Deployment of Automated Driving as an Example for the San Francisco Bay Area

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Abstract There is a lot of discussion about the different levels of vehicle automation and when respective products will come to the market. When taking a closer look, one actually observes that different experts often talk about different scenarios even when contemplating the same level of automation. In order to generate a more comprehensive perspective on the different levels of automation and their timelines for market deployment, this contribution analyses expert interviews and extensive media research. The picture that emerges from this spans a deployment roadmap from automated shuttle services launching still this decade to automated highway driving and delivery services some 20 years into the future. Hypothetical scenarios for the San Francisco Bay Area are provided as potential examples.

Keywords Automated driving · Autonomous driving · Deployment scenario Automated shuttle · Truck automation · Platooning · Automated delivery San Francisco Bay Area

1 Context and Scope

Without any doubt has automated driving become one of the most defining trends shaping the future of the automobile and with that the future of mobility and transportation. The general media, industry announcements, analyst reports, etc. continuously entertain this field and there is no shortage of forecasts as to when automated driving will come to the market [1–8]. The 2017 Automated Vehicle Symposium was no exception to this discussion and many presentations also included timelines for the deployment of respective automated driving concepts or

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products. When engaging in those discussions on deployment scenarios, one often observes contradiction, rejection, or misunderstanding in terms of the projected timelines.

Given this situation of high interest and at the same time much confusion, this contribution aims to summarize the discussion among experts and observers, to align with the many forecasts, and to integrate different perspectives in the field. Therefore publicly available information was analyzed for deployment timelines and expert interviews were conducted to inform a comprehensive deployment scenario. Many of those interviews were conducted at or around the 2017 Automated Vehicle Symposium, so that this determines the timeliness of the scenarios and this also creates a strong tie to the Symposium. As the list of references at the end of this contribution shows, almost 50 media articles and press announcements were analyzed to create this perspective.

The automated driving scenarios to be discussed in this contribution are supposed to cover a broad spectrum of directions. That is important to align the discussion in industry, regulation, and media as to which kind of automated vehicle will come to the market when and where. On can easily attest that the now broadly used levels of automation as established by SAE International [9] are very helpful to determine the kind of automation, and therefore they are also used throughout this publication as "L3, L4, L5". However, they do not unambiguously determine what kind of vehicle and what kind of use case is referenced. Therefore the following scenarios and concepts will be discussed further in this contribution and an outlook for their public deployment will be made:

- Private passenger vehicles
- Shared passenger shuttles
- Long-haul trucks
- Local delivery vehicles.

2 Automated Driving Concepts to Be Differentiated

In order to map out deployment scenarios for automated driving, different concepts should be differentiated as they are characterized by distinct aspects and have different time horizons regarding their deployment in public. Therefore, before considering respective deployment scenarios, the different concepts will be discussed first one by one.

2.1 Private Passenger Vehicles

The automated private passenger vehicle is the most anticipated form of an automated vehicle, which means it is arguably most often talked-about in the technical

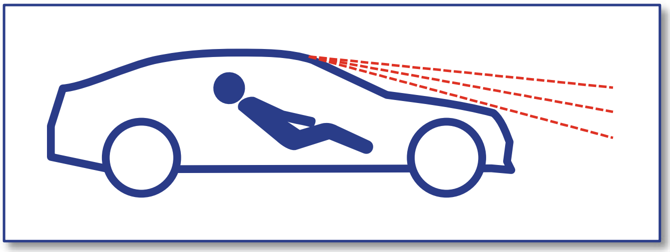


Fig. 1 Schematic depiction of an automated private passenger vehicle (red lines symbolize the automation concept, such as beams from a LiDAR system)

community and pubic media, and it is arguably the one that first comes to consumer minds when thinking about a “self-driving car”. Figure 1 shows a schematic depiction of this concept, which is a privately used and typically also privately owned light duty vehicle that can drive without human interaction. The depiction even shows the often-discussed scenario that the driver becomes a passenger and does not need to engage in the driving process at all.

The established automotive industry pursues this scenario at large [10–12]. This is basically the evolution of today’s passenger vehicles toward L5 automation, i.e. a vehicle that consumers own or lease for a certain number of years as their primary means of transportation, which can typically accommodate 4–7 people, and which can carry personal items such as shopping goods, leisure equipment or baggage. Thereby it is intended to cover many use cases from the daily commute and errands to occasional travel and leisure. The goal is to automate as many driving situations as possible, currently highway driving and parking are the furthest developed with L2 and L3 features available on the market [13–15].

The benefits of such an automated private passenger vehicle, which has been discussed in many publications, are improved safety, more productive transit time, and increased mobility [16–18]. In order to implement such technology, the industry is in need of high performance sensors for object detection, processing for situation classification and maneuver planning, and potentially a communication infrastructure that allows for a coordination of eventually driverless vehicles. Given the nature of those vehicles, i.e. a privately owned and unsupervised product, the automation concept needs to be highly reliable, low cost, and maintenance-free. As those requirements are relatively extreme, it can be expected that such automated private passenger vehicles will take a long time to reach full potential and therefore an evolutionary deployment scenario seems likely. Currently the first L3 systems are introduced to the market [14], L4 might be introduced within the next 5–10 years, and L5 should not be expected before 2030 [19, 20].

2.2 *Shared Passenger Shuttles*

Recently, the automated shared passenger shuttle has gotten much attention by corporations and also the media [21–23]. The idea here is a passenger vehicle specifically tailored to public usage in a pre-determined operating area (e.g. downtown of a particular city) and that is entirely intended for driverless operation.

Figure 2 shows such a concept as a schematic rendering, which makes the difference to the before described private passenger vehicle clear. While both are intended to transport people, the shuttle is a rather utilitarian vehicle that is optimized for short trips in an urban setting. And also, in contrast to the privately owned and operated vehicle, which can be taken to any destination on any route, an automated shared shuttle does not service any arbitrary route or destination, but only the ones pre-determined as the operating area (e.g. a certain downtown district but not the highway to the next city).

The benefits of such a mobility service are financial savings through the driverless operations as the labor cost for typical transportation solutions often amounts to up to 50% of the fee [24]. And as the overall cost for such a driverless operation is lower, a denser service network and freely scheduled operation can be realized. Thereby consumers take advantage of the flexibility known today from personal mobility and the low cost known today from public transportation.

The needs to implement such an automated shared passenger shuttle are similar to the private vehicle, which are respective sensors, processors, and infrastructure. However, since those shuttles will be operated by a professional entity (e.g. transportation network company) in a specific operating area (e.g. downtown districts), the operation can be planned and supervised. Therefore, early-stage systems can be deployed, which might be upgraded over lifetime and can be of higher per-unit cost because the anticipated high utilization enables faster amortization than in case of a privately owned vehicle. For those reasons, automated shared passenger shuttles might be deployed in public in the very short term, i.e. by the end of this decade. Pilot operations and announcements from tech companies support this projection [25–28]. Those announcements also document that, other than the traditional automotive companies, who primarily pursue the automation of the

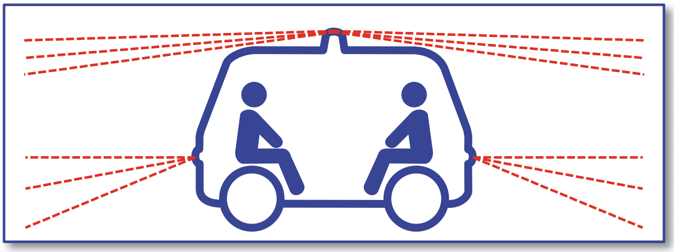


Fig. 2 Schematic depiction of an automated shared passenger shuttle (red lines symbolize the automation concept, such as beams from a LiDAR system)

private vehicle, it is the tech industry that aims for the automation of shared vehicles as a new service business. With this combination of new technology (automated vehicle), new business models (shared ownership/renting), and new operating modes (pre-determined service areas) this arrangement is a rather transformative shift in personal mobility while the traditional automotive manufacturers pursue a more evolutionary approach as discussed before.

2.3 Long-Haul Trucks

Trucks, especially the ones for long-haul operation, are another often-discussed topic in the field of vehicle automation. Established automotive players and startups alike pursue those concepts [29–34]. In this, a setting where two or more vehicles are tethered to one another via a virtual link plays a special role as the long distances on relatively predictable highways present a favorable situation. Such an automated platoon is also depicted in Fig. 3 as a special, and quite likely scenario for automated long-haul trucks. In contrast to a single automated vehicle, the platoon is, strictly speaking, not a completely automated vehicle as there would still be a human driver in the lead vehicle and only all following vehicles (concepts with up to eight vehicles total have been discussed) are driverless.

The benefit of an automated platoon is primarily the lower operating cost as the aerodynamic drag is reduced making fuel savings around 10% possible [35]. Additionally, safety can be increased as automatic steering and longitudinal control of the tethered vehicles is less prone to errors like lane departure or rear-ending, an imminent risk of human drivers due to inattention or fatigue.

In order to implement such platoons, on-board sensors and data communication between the vehicles is necessary, which basically exist today. In that regard, the major challenges for deployment are regulation and coordination to integrate such convoys of up to 8-vehicle lengths into existing traffic patterns. It can be expected that those hurdles will be overcome soon, especially as intensive testing has been

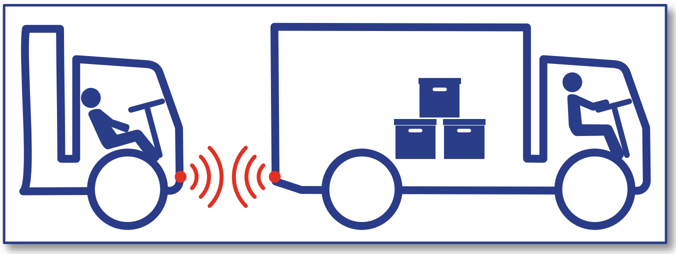


Fig. 3 Schematic depiction of an automated long-haul truck platoon (red lines symbolize the automation concept, such as WiFi communication between the vehicles)

undertaken for about 10 years now [33, 35] so that public deployment might happen early in the next decade.

In addition to such platoons, other concepts for automated long-haul trucks target specifically highway operation as well. Those focus however on single vehicle operation with special assistance to get the vehicles with human interaction onto and off the highway [34]. Such examples could be that a human is on the vehicle for on- and off-ramp driving but can perform other tasks while on highway, or a human can tele-operate the on- and off-ramp situations so that one operator can drive many more vehicles than in today's setting where one driver is assigned to exactly one truck for the entire journey. Either way, the motivation is to increase productivity or to reduce operating cost. However, those concepts might take longer to implement in public because of their higher complexity.

2.4 *Local Delivery Vehicles*

Another automation concept that focuses specifically on the transportation of goods is the automated local delivery vehicle. Figure 4 depicts schematically such a concept that is basically a driverless version of the van typically used by delivery companies like the postal or courier services.

Other types can easily be envisioned such as small automated ground vehicles like delivery robots or even flying automated areal vehicles like drones. All of those are actively be pursued, in particular by said delivery services and tech companies [36, 37].

The benefit of such automated delivery vehicles is again a lower cost structure as human operation or supervision is not necessary. The reason is that the last mile delivery accounts for about 50% of the cost in the logistics chain because humans need to spend time driving from the local distribution center (LDC) to the delivery area, then find the exact address, take the shipment from the vehicle, deliver it to the recipient, and confirm delivery [38]. Often however there are problems such as unclear directions, unavailable parking, unsuccessful delivery, or retuned

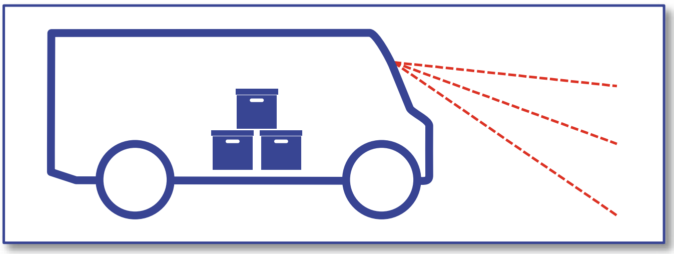


Fig. 4 Schematic depiction of an automated delivery vehicle (red lines symbolize the automation concept, such as laser beams from a LiDAR system)

shipments. The time associated with those problems increases the overall cost significantly as a human driver with a fixed salary gets less productive. Through automation however, this extra time does not matter that much, which is why automation will be very beneficial here. This concept gets even better when supplemented with those small-scale delivery robots or even drones for delivery from the vehicle to the recipient.

The necessary components to implement such automated local delivery vehicles are similar to the described shared passenger shuttles, i.e. respective sensors, processing, and infrastructure. And also very similar, those solutions can be rather early-stage and less cost effective given that those vehicles would be operated by professional entities that can check and upgrade components when necessary.

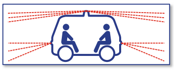
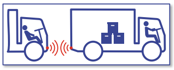
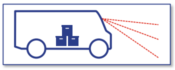
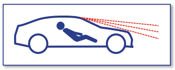
However, the operating area would probably need to be broader than for the shuttle, simply because the driving distances would be larger as otherwise shipments would need to be transferred too often between vehicles. However, those longer distances and therefore broader operating area pose higher uncertainty of the traffic and environmental setting in the service district so that the automation concept needs to meet higher performance levels than for the automated shuttle. This means that the delivery vehicles should be expected to launch after the passenger shuttle, and the middle of the next decade appears plausible for public deployment.

3 Comparison of Automated Driving Concepts

The previous parts highlighted the specific concepts that help to map out an overall deployment scenario for automated driving. While those concepts have several aspects in common, such as general sensor and processing technology, there are also important differences, which were pointed out already as they give an indication for implementation challenges and timelines. To gain an overall perspective, those aspects should be compared directly, which Table 1 summarizes.

The overview in Table 1 shows that the different concepts share largely the challenge of integration into existing traffic patters, i.e. how respective automated vehicles would negotiate situations with human driven vehicles as well as other automated ones. The solutions for this can be seen in an infrastructure, which comprises communication (vehicle-to-vehicle and vehicle-to-infrastructure), construction (dedicated areas, barriers…), and regulation (certification, general and local permits…). This infrastructure would be easier to implement and operate in a limited area, such as a specific downtown district or on a dedicated highway, than blanketing the entire nation. And also, slow speed operations help with operations because a safe state (e.g. emergency stop) can be attained immediately if needed. For those reasons, the automated shared passenger shuttle should be expected as the earliest implementation among the concepts discussed here, which is consistent with recent announcements [25–27], and the private passenger vehicle might be last to launch to public operations.

Table 1 Comparison of automation aspects for different concepts based on media research and expert interviews (L4/5 refer to SAE J3016 automation levels, + specific advantages, − specific challenges)

Concept	Specific characteristics	Steps to deployment
Shared passenger shuttles L4 	+ Finite number of routes limits unexpected situations + Pre-determined operating area allows for specific infrastructure + Slow speed reduces risk	• Implementation of special infrastructure (communication, regulation/permit…) • Further improvements of object/ situation recognition
Long-haul truck platoons L4 	+ Well-defined use case makes scenarios predictable − Mixed traffic, esp. merging difficult to navigate	• Regulation to allow for special driving settings (e.g. close distance in platooning) • Infrastructure to harmonize with existing traffic patterns • Testing in real-world traffic
Local delivery vehicles L4 	+ Finite number of routes limits unexpected situations +/− Slow speed reduces risk, but difficult in mixed traffic − Drop-off from driverless vehicle at recipient still unsolved task	• Regulation, infrastructure to operate in dedicated areas • Testing in real-world traffic • Solution for automated drop-off at recipient, drones might be an option
Private passenger vehicles L5 	− Virtually infinite driving situations and operating area − Passengers expect human-like driving performance, safety/trust concerns prevail − No reliance on human supervision or fallback	• Improvement in sensor and processing technologies • Installation of roadside infrastructure (communication, construction, regulation) • Experience from earlier implementations of automation

In between the early deployments of automated shared passenger shuttles and the ultimate scenario of the automated private passenger vehicle, the launch of automated trucks is conceivable, potentially first with platooning concepts [30, 32, 33], and a bit later local delivery services. The reason why platoons might launch before local deliveries is that in platoons there is still a human in the loop, i.e. the driver of the lead vehicle, even if all following vehicles satisfy the definition of L4 automation. Local delivery vehicles however are expected to operate without any human intervention and therefore will take longer to the market, also compared to the shared passenger shuttle as the operating area of a delivery network is probably larger than the service area of a shuttle.

In this comparison it becomes clear why the L5 private passenger vehicle will probably take the longest to implementation, despite it being the most anticipated concept as pointed out at the beginning of this contribution. The reason for this lies in the virtually unlimited and therefore unknown operating domain, i.e. road, traffic, weather, etc. Therefore this uncertainty presents an infinite multitude of settings and makes the implementation most difficult and therefore probably the last to happen among the concepts discussed there. However, it also should be emphasized that all concepts build on one another and the experience that industry, regulators, and general public learn from earlier implementations prepare the path to the launch of this ultimate scenario of the L5 private passenger vehicle.

4 Hypothetical Deployment Scenario for the San Francisco Bay Area

Different deployment scenarios like the transformative (shared shuttle) and evolutionary (private vehicle) path toward automated driving were discussed in other publications already [39, 40]. And it was also already pointed out that while it seems that those two trajectories toward automated vehicles are disjoint in their timelines, they still share essential synergies regarding technical, regulatory, and societal aspects.

In order to further concretize the concepts discussed in this contribution, the following describes now in closing how an overall scenario could unfold in the San Francisco Bay Area. This region is chosen for this hypothetical scenario as there are many traffic challenges (urban sprawl, extensive industrialization, and sparsely developed public transit, all leading to traffic congestion) and also many of the automated driving players (in industry and academia) are located in that area. Taking all this and the different automation concepts together, Fig. 5 shows how the different types of automated vehicles might get deployed in this specific area. It is important to note that this is a hypothetical depiction as no one can reasonably say what is going to happen in the next 5–10 and even less 10–20 years. Therefore the following can very well be seen as some sort of a science fiction narrative. However, those scenarios should help the reader to visualize the deployment of

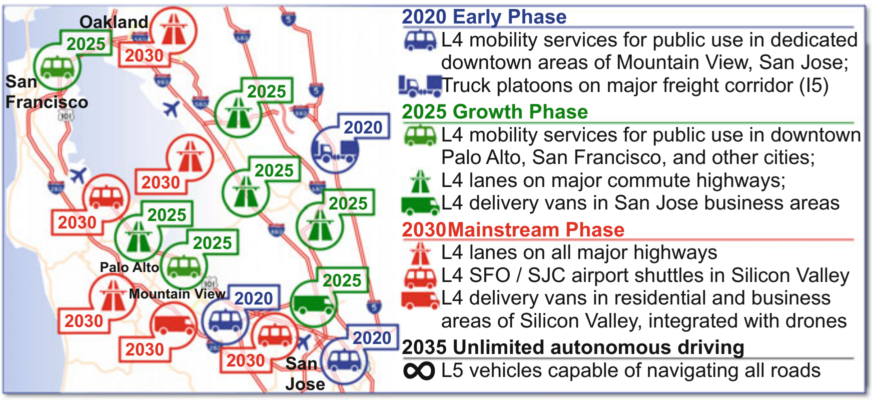


Fig. 5 Depiction of a hypothetical deployment scenario for automated driving in the San Francisco Bay Area (based on expert interviews and media research)

automated driving while keeping in mind that the narrative is based on expert interviews and extensive media research, using the theoretical assessment of the concepts per the previous parts of this contribution.

For the near future, the "Early Phase" of automated driving implementations around 2020, one can expect for the San Francisco Bay Area initial deployments of shared passenger shuttles. Those would be the services from local tech companies that are already testing respective pilot programs in Chandler (AZ) and other places [25, 26, 41, 42], which would then be brought to the home region near the companies' headquarters. There are respective announcements that make such scenarios likely [43, 44] and Mountain View, Santa Clara, and San Jose could be well situated to see the first implementations given the presence of the tech companies, a supportive regulatory environment, and the population's tech savvy. Around the same time, one might expect truck platoons on a major freight corridor like the I5, which is part of the broader San Francisco Bay area. Here again, announcements have been made, which support this scenario [45, 46].

Following this Early Phase, one can assume that a "Growth Phase" could follow around 2025, which would build upon the experience from the early deployments such as initial consumer reaction, policy revisions, and further refined on-board technology as well as roadside infrastructure. This could lead to early deployments of L4 automation on major commute highways, such as for instance I580, 680, 880 in the East Bay where telematics infrastructure like electronic toll systems (ETS) and express lanes are piloted already today [47, 48]. Evolving those telematics installations further, one can imagine L4 automation on certain lanes for especially equipped passenger vehicles and trucks. At the same time, i.e. around the middle of the 2020s, the early phase shared passenger shuttles might expand operations from initial locations to downtown San Francisco, an area that will be more difficult to navigate due to an erratic mix of pedestrians, cyclists, and any kind of motor vehicles. Such an expansion would benefit from previous experience and the deployment in a more complex setting becomes manageable. Similarly, early implementations of automated delivery vehicles might be observed in and around San Jose with the airport as a major hub for logistics companies.

In a "Mainstream Phase" around 2030 one might find L4 lanes on all major highways in the area, which would particularly benefit commuters and trucks. The latter would then add to the logistics network that provides the Bay Area with any kind of consumer and commercial goods. This is expected to improve efficiency and safety in the region of about 8 million population that is home to a vast number of businesses, the large trade port in Oakland, as well the international airports in San Francisco, San Jose, and Oakland. In addition to this, the shared passenger shuttle as well as delivery services might further expand in this phase. For instance, it becomes conceivable that respective automated shuttles transport air travelers to and from the SFO, SJC, and OAK airports. And also, the delivery services that launched earlier around the logistic hub would subsequently further expand into the metro area, enabling automated home delivery, potentially combined with drones for the drop-off at the recipient.

Finally, the L5 private passenger vehicle should not be expected before 2035, if at all, as L5 implies that the vehicle could go anywhere at any time. However, for such an unlimited operation to become possible, the situation in the rest of the nation needs to be compatible with the San Francisco Bay Area. And as such parity might take even longer than another 20 years, this scenario of unlimited L5 operation around 2035 should be seen as highly speculative. And still it could be possible as the deployment of private passenger vehicles with L5 automation would benefit from all the earlier launching automation concepts as discussed, so that this evolution will eventually reach this ultimate scenario.

5 Summary/Additional Remarks

This contribution discussed first different concepts of automated vehicles and then potential deployment scenarios specifically for the San Francisco Bay Area. The assumptions and projections are based on experts interviews conducted at the time of the Automated Vehicle Symposium 2017 and contemporary media research. The proposed overall deployment path points to automated shared shuttle services by the end of this decade, automated delivery vehicles around the middle of the 2020s, and L5 private passenger vehicles in the 2030s. Across those phases, different concepts in truck automation are expected, first with platoons and later single vehicle automation.

It is a crucial aspect of this contribution that those projections were developed specifically for the San Francisco Bay Area as there are unique characteristics in terms of technology presence, traffic challenges, as well as economic and political interests. Other regions have different characteristics and respective scenarios vary in their timelines and automation concepts. Thereby it is also important to note that this contribution does not provide exact dates for the deployment of specific automation concepts but rather proposes phases when respective implementations can be expected.

Therefore it can be maintained that those scenarios are hypothetical if not speculative as no one can safely say what the situation in technology, regulation, and society will be like in 5, 10, 20 years from now. However, this contribution took expert opinions and media coverage in the vehicle automation field to come up with a comprehensive perspective. Further work is encouraged to increase accuracy as well as detail regarding those scenarios. They will certainly change as time progresses. In that sense, this contribution closes with a quote that fits well:

> We always overestimate the change that will occur in the next two years and underestimate the change that will occur in the next 10. Don't let yourself be lulled into inaction. Bill Gates, [49]

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