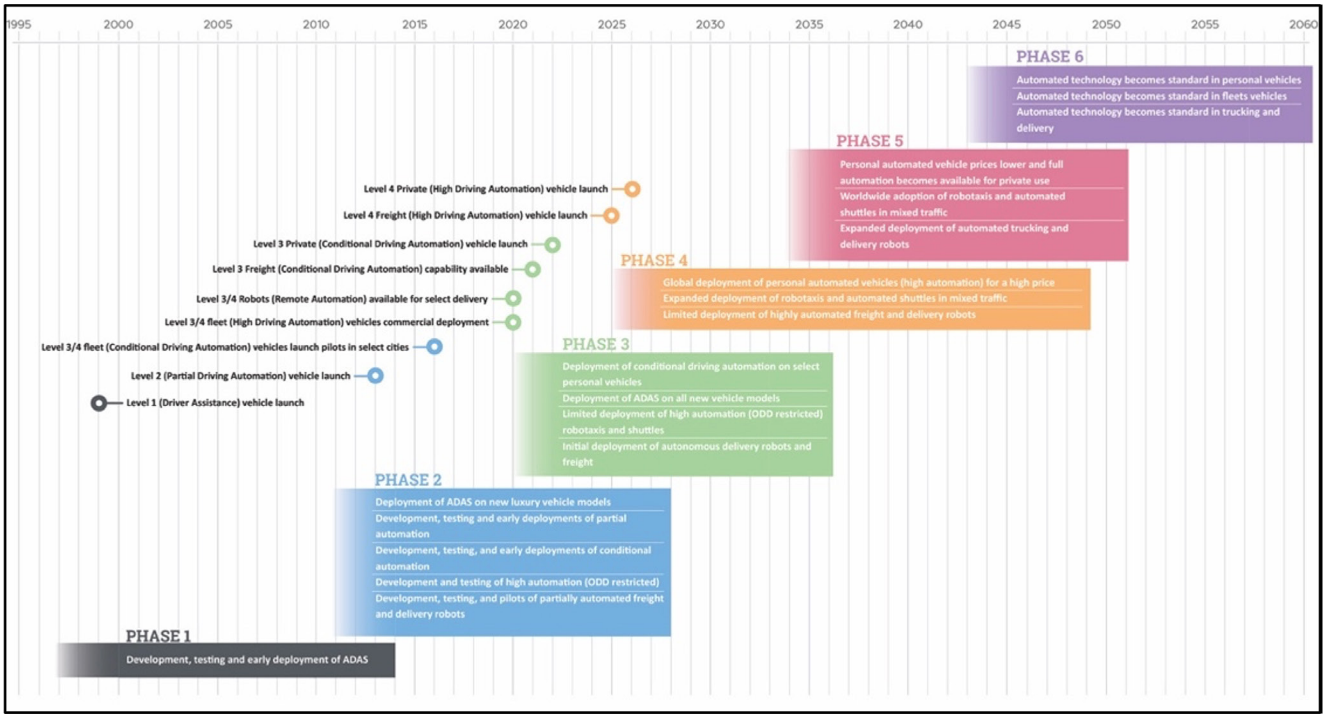

Figure 7: Approximate Deployment Projections

Going Forward

Creating a “roadmap” for AVs in 2022 has proven to be more challenging than previous iterations—but likely a more realistic endeavor. The expectations for AVs today are far less optimistic than they were five years ago. In 2017, consultants, technology and vehicle developers, and AI experts were touting a robo-taxi future by 2025. Those voices have gone quiet. Although the expectations for implementation have decreased greatly, nuances allow for a clearer picture of what an AV future may entail. AV progress has slowed, and fewer companies exist today than a few years ago, but work continues.

Automation in *very limited* ODDs is seeing initial application in freight operations and robo-taxi. These initial applications use highly focused, limited ODDs that rely on predictable routes and weather. They present a sensible (if much more modest) first use case for automation in transportation and offer a “win” for developers. Currently, most AV fleet operations are located in highly predictable (or at least highly studied) environments, such as Arizona, California, and Texas. None of these initial test cases yet support a scale to be deemed anything near “market acceptance,” but they may present first steps in what many now expect to be a very long process. Each of these early test cases will be challenged to gain scale within the ODD, and may be even more challenged in transferring those learnings to other ODDs.

While there are some early, very ODD-limited fleet AV applications, developers appear much less interested in AVs for non-fleet consumers in the coming years. Costs associated with full AV technology continue to be well above the price-points consumers would likely tolerate. However, some manufacturers continue to develop a near-term fully self-driving future for consumers.

The regulatory structure has adjusted to allow for AVs, but it likely will not change further until AVs prove more viable. State policies may stagnate as technology development stalls and federal policy could remain limited if development fails to progress significantly. The rush to be the first to create AV-specific policies has slowed and will likely continue at a much more measured pace in the coming years. While it is useful for governments to assess the needs and opportunities of AV technology, there is a growing agreement that there is ample time to consider and develop the most effective strategies.

Connectivity

Overview

Connectivity, specifically V2X applications, has been projected as an essential factor for optimizing vehicle mobility and augmenting automation. V2X applications include Vehicle-to-vehicle (V2V), Vehicle-to-infrastructure (V2I), and Vehicle-to-network (V2N).

Potential forms of optimization include better traffic flow, crash detection, reduced fuel consumption, and enhanced self-driving features (Neumann, 2019). These efficiencies can also improve highway safety, thus making the business case for them appealing.

Connectivity can apply to many use cases for vehicles, some of which use connectivity through cellular networks. Advanced V2X systems rely on roadside units (RSUs) and have their dedicated spectrum. Of the advanced V2X systems, two forms have emerged as the prominent technologies, Dedicated Short Range Communication (DSRC) and Cellular Vehicle to Everything (C-V2X) (Canis & Gallagher, 2021).

Many AV companies are avoiding investments in C-V2X or DSRC technology in the near term because of regulatory uncertainty and potential data exposure. Another reason for hesitancy in adoption is that connected technology works best when there are many other connected vehicles and a robust connected infrastructure – both of which are currently lacking. Cloud-based connectivity may get more investment if it can provide companies with similar results, at a lower price point, than either DSRC or C-V2X.

While safety was the original selling point for connectivity, there are more business cases, including data collection for auto manufacturers.

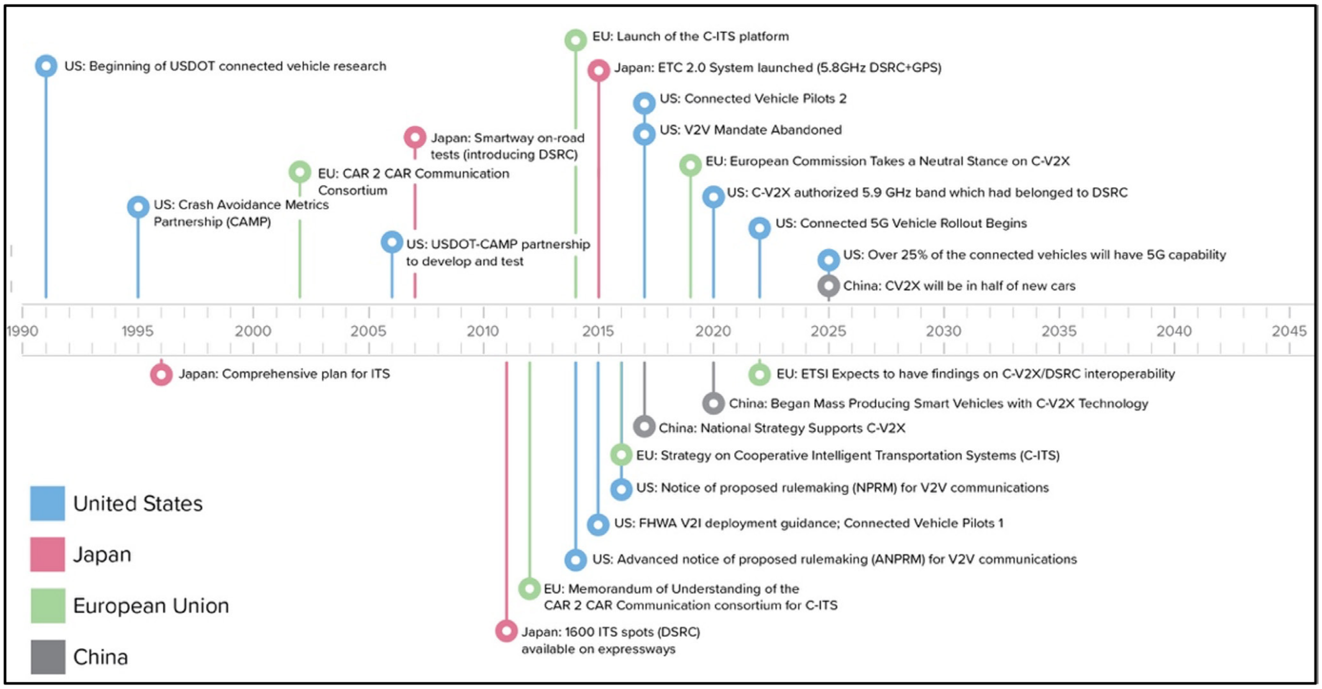

Figure 8: Vehicle Connectivity Global History

DSRC vs. CV2X

DSRC is an initial Wi-Fi-based vehicle communication mode that does not rely on cellular networks (Gettman, 2021). DSRC was allocated spectrum in 1998 by the Federal Communications Commission (FCC), in consultation with the Department of Transportation (DOT). Over the past 20 years, DSRC has been installed in many cars and trucks to optimize vehicle communication under this federal guidance and has been the predominant vehicle communication technique, receiving investments from industry, federal, and state governments.

C-V2X was a vehicle technology developed in 2017, and unlike DSRC, can connect 4G and 5G networks. For these reasons C-V2X received backing from telecommunications providers and technology companies. At the time of its inception, there were fewer standards and procedures for C-V2X because it was still in its developmental stage.

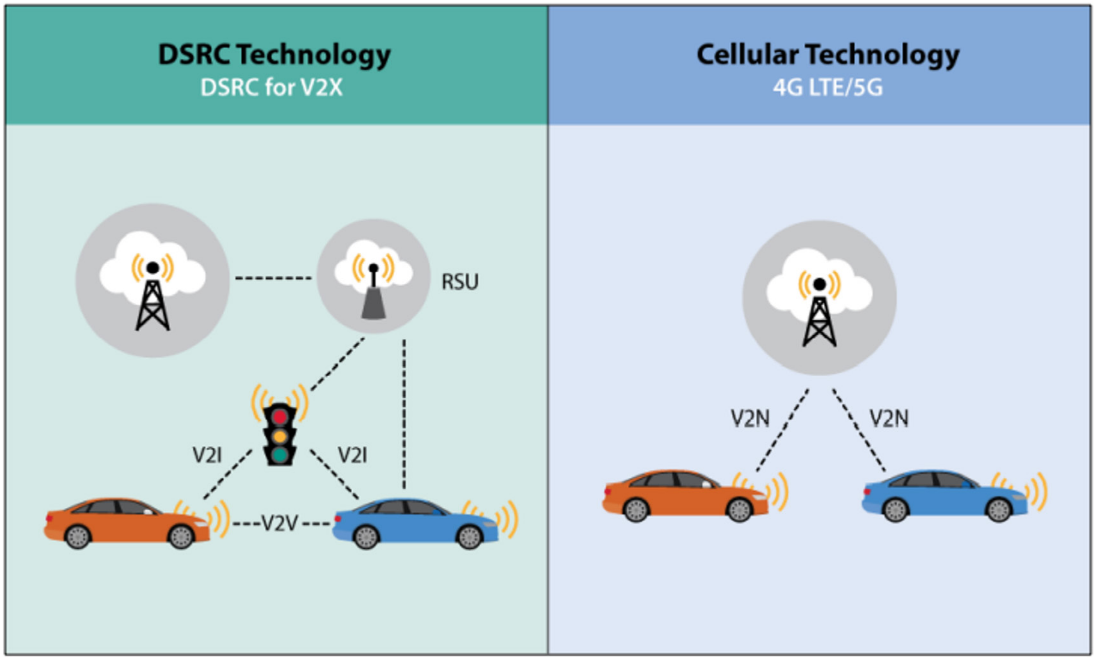

Figure 9: Vehicle Communication Modes
Source: Canis, B. (2021, April 23)

Status of Regulation

In 2016, the Obama administration proposed a V2V mandate using DSRC. The proposal never passed and lost momentum as administrations changed. In 2020, the FCC announced in a Notice of Proposed Rulemaking (NPRM), that parts of the 5.9GHz spectrum that at the time was allocated for DSRC, would be opened up for use by Wi-Fi and C-V2X devices (Canis & Gallagher, 2021). The FCC justified the action based on an underutilization of DSRC, while the DOT pushed back, citing concerns based on long-term investment in DSRC. In early June, the FCC sought to comment on the spectrum's reallocation. Discussions centered around reimbursements to parties affected by the spectrum shift. Approaches to reimbursement varied, but most commentators supported the idea (McCurdy, 2022).

The Advanced Transportation Technologies and Innovative Mobility Deployment (ATTIMD) Program is a federal grant program with funding dedicated to retrofitting DSRC to C-V2X. The federal Carbon Reduction Program also has stipulations supporting this retrofitting. There are still entities fighting for DSRC beyond reimbursements because of the investment precedent, and these challenges have occurred at the legal level. Recently a court approved the FCC's decision to reassign the 5.9 GHz band (Gitlin, 2022). Despite the fights and regulatory battles, the ruling likely marks the end of DSRC in the U.S. and will make C-V2X the only choice for advanced V2X technology.

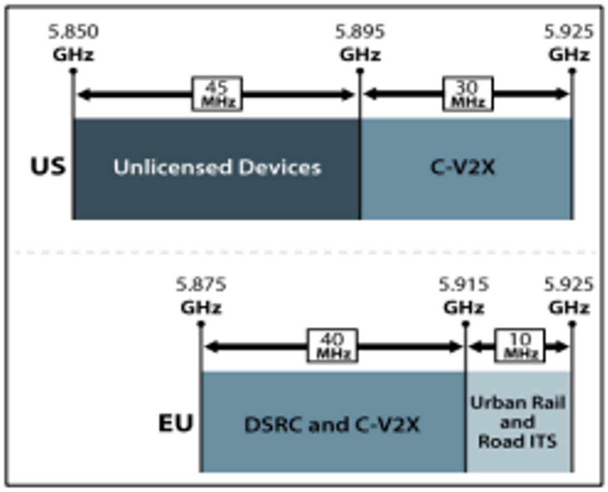

Figure 10: Spectrum Methods
Source: Canis, B., & Gallagher, J. C. (2021, April 21)

International Scope of Regulation

China has made C-V2X mandatory, which could spur the adoption of vehicle communication. China's centralized regulatory structure shortens the implementation period for C-V2X, with estimates that up to 78% of all V2X in China will have C-V2X technology by 2025 (Berg, 2021).

Automakers in China quickly reacted to the regulatory adoption standards by deploying C-V2X in their vehicles. There are estimates that up to 50% of new cars sold in China will have C-V2X capability by 2025.

Like the U.S., the European Union (E.U.) connectivity regulations have been in flux. They have yet to determine their predominant form of vehicle connectivity, taking a neutral approach in the DSRC and C-V2X debate and allowing both to operate. Eventually, the E.U. will have to choose a technology or risk interoperability issues.

Japan and South Korea are taking a similar approach to the E.U. as they test both technologies in their respective jurisdictions (Canis & Gallagher, 2021).

Data Privacy

Data privacy standards and regulations are still in their developmental stage in the U.S., complicating the vehicle technology implementation process. While China has a strict regulatory policy to promote government data access and the E.U. conversely has consumer data safeguards, the U.S. is still without a comprehensive regulatory basis for its data management (Mulligan & Linebaugh, 2019).

Since the business case for data collection focuses on near-term benefits, substantial federal regulatory standards will need to follow if companies hope to manage and monetize driver data. As seen in the E.U., there will likely be internal jockeying within the industry for data rights in the U.S., which will be a competition between manufacturers, technology companies, insurance companies, and the states (Cohn & Jones, 2022). These stakeholders are currently lobbying for their respective access to the data and carving out rules in their favor (Mitchell, 2021). However, most of these policies, like the proposed American Data Privacy and Protection Act (ADPPA), are data agnostic and do not address vehicles specifically.

California is an early actor in this space as the federal government still develops a framework. The California requirements may provide the manufacturers with a guiding principle before they build business models on data monetization. From a consumer standpoint, there will be concerns about data access and privacy that may hinder the business model for connectivity. If consumers are hesitant to give up their data and have no financial, regulatory, or safety incentive, the business case for manufacturers will come into question (Dyson & Ross, 2022). At this point, auto companies are creating financial and insurance incentives if consumers are willing to hand over data which may be the business case for data monetization (Hall, 2022).

Alternatives in the Market: Cloud Computing

V2X technology has improved, but cloud-based connectivity and telematics technologies are currently available that promote connectivity without the same regulatory and cost burden as C-V2X and operate independently of the roadside units (RSU) found in C-V2X and DSRC technologies (Neumann, 2019).

Roundtable input made clear that the lower costs associated with these applications are an appealing alternative to auto companies because they do not need the same regulatory approval as other V2X technologies. Additionally, these alternate forms of connectivity ensure communication and data remain within a manufacturer's desired network. The combination of a localized network and limiting vehicle communication avoids the threat of privacy breaches and data vulnerability. According to industry participants, these cloud-based vehicle technologies are more advanced than C-V2X technologies and offer solutions like evaluation of vehicle operability.

These cloud-based technologies may temporarily cause adoption to diverge from both of the FCC's regulatory choices (Brady, 2022). Even before regulation is complete, automakers are adopting alternate solutions that may have a more immediate and practical impact.

Business Case for Connectivity and the Cost Elements from OEMs

Initially, the value proposition for connected vehicles and V2X was safety and the subsequent optimization of a connected fleet. Since then, the value proposition has changed from safety – where there was a struggle to rely on connectivity to make all safety decisions - to manufacturers, who recognize the value of vehicle data (Hall, 2022).

Despite safety not providing the sole business case, OEMs realized the value of data and the need to collect it in order to effectively evaluate the vehicle's functionality through cloud computing. Even without C-V2X and DSRC, there is still data collected on driving patterns with cloud-based connected vehicle technology. Cloud-based technology may have lower cost barriers and regulatory uncertainty than C-V2X and DSRC, but manufacturers will still need to manage several cost elements to ensure adequate network speed across all locations.

Manufacturers will also need to determine the cost elements for the rollout of their technology. Industry experts from the roundtable indicated that in these cases, auto manufacturers might opt to manage their own 5G networks, which could be the lowest-cost solution.

Business Case for Connectivity in Automation

Connectivity can augment automated vehicles in specific applications like platooning and fleet operations (Brown et al., 2021). These applications can offer enhanced safety under certain circumstances, even if connectivity rollout is independent of automation and vice versa. Particular ecosystems, (e.g., fleets) may be significant contributors to enhanced safety via connected applications and experiments with rollouts. As markets evolve, some ecosystems will prove more advantageous than others and adoption will be driven by the best business case.

Presently, cloud-based connectivity is the foundation for AV data evaluation. Data may prove to be a significant cost barrier due to insurance implications currently preventing AV companies from allowing vehicle communication. Data breaches will also drive up the cost of insurance of AV vehicles, thus motivating companies to restrict connectivity to internal loops, and performance evaluation to the present case (Dyson & Ross, 2022).

As federal standards and communication technologies develop, the business case for vehicle communication will become more lucrative. The communication business case will enable platooning, fleet operations, crash reduction, and congestion mitigation, but cloud-based connectivity will be the dominant vehicle communication platform in the present term.

Going Forward

Innovation and regulation have altered the connectivity path in the last few years. V2X technology development and adoption will likely succeed most in countries with highly centralized regulatory processes like China. Conversely, V2X adoption in the US will remain limited because of regulatory uncertainty, business case validity, and data concerns. Regulations like the ADPPA may allay auto manufacturers' data concerns surrounding V2X technologies. Court rulings affirming C-V2X may also help auto manufacturers move past the phase of regulatory uncertainty but there should be no expectation that auto manufacturers will implement these V2X technologies in the near-term.

For the foreseeable future, it is reasonable to assume that auto manufacturers will opt for cloud-based connectivity to avoid data exposure and regulatory challenges.

In the near term, data monetization will present a clear business case through cloud-based connectivity. In the long term, vehicle automation and freight platooning will offer a favorable business case through V2X. Until there are higher adoption rates of V2X technologies, incentives to implement V2X will be absent. Since cloud-based connectivity is already advanced and has lower cost barriers than V2X, auto manufacturers should expect to invest in these applications in the interim.

Conclusion

The landscape for these vehicle technologies has changed in the last few years as ADAS, automation, and connectivity have matured. The roadblocks to the widespread adoption of ADAS include a lack of standardization, high prices, and consumer uncertainty. Overcoming these barriers to ADAS adoption will likely occur by educating consumers on how to use the technology, prices becoming more accessible, and the technological benefits being apparent. AVs face challenges in reaching widespread market penetration, but as development has progressed over the past few years, the obstacles are easier to identify. The implementation of AVs is currently incremental and targeted toward specific ODDs, which makes their near-term implications more predictable. If the fleets of AVs prove to have success in their limited ODDs, deployment could scale to new domains. However, as development has stalled, regulators and investors have tempered their expectations for high automation coming imminently, allowing the industry to make progress before altering policy strategies or investments any further for AVs. Vehicle connectivity has also faced changes due to regulatory and technological uncertainty. Advanced V2X technologies like C-V2X and DSRC are limited in application because of data concerns, lack of infrastructure, and regulatory irregularity. Despite these advanced V2X technologies stagnating, the auto industry has quickly adapted to regulatory uncertainty and adjusted to provide a near-term business case for connectivity through applications like cloud-based connectivity. The perseverance in finding ways to implement connected vehicle technologies comes from their benefits, like vehicle performance evaluation, safety, and data monetization. With time, advanced V2X technologies may supplant cloud-based technologies, but cloud-based technologies ensure a present-day business case. While the development of ADAS, automation, and connectivity has been more complex than predicted years ago, there are current use cases for all, even if some are limited. Development leading to the widespread use of ADAS, high-functioning level 4 AV fleets, and adoption of C-V2X remain uncertain, but the barriers to getting there are now visible.

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