Technical University of Munich

TUM School of Management

Innovation Ecosystems in the Race to Autonomous Driving: A Comparative Case Study of Four Automotive Manufacturers

Master Thesis – Executive MBA

Supervisor: Prof. Dr. Isabell Welpe
Chair for Strategy and Organization
TUM School of Management
Technical University of Munich

Person in Support: Ann-Carolin Ritter

Submitted by: Daniel Ruflin

Submitted on: 22 February 2022

Declaration of Authorship

I hereby declare that the thesis submitted is my own unaided work. All direct or indirect sources used are acknowledged as references.

I am aware that the thesis in digital form can be examined for the use of unauthorized aid and in order to determine whether the thesis as a whole or parts incorporated in it may be deemed as plagiarism. For the comparison of my work with existing sources I agree that it shall be entered in a database where it shall also remain after examination, to enable comparison with future theses submitted. Further rights of reproduction and usage, however, are not granted here.

This paper was not previously presented to another examination board and has not been published.

Daniel Ruflin

Table of Contents

1 Introduction

On 4 July 2019 it was announced that BMW and Daimler would cooperate on the development of autonomous driving (BMW Group, 2019). According to SAE International (previously known as the Society of Automotive Engineers) there are 5 levels of driving automation from SAE Level 1, where there is lane centering or adaptive cruise control, up to SAE Level 5, where the vehicle is fully autonomous and a driver is not required anymore. Currently, leading automotive manufacturers like Audi, BMW, Daimler & Co. are in a race with other major OEMs[1] (e.g. GM, Toyota, Tesla), startups and new players in the field (mainly technology companies like Waymo and Uber) to develop the autonomous driving technology of the future. Companies are increasingly collaborating[2] with each other, including with their competitors, in order to stem the high development costs and to reduce the risks associated with it (Matousek, 2019).

There are new players in the field and Waymo seems to have a leading position with 20 million miles of self-driving on public roads (Waymo, 2020a)[3]. Waymo and Uber as well as Tesla want to operate fleets of self-driving cars (Lambert, 2019). The incumbent automotive manufacturers need to react and are faced with new strategic choices. "Car manufacturers' traditional strategic choices [...] are already outmoded because the automotive sector needs to anticipate a future ecosystem whose epicenter will be the intelligent and autonomous car." (Attias & Mira-Bonnardel, 2017). What is less well known is the progress of the traditional OEMs and what strategies the incumbent automotive manufacturers choose to counter the threat of new entrants in order to stay relevant.

While the ecosystems theory is not fully developed (i.e. it does not give a clear guidance on which partners to choose, how to build such an ecosystem, and finally how to manage it),

[1] Original Equipment Manufacturers
[2] We use collaboration and cooperation interchangeably (in this work)
[3] By January 2020, 20 million miles of driving on public roads had been completed (*Wikipedia - Waymo*, 2021).

there is some consensus among strategy scholars that the concept originally proposed by Moore (in 1993) moves the focus away from “industry-focused strategic planning” and opens up possibilities for cooperations outside traditional industry boundaries (Dodgson et al., 2015, p. 204). Therefore, it is important to get an overview on the players in the field of autonomous driving, what kind of cooperations they choose (i.e. whether ecosystems get established), and ultimately what are promising strategies. As Alejandro Vukotich, Senior Vice President of Fully Automated Driving and Driver Assistance at BMW, put it: "In the end only a few ecosystems for automated driving will survive, because the effort is too big" (Dahlmann, 2019).

The research methodology to be applied is the Case Study method described by Robert K. Yin in the book "Case Study Research and Applications" (Yin, 2017). The innovation strategies of four different companies / innovation ecosystems are analysed: Ford/Volkswagen (Argo AI), GM (Cruise), BMW/Daimler and Tesla. The data used for the empirical research comes from open sources: Company Information (Homepage, Annual Reports, Product Brochures), Investor Conferences / Analyst Reports, Interviews with Managers, Magazine Articles, etc. Additionally, external experts are asked for their opinion on the strategy of the four automotive manufacturers.

Finally, we try to come up with some recommendations for managers on the most promising innovation strategies.

2 Current State of Autonomous Driving

The current state of Autonomous Driving will be described in the following three sections.

2.1 Technology

The autonomous driving technology is quite advanced in terms of Level 2 autonomy (for a taxonomy of the Levels of Driving Automation (SAE J3016) see the Appendix B). Level 2 is what we currently call driver assistant systems (speed limit control, automatic steering correction) but the driver permanently needs to supervise the system. Interesting is Level 3 (where the car could drive autonomously on a section of a highway for example or could park automatically in a specially equipped car park) and Level 4 (where the car could drive autonomously in most situations, including most probably cities)[4]. The US and Chinese startups (see Table 4) are testing Level 4 autonomous vehicles in different American (and Chinese) cities; for example Waymo has a test fleet in the state of Arizona (Randazzo, 2021).

Tesla's "Full Self-Driving" Hardware includes 8 cameras, ultrasonic sensors and a forward-facing radar - however, the Tesla Autopilot is currently only an SAE Level 2-system - the driver permanently needs to supervise the system. Mobileye is developing a system with 11 cameras - for Level 2, maybe Level 3 only - and want's to enhance it with new radar and Lidar sensors in order to reach Level 4 by 2025 (Intel Newsroom, 2021a). There is a battle between the technologies. Elon Mask argues that High-Definition maps and Lidar sensors are not required for "Full Self-Driving" (TopSpeed, 2019) whereas Mobileye (an Intel company) is developing their own maps and Audi, BMW and Daimler bought the mapping company

[4] Strictly speaking, the difference between Level 3 and Level 4 is the fallback (if the system fails). In Level 3 the driver needs to take over control within a short period of time (e.g. 10 seconds), whereas in a Level 4 system the system needs to have some redundancy to get into a safe state (if part of the system fails) - independent of driver intervention - so the driver is no longer a fallback.

'Here Technologies' in 2015 (*Wikipedia - Here Technologies*, 2021). Elon Musk claims everyone who uses Lidar technology is "doomed to fail" while all other players use Lidar as an additional sensor technology and Frank Weber, Head of Development at BMW, says that Lidar is required for Level 3 autonomy - for every company (Fasse & Hubik, 2020).

Also, there seems to be a different perspective in terms of "risk-aversion"[5]. While Tesla markets its systems as full self-driving (even though it isn't) the Germans follow a much more cautious approach (maybe because of legal hurdles and the regulations). It is interesting to note that Tesla had a fatal accident in 2016 (there were other accidents) and the NTSB (National Transport Safety Board) concluded that Tesla was not at fault (the driver was watching a movie) and that the crash rate for Tesla cars (Model S at that time) dropped by 40% after Autopilot was installed (*Wikipedia - Self-driving car*, 2021). This shows that the early introduction of new technologies can save lives - however it should not be marketed in a miss-leading way.

2.2 Regulations

It is difficult to get a global overview on the regulations at this point in time. There are various efforts (and evolving status) in different regions around the world (countries and legislations). Without going into detail or trying to provide a complete overview we want to highlight the following developments.

UNECE: There is the "UN Regulation on Automated Lane Keeping Systems" (24 June 2020) which will be approved by the different countries starting in 2021. It was developed under the lead of the German and Japanese government and allows the automated driving on the high-way for up to 60 km/h (it is planned to increase the speed to 130 km/h) (UNECE,

[5] BMW Group and Daimler together with Aptiv, Audi, Baidu, Continental, Fiat Chrysler, HERE, Infineon, Intel and Volkswagen have published a white paper with the title "Safety First for Automated Driving" (Daimler, 2019c). The CEOs of the automotive players seem to agree that an autonomous car must be at least 100 times safer than a human driver (Interviews with Herbert Diess and Amnon Shashua) (Volkswagen, 2018).

2020). The German media argue Germany will have the most advanced legislation regarding autonomous driving - once the law is approved (BMVI, 2021a). Clearly, this view is very limited since there are other developments in the US (and China) as we will see below. The UN Regulation on Automated Lane Keeping Systems only applies to separated traffic (physical separation between opposite directions) and cannot be applied to Level 4 autonomous driving in the city. The first country who has introduced a Level 3 autonomous car for the highway is Japan (even though it is limited to 100 leased cars) (Sugiura, 2021).

US (California): In the United States the laws vary from state to state. Waymo is currently testing its fleet of autonomous vehicles in Phoenix, Arizona (Waymo, 2021a). In California, there is the Autonomous Vehicle branch of the DMV (Department of Motor Vehicles, State of California) which developed the 'Autonomous Vehicle Tester Program' in 2014 and established the 'Autonomous Vehicle Driverless Tester Program' for manufacturers in 2018. The idea is that car manufacturers can test their autonomous vehicles in specified areas (streets in cities, for example San Francisco) without a driver in the seat (even not a test driver) (DMV, 2020). Currently (as of 21 May 2021), there are eight companies holding such a license: Waymo, Nuro, AutoX, Zoox, Cruise, Baidu, WeRide and Pony.ai (all those companies are either US or Chinese startups) (DMV, 2021). Cruise was bought by GM (in 2016). Waymo is the leader in the field (followed by Cruise according to miles driven per disengagement – see Table 4) and AutoX, WeRide, Pony.ai and Baidu are Chinese companies (Stone, 2021).

China: The legislation in China is not so straight forward. Even though China has drafted a new law for autonomous vehicles (mostly buses) it would only catch up with the UK and some US states in terms of allowing "road testing … of smart connected vehicles" and "with highways permitted as a test site" (Minchin, 2021). It is The Ministry of Industry and Information Technology's (MIIT) new draft regulation. Currently, it seems to be up to the local governments and they allow testing of autonomous vehicles in specific economic zones, as is the case for AutoX in Shenzhen (Liao, 2020a). Another Chinese startup Momenta (a $1 billion "unicorn") has its headquarters in Suzhou (according to other sources in Beijing) and is testing its autonomous cars in Beijing and China's eastern city of Suzhou (Liao, 2019) (Reuters, 2021a) (Liao, 2021b). It is interesting to note, that Toyota, Bosch and Daimler also invested in Momenta. It is not known what the exact conditions for this testing are - nor what test sites (e.g. which parts of the city) can be used. Most probably in Beijing[6] there is still a test driver on board, but the service of AutoX in Shenzhen is without a safety-driver.

I want to point out that there are striking differences between Germany (where they think they are ahead because they will get the laws for "Autopilot" on the Highway, and Daimler laments that the European laws are not uniform (Daimler, 2017)), and the US and China where innovative startups put Level 4 cars on the streets (independent of the costs and they try to change the local rules and regulations to get their approval for the new technology)[7,8].

2.3 Cooperations

There are many cooperations in the field of autonomous driving and the field is quite fluid considering that new cooperations are announced almost every week. We cannot guarantee that our overview is exhaustive but we try our best to list the most important and up-to-date cooperations. We focus on cooperations in the field of passenger cars, there are also many cooperations in the area of trucks, we will mention some of them shortly but will not go into more detail since trucks are not the focus of this work. We are mostly interested in passenger cars and vans since they can be used for autonomous ride-hailing in the future and automatic

[6] In May 2021 it was in the news that Baidu launches Apollo Go robotaxis in Shougang Park in Beijing before the 2022 Winter Olympics (there is no backup driver in the car, but there is a remote backup driver in case of an emergency) (Ramey, 2021).

[7] The ADAC mentions in a report about the current state of technology that VW tries to develop and commercialize autonomous cars in the US and China, but not in Germany (since the necessary legislation will be ready in those countries) and that VW plans a test track for Level 4-cars in the city of Berlin (which is not ready yet).

[8] "Cities from Shenzhen to Shanghai are competing to attract autonomous driving upstarts by clearing regulatory hurdles, touting subsidies and putting up 5G infrastructure." (Liao, 2020a)

delivery of goods. Platooning of trucks on the motorways will also change the economics of the business (the driver can do other tasks during the ride for example) but we don't have a look at those ecosystems.

The list of companies/cooperations is tilted towards Chinese and US companies. The reason herefore is that it is doubtful whether European companies (established car manufacturers) are actually working on Level 4 autonomy at the moment. They claim this to be the case, but we neither see proof on the streets nor in product announcements.

There are cooperations of the established car manufacturers (e.g. Toyota with Denso and Aisin, BMW with Daimler, Volvo) but we do not list those cooperations here because some of them have been dissolved (e.g. Zenuity of Volvo with Autoliv, the cooperation between BMW and Daimler is "on hold") or the status of the progress is not known (e.g. Toyota). The Hyundai-Aptiv Autonomous Driving Joint Venture (Motional) plans to begin testing autonomous vehicles in Los Angeles in 2021 (Korosec, 2021g). Waymo will begin mapping New York City streets (Bellan, 2021b) and "Intel's Mobileye became the first to win a permit to test its autonomous vehicle technology in NYC" (Korosec, 2021e). Tesla does only provide an SAE Level 2-system and the claim that it is "Full Self-Driving" is false[9].

The list of the cooperations can be found in Appendix A. We only want to showcase Toyota here as an example, because it is in some ways exemplary and similar to Volkswagen.

- Toyota started the Toyota Research Institute-Advanced Development (TRI-AD)[10] in 2018 to develop self-driving car software (O'Kane, 2018b)[11]

[9] The DMV is currently even investigating whether Tesla violates state regulations with its self-driving claims (Mitchell, 2021a). Contrary to its marketing, Tesla told the regulators a very different story (Mitchell, 2021b).
[10] TRI-AD (Toyota Research Institute - Advanced Development) is the research institute for autonomous driving of Toyota. It employs software experts from California and has more than 1000 employees (Kölling, 2019). It was established in 2018, is based in Tokyo and is a "new [USD] 2.8 billion company to develop self-driving software" (O'Kane, 2018b). Partners are Denso and Aisin (Toyota Group companies) (Denso, 2018) (Toyota, 2018). TRI-AD became 'Woven Planet Holdings' in 2020 (woven planet, 2020).
[11] Toyota currently invests in Apex.AI which builds the new operating system for cars of the future (Apex.AI, 2021).

- Toyota with Denso and SoftBank's Vision Fund invested USD 1 billion in the Uber Advanced Technology Group (ATG) which was later acquired by Aurora (Korosec, 2021a)
- Toyota invested USD 400 million in the Chinese self-driving startup Pony.ai (Beresford, 2020)
- Toyota bought the autonomous vehicle division of Lyft in 2021 (Hawkins, 2021a)
- Toyota, Bosch and Daimler also invested in the Chinese autonomous driving unicorn Momenta (Liao, 2021b)
- Toyota has its own investment funds in Silicon Valley where it invests in startups mostly related to artificial intelligence (which can be used for self-driving cars) or robotics (which can be used for car manufacturing) (Nakayama, 2019)

As a general trend it can be seen that the big and established automotive companies invest in startups in the US as well as in China or partner with technology companies[12].

[12] We will later see that there is currently an opposite trend where automotive manufacturers want to develop the software inhouse (e.g. Daimler, BMW, Volkswagen, Toyota), at least for privately-owned passenger cars (Fasse et al., 2021) (Fasse, 2020) (Kölling, 2021).

3 Theoretical Background

3.1 Developments in Corporate Strategy

In Competitive Strategy (1980) Michael Porter established a classic strategy framework for industry analysis along five dimensions (competitors, buyers, suppliers, threat of substitute products or services and threat of new entrants) (HBS, 2021; Porter, 1979). While some argue Porter's Framework is superseded by new business models in the new economy (Ovans, 2015) others claim "there are still only two ways to compete": either the ecosystem enables product or service differentiation or generates a cost advantage (Martin, 2015). There seems to be consensus among strategy scholars that the business ecosystem plays an important role in the future (Greeven, 2019) ("An increasing literature argues that strategic networks and innovation ecosystems have become a new basis of competition", however "the managerial implications of this insight remain insufficiently developed" (Dodgson et al., 2015, p. 223)); at the same time some professors note that "The term "ecosystem" has been used in business for 20 years. Companies including Volkswagen and Toyota have been orchestrating huge networks of suppliers and distributors for more than 50 years." (Birkinshaw, 2019). Therefore, a clear definition of innovation ecosystem is needed. What further complicates matters, is the fact that it is not clear how to create such an ecosystem, how to coordinate/control it (value appropriation) and specifically to our case how to select the partners[13]. Indeed, according to consultancies only 15% of ecosystems succeed[14]. In summary, "The basis for managerial insights remains fragmented, reflecting the general fragmentation of this important domain" (Dodgson et al., 2015, p. 223).

[13] Consultancies jumped into the breach, with offering some guidance on "How Do You "Design" a Business Ecosystem?", "How Do You Manage a Business Ecosystem?", "Do You Need a Business Ecosystem?" and most importantly "Why Do Most Business Ecosystems Fail?" (BCG Henderson Institute).

[14] "A recent study by the BCG Henderson Institute found that fewer than 15% of the 57 ecosystems investigated were sustainable in the long run." (Pidun et al., 2021; Pidun et al., 2019, 2020)

3.2 Trends in the Automotive Industry

Currently, the Automotive Industry is undergoing major change: Not only are they switching from classic petrol engines to electric vehicles, but also autonomous driving offers huge challenges and potential opportunites (opening doors for new competitors/rivals). Based on a definition of Emma Muckersie in 2016, it can be argued that the autonomous car is a "radical innovation" since it not only requires the introduction of a new technology but also allows the adoption of a new business model (JAYDIAZ2013, 2016). Also, "A study conducted by KPMG in partnership with the Center for Automotive Research shows that a business model must be reinvented for car-makers: the advent of the autonomous car allows us to imagine vehicle fleets for collective use where the user would pay per kilometer instead of buying his car.“ (Attias, 2017).

IBM business consultants already wrote in 2003: "While companies will continue to seek competitive advantage by maintaining tight control on costs throughout the supply chain, the industry will have entered a new era in which success will depend on three critical factors: (1) Customer responsiveness – understanding changing market demands to create products and services that meet and exceed customer expectations. (2) Faster speed to market – using integrated/collaborative design and development capabilities to bring new products and services to market faster than competitors. (3) Innovation – rapidly assimilating new technology into vehicular systems. To compete and win on these fronts, leading manufacturers will need to embrace a new business model. In essence, this model takes the form of a race between closely integrated collaborative communities of manufacturers and suppliers. The leading players in these communities will increasingly operate with skills proven in other industries, especially the hightech sector. They will form tight-knit collaborative communities that compete against each other for margin and market leadership."

While there are many studies on research cooperations between universities and industry and a lot of studies on cooperations in the automotive industry, mostly focusing on the innovation collaborations with suppliers (e.g. the Toyota Production System)[15] we want to focus our research on innovation ecosystems and their significance in the automotive industry.

3.3 What is an Innovation Ecosystem?[16]

In his seminal paper *Predators and Prey: A New Ecology of Competition* (Moore, 1999) describes a business ecosystem as a space, where "companies coevolve capabilities around a new innovation: they work cooperatively to support new products, satisfy customer needs, and eventually incorporate the next round of innovations".

From this follows a definition of an innovation ecosystem: "An **innovation ecosystem** refers to a loosely interconnected network of companies and other entities that coevolve capabilities around a shared set of technologies, knowledge, or skills, and work cooperatively and competitively to develop new products and services." (Moore, 1999). Granstrand and Holgersson compare different definitions of the concept of innovation ecosystems and come up with their own definition: "An innovation ecosystem is the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors." (Granstrand & Holgersson, 2020). For our purpose the definition derived by (Moore, 1999) is suitable and it highlights that an innovation ecosystem includes **cooperative and competitive**

[15] The Toyota case shows that learning capabilities in a network can be a competitive advantage (Dyer & Nobeoka, 2000).

[16] We use 'Business Ecosystem', 'Innovation Ecosystem' and 'Ecosystem' interchangeably in this work; it is to stay in line with literature (and different sources). We focus on ecosystems with the aim to create new products or services, therefore 'Innovation Ecosystems'. An innovation is defined as follows: "A common feature of an innovation is that it must have been implemented. A new or improved product is implemented when it is introduced on the market. New processes, marketing methods or organizational methods are implemented when they are brought into actual use in the firm's operations (OECD/Eurostat 2005, para. 150)." Also, we use 'Innovation Strategy' and 'Cooperation Strategy' interchangeably in this work (while the former includes the option not to cooperate, the latter highlights the cooperative element of many ecosystems).

elements[17].

For the purpose of our work and analysis we extend the concept of ecosystems by the theory on (R&D[18]) alliances; this not only allows us to extend the ecosystems theory by potential advantages and disadvantages of cooperations, but also to better understand why ecosystems get established – or why not. In "Do you need a Business Ecosystem?" the authors argue that a complex technical product that requires integration of its components must be done by the OEM (in a hierarchical supply chain) (Pidun et al., 2019).

3.4 Interorganizational Relationships

As already hinted we don't want to focus on the classical (hierarchical) supplier integration in this paper – even though they certainly are part of the ecosystem – but rather on the cooperation between established firms – often former competitors – in the creation of innovation ecosystems. While the theory on ecosystems often assumes that there is one central coordinating firm - the keystone[19] - (Farhadi, 2019), the partnerships we look at are better characterized by interorganizational relationships between peers (e.g. R&D cooperations, alliances).

Barringer & Harrison give a good overview on the theories behind alliance formation (among them Transaction Cost Economics, Resource Dependence and Strategic Choice)[20] and the different forms of interorganizational relationships (Joint Venture, Network, Consortia, etc.) (Barringer & Harrison, 2000). Barringer & Harrison further refer to (Powell, 1990) who

[17] We further like the definition of "Collaboration" by Mark Dodgson as "it is only collaboration in our definition if all contributors commit resources to it and mutually determine its objectives" (Dodgson et al., 2015, p. 463). Such a definition of cooperation and "Innovation Ecosystems" would narrow it down – but then also ecosystems like for example Apple's iOS and App Store could not serve as a benchmark anymore, because in fact they behave quite monopolistic (Leswing, 2020) – which even might have antitrust implications as in the case of Google or amazon (European Commission, 2015) (Ovide, 2021) (European Commission, 2019) (Edelman, 2021).

[18] Research & Development

[19] Also called 'orchestrator' or 'focal firm' in part of the literature (See chapter about 'Innovation Ecosystems' or 'Innovation, Strategy and Hypercompetition' in (Dodgson et al., 2015)).

[20] Transaction Cost Economics treats any trade as a transaction (can be inside an organization or between organizations) and analyses the costs associated with it; Resource Dependence is based on the principle that an organization needs resources (and therefore must engage in transactions with employees or external parties); finally, Strategic Choice leaves it up to the management to decide for example based on a benefit and cost analysis.

explains the rationale for alliance formation as follows: "firms pursue cooperative agreement in order to gain fast access to new technologies or new markets, to benefit from economies of scale in joint research and/or production, to tap into sources of know-how located outside the boundaries of the firm, and to share the risks of activities that are beyond the scope of the capabilities of a single organization". This summarizes well the rationale for the cooperations that we are going to investigate in the course of this case study. Finally, we want to elaborate potential advantages and disadvantages of cooperations (partially adapted and further extended from Barringer & Harrison); we call them alliances for simplification, but we believe equal arguments apply for ecosystems.

3.4.1 Potential Advantages of Cooperations[21]

- Gain access to particular resources (e.g. limited IT-resources / specialized knowhow)
- Economies of scale (Research & Development cost can be shared, avoidance of "Duplication")
- Risk and cost sharing (Level 4 requires enormous investments; the technological and market risk is high and it is not clear when the commercial breakthrough will happen)
- Product and/or service development (through pooling of resources, complementary capabilities)
- Learning (i.e. if the partners have different capabilities, different cultures w.r.t. innovation or risks, and/or different processes, e.g. agile methods)
- Speed to market (see also potential disadvantages)[22]

[21] The 'Potential Advantages of Cooperations' come primarily from (Barringer & Harrison, 2000) but have been extended by own research and stimulus from the Oxford Handbook of Innovation Management.
[22] We want to highlight those potential advantages, e.g. "Speed to market", can also be reversed when additional coordination effort and decision making is required.

- Market Power (Jacobides, 2019; Jacobides & Lianos, 2021); established ecosystems can have monopoly power (which then again has antitrust implications)

3.4.2 Potential Disadvantages of Cooperations[23]

- Loss of proprietary information (can be managed through proper agreements related to value appropriation, opportunistic behaviour must be avoided, trust)
- Management complexities / e.g. coordination overhead (may lead to significant delays) "it is typically easier to work within a firm only than to open up to collaborations"
- Financial and organizational risks (in case the cooperation fails or does not produce the expected results); "Failure rate of [alliances] is high"
- Risk of becoming dependent on a partner / Loss of organizational flexibility (an ecosystem is attractive if the partners are respected and competent)
- Partial loss of decision autonomy (e.g. control over what is being developed); this may increase the risk of failure and might cost time; standards might be a good mitigation
- Partners' "cultures" may clash (power of management); in an ecosystem power should ideally be shared between partners (this certainly is new to managers in established corporations)
- Antitrust implications: there might be regulations of ecosystems in the future

[23] The 'Potential Disadvantages of Cooperations' come partly from (Barringer & Harrison, 2000) but have been adapted based on a discussion with a technology and innovation management professor and own research.

3.5 Research Questions

The overall research question is "How do the different automotive manufacturers cooperate and compete in the race to autonomous driving?"; to sharpen the research question, we want to look at the innovation strategies in closer detail:

- What innovation strategies do the different automotive manufacturers and their innovation ecosystems follow to compete in the field of autonomous driving?
- What kind of cooperations develop (e.g. between established automotive manufacturers, with technology companies and/or investments in startups)?

This will also reveal whether ecosystems get established – or not. At least to the extent where it can be defined what an ecosystem is (cooperations with suppliers are still an option).

Ultimately, we would like to answer the following question:

- What are promising innovation strategies and are there any recommendations for the improvement of existing strategies?

We may caution here that the reasons why ecosystems are established or not cannot be fully explained in the scope of this work. We may receive some information in press releases but as always with strategic decisions – the reasons of the decision makers can only be read between the lines (and might even not be fully revealed in direct interviews).

4 Research Methodology

4.1 Research Method

The research method used in this paper is the Case Study method described in the book "Case Study Research and Applications" of Robert K. Yin (Yin, 2017). He gives a definition of the method as follows (p. 14): "The essence of a case study, the central tendency among all types of case study, is that it tries to illuminate a decision or set of decisions: why they were taken, how they were implemented, and with what result." (Schramm, 1971) Wikipedia states: "a case in business might study a particular firm's strategy" (*Wikipedia - Case study*, 2021). Robert K. Yin (Yin, 2017) further defines the case study method in two steps:

1. A case study is an empirical method that
    - investigates a comtemporary phenomenon (the "case") in depth and within its real-world context, expecially when
    - the boundaries between phenomenon and context may not be clearly evident.
2. A case study
    - copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result
    - benefits from the prior development of theoretical propositions to guide design, data collection, and analysis, and as another results
    - relies on multiple sources of evidence, with data needing to converge in a triangulating fashion.

Yin mentions triangulation[24] as an important feature of the method and reason for selecting the case study method.

[24] In social science 'triangulation' is the use of multiple cross-checked sources and methodology (*Wikipedia - Triangulation*, 2021)

4.2 Selection of Cases

The cases have been selected for relevance. Given that the collaboration of BMW and Daimler is of utmost interest and they compete directly with major OEMs (at least for the time being) an analysis has been done of all major collaborations in the field of autonomous driving. Even though the technology and software of Waymo ("We are building the World's Most Experienced Driver" (Waymo, 2020b)) might be a great competition in the future they want to improve their algorithms and do not plan to build cars themselves (Wiggers, 2020). The most relevant competitors at least in Europe and the US have been identified. It is possible that in the future powerful Asian players will emerge as well (for example Toyota, Volvo owned by Geely and/or Chinese startups).

Therefore, in this work the following companies / innovation ecosystems are analysed:

- Ford/Volkswagen (Argo AI)
- GM (Cruise)
- BMW/Daimler
- Tesla

Note: It is important that those four cases are embedded in the wider context. There are many more ecosystems, for example Renault-Nissan-Mitsubishi and Fiat Chrysler (now Stellantis) partner with Waymo and Fiat Chrysler teams up with AutoX on robotaxis in China (Korosec, 2020b). There are many startups backed by US and Chinese technology companies; it is interesting to see that even the established car manufacturers invest in startups in China[25]. For a list of the cooperations and startups see section 2.3 and Appendix A.

[25] There are articles that Baidu wants to build an own electric car, also contract manufacturers like Foxconn have their own car platform, and even Apple has a long history of rumours that it plans to build an own electric car (Reuters, 2020c) (Baidu, 2020) (Vijayenthiran, 2021) (O'Kane, 2021b) (MacRumors, 2021) (O'Kane, 2021a).

4.3 Focus on Innovation Strategy

Legal and organizational aspects relating to potential cooperations are not in the scope of this work. Also, we purely focus on the innovation strategy (strategic options) and not on operational and managerial aspects. Joe Tidd and John Bessant explain in their book "Managing Innovation" why innovation in general and an innovation strategy specifically is important (Tidd & Bessant, 2018). Based on a discussion with colleagues it seems not every company has an innovation strategy and some companies do not even mention innovation in their strategy (even though technology leadership is important)[26].

4.4 Why is Waymo excluded?

Companies like Waymo and Uber are excluded, but serve as an important benchmark. The reasons are two-fold: Firstly, Waymo is a technology company and does not produce cars like the other OEMs (they partner with Renault-Nissan-Mitsubishi, Fiat Chrysler and Jaguar Land Rover) (Jaguar Land Rover, 2018). The same is true for Uber Technologies. Secondly, Waymo seems to have a leading position (it is the only company that offers a Level 4 Autonomous Driving service in geofenced areas, currently in Phoenix, and has already reached 20 million miles of self-driving in open streets (Waymo, 2020a)). Uber is in some legal disputes, since one former Google employee has stolen technology and was sentenced to 18 months in prison recently (Korosec & Harris, 2020). After a deadly accident in 2018, Uber halted its test program and late in 2020 abandoned its plan to develop self-driving cars (Sun, 2021) (Metz & Conger, 2020).

[26] McKinsey highlights in "Building an R&D strategy for modern times" that bold bets are important in order to have high margins (Brennan et al., 2020). However, they do not clarify what the risks are when betting on the wrong technologies.

4.5 A note on Chinese players

While there are many players testing their autonomous cars and technology in China as well as in the US we still believe that the relevant and most advanced market is in the US[27]. Some argue while California is ahead with the regulatory framework, the more complicated traffic conditions and the higher acceptance of self-driving in China favor testing and commercialization in Chinese cities (Sun, 2021). Leaders in China's self-driving race are Baidu Apollo, Pony.ai, WeRide, DiDi Chuxing, AutoX and Momenta according to (Sun, 2021).

4.6 Data Gathering

As already mentioned data triangulation is an important element of the case study method. Whenever possible, received information in articles was verified with original sources (e.g. company homepages, annual reports, publications of research institutes, public databases of government agencies). The public interviews with industry leaders have been cross-checked with product brochures and other industry sources, and additionally internal employees of the companies or external experts who can judge the quality of the announcements made by the senior managers have been asked for their opinion. Test cars were driven for comparison (if available) and videos have been analyzed. Unfortunately, it was not possible to visit sites and experience promised functionalities or robotaxis firsthand.

[27] There are trials with (public) buses in China, and Baidu won a contract to build the 'Yongchuan District Smart Transportation Phase I Pilot Project' in Chongqing (Pandaily, 2021). Others build L4 Cargo vans for delivery of goods (commercial pilot with ZTO Express) (WeRide, 2021c).

5 Analysis of Four Automotive Manufacturers

In this section, the innovation strategies of the four automotive manufacturers / innovation ecosystems are analyzed.

Figure 1

Short History of Autonomous Driving (Non-exhaustive list of players in the field)[28]

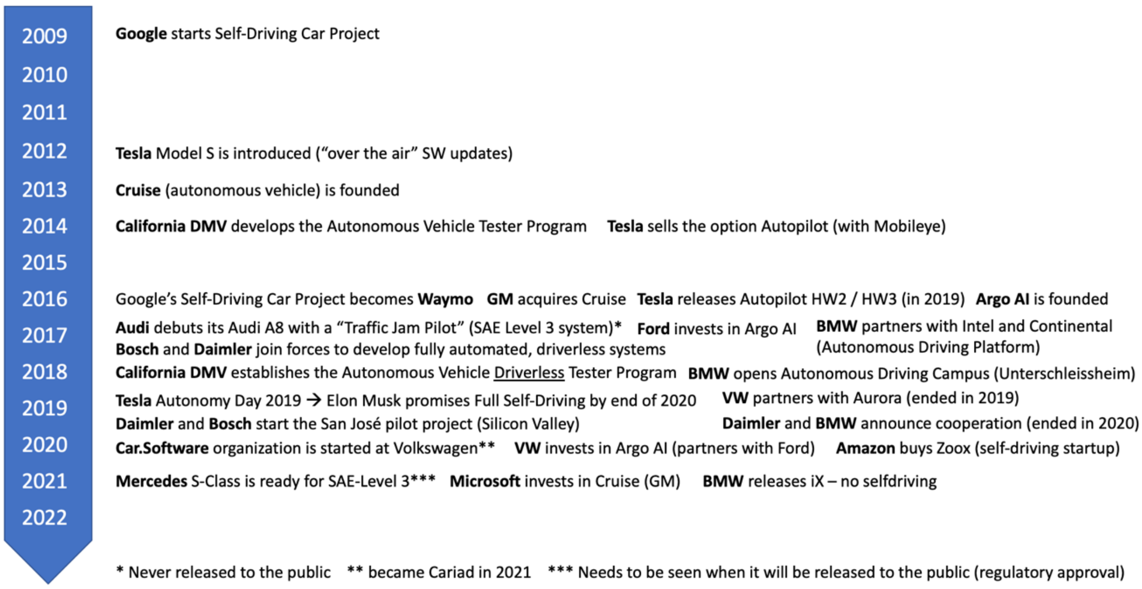


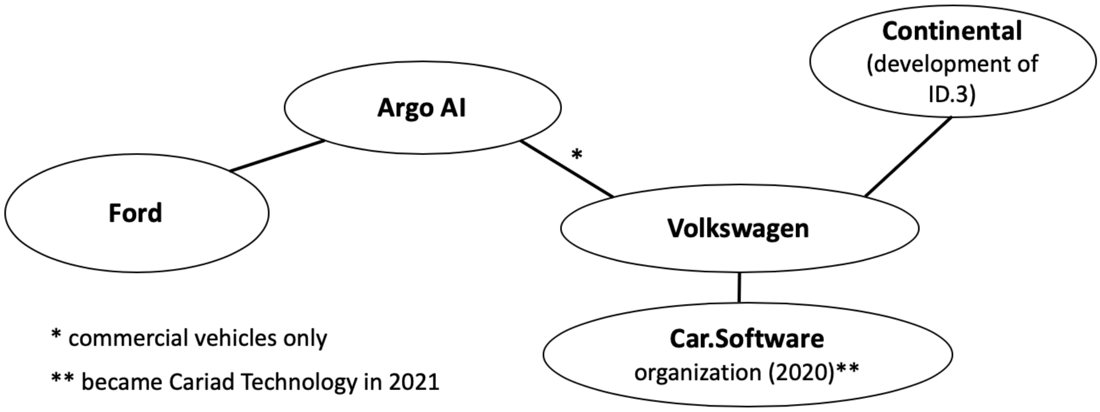
Figure 1 gives an overview about the history of autonomous driving (with respect to our cases including Waymo). As can be seen the development picked up speed in 2016 with major promises for products being made in 2018/2019. Autonomous Driving SAE Level 3 on the highway will probably only have its breakthrough in 2022 – if at all. Robotaxis are left to companies like Google or the many Chinese startups/technology companies (with the exception of GM's Cruise and Intel's Mobileye[29]). Probably it will be far beyond 2030 until we have automated city driving in our private cars – however, Robotaxi services will become available in the US and China (Mobileye plans trials with Sixt in Munich in 2022) (ADAC, 2021).

[28] Many startups and Asian players are excluded
[29] See Appendix A

5.1 Ford/Volkswagen (Argo AI)

Figure 2

Ecosystem of Argo AI (40% Ford, 40% Volkswagen) and Volkswagen[30]



In 2018, Volkswagen officially announced a partnership with Aurora co-founded by Chris Urmson, the former leader of Google's self-driving car project. The partnership ended in 2019, after Herbert Diess joined as CEO of Volkswagen in May 2018 (O'Kane, 2018a) (Korosec, 2019b). Volkswagen reportedly "wanted more control over its autonomous vehicle program".

In 2017, Audi debuted its "Traffic Jam Pilot" (a Level 3 System) which was developed together with Mobileye (Halvorson, 2017). In 2020, it was announced that the functionality would not be released to the market - mainly due to complications with regulatory approval (Edelstein, 2020). According to Automotive News Europe, "corporate lawyers had warned Audi executives of the potential for misuse of Traffic Jam Pilot, saying Audi would be liable in the event of crash with the system activated."

Argo AI is an autonomous driving technology company co-founded in 2016 by Bryan Salesky and Peter Rander and headquartered in Pittsburgh, Pennsylvania (*Wikipedia - Argo AI*, 2021). Argo AI is an independent company and has two major investors: Ford 40% (2017),

[30] We mostly focus on Volkswagen in this paper.

Volkswagen 40% (2020). The remaining 20% belong to Argo AI founders and employees. In July 2020, the company had more than 1000 employees (*Wikipedia - Argo AI*, 2021) referencing (Korosec, 2020c). Company homepage: www.argo.ai

The cooperation between Ford and Argo AI started in 2017[31] (Statt, 2017). In July 2019, it was announced that Volkswagen would cooperate with Ford and invest USD 2.6 billion into Argo AI: “Volkswagen committed USD 1 billion in cash into Argo AI and its Munich-based Autonomous Intelligent Driving (AID) unit valued at USD 1.6 billion” ("Wikipedia - Argo AI," 2021) (Korosec, 2019a).

In 2019/2020, Volkswagen released the ID.3 - the new electric car developed together with Continental (Menzel, 2019). Continental delivers the central control units, and the car should have “over the air” (OTA) updates. Volkswagen had massive software problems, unfinished cars were parked on production spots, and the first cars delivered did not have full software functionality (OTA functionality should be available in summer 2021) (Henßler, 2019) (Menzel, 2020) (Menzel, 2021).

End of 2019, it was announced that Volkswagen would start the Car.Software Organization (Volkswagen, 2019c) (Volkswagen, 2019a). In 2020, Markus Duesmann took charge of the Car.Software organization and in 2021 it was renamed to CARIAD (Volkswagen, 2020) (CARIAD, 2021). The goal is to increase the share of software developed inhouse from currently around 10% to 60% in the future (Fasse et al., 2021).

Note: The cooperation between Ford and Volkswagen is limited to commercial vehicles (Reuters, 2021c)[32]. In fact, the self-driving ID Buzz vans that VW is going to start testing in

[31] Ford made an investment of USD 1 billion (Statt, 2017).
[32] Volkswagen clarified that it would continue to work with its partner Argo AI on commercial vehicles. It also added that it expects to have its first commercial vehicles in service in Germany by 2025. The move to develop tech in-house only applies to production vehicles destined for private ownership. The parent company of VW, Audi and Porsche will take the majority of its development in-house (Reuters, 2021c).

Germany in the summer 2021 use hardware and software developed by Argo AI (Hawkins, 2021e). The plan is to launch a commercial ride-sharing fleet in 2025.

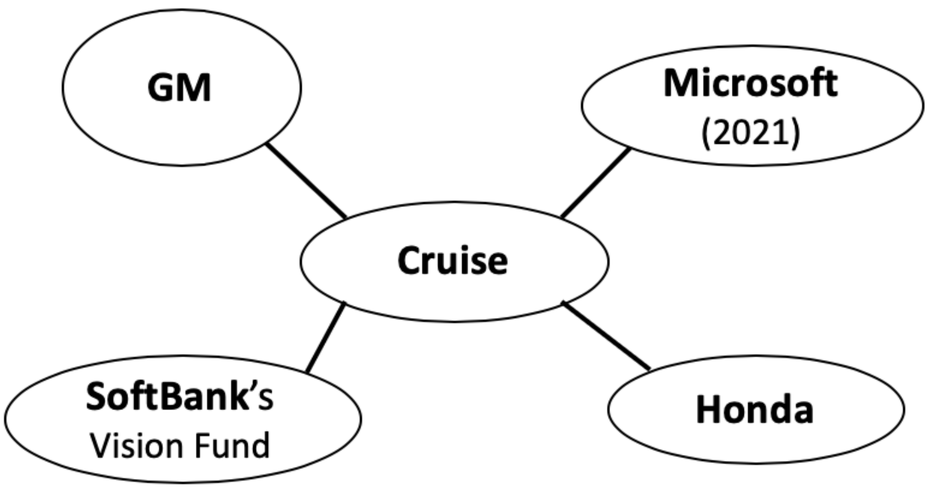
Currently, Volkswagen is focusing on developing the software for its new flagship cars[33] in 2024 and 2026. According to a colleague at Audi, they are currently focusing on the basic functionality of the software (e.g. wireless updates) - and are probably far from autonomous driving - and they have difficulties to hire the required experts (since there is competition from companies like Google). In 2021, it was announced that Volkswagen Group teams up with Microsoft to accelerate the development of automated driving (Microsoft, 2021). Private cars will only be developed up to SAE Level 3 for now (Pluta, 2021).

In an interview at the IAA, Herbert Diess mentioned that by 2030 only a small proportion of customers will use robotaxi services (Diess, 2021).

5.2 GM (Cruise)

Figure 3

Ecosystem of Cruise (Parent company GM)



[33] In the Annual Report 2020 Herbert Diess announced that they are planning to invest **EUR 27 billion** in digitalization over the next 5 years (Volkswagen Group, 2021). They have the Artemis project (premium segment) and the Trinity project (volume segment) where a new Group-wide software platform should be used in 2024 and 2026 respectively. According to the annual report 3'500 IT-experts worked in the organization and this number should increase to 10'000 within the next 5 years.

Cruise (autonomous vehicle) was founded in 2013 by Kyle Vogt and Dan Kan and is headquartered in San Francisco, California. Originally building a retrofit kit for autonomous driving on the highway, they later decided that "the greater challenge lay in conquering city driving". They currently test and develop robotaxis and have 1800 employees and a fleet of 200 electric robotaxis as of 2000 (*Wikipedia - Cruise (autonomous vehicle)*, 2020) referencing (Wayland, 2020b) (Hawkins, 2020a).

In March 2016, Cruise was taken over by General Motors (Ziegler, 2016). "GM CEO Mary Barra has stated, that GM allowed Cruise to remain responsible for both technology and commercialization, giving Cruise independence in order to avoid the pitfalls common when a large company acquires a technology startup." (*Wikipedia - Cruise (autonomous vehicle)*, 2020) referencing (Wayland, 2017). Since November 2018, Dan Ammann is the CEO of Cruise. Company homepage: www.getcruise.com

- In May 2018, SoftBank's Vision Fund invested USD 2.25 billion (Burns, 2018)
- In October 2018, it was announced that Honda would invest USD 2.75 billion over the next 12 years (Roberts & McLain, 2018)
- In January 2021, it was announced that Microsoft would also partner with GM's Cruise on self-driving cars (Korosec, 2021f) (Wayland, 2021b)

In July 2019, Dan Ammann (President of GM between 2018 and 2019) did not give a specific date, when asked about when the technology would be ready for the rollout (CNBC Television, 2019). According to the DMV (see Table 4) Cruise has most autonomous miles driven next to Waymo in California. In October 2020, Cruise got a license to test driverless vehicles in California (Hawkins, 2020a). Since December 2020, Cruise began testing vehicles without a human safety driver on the streets in San Francisco (Said, 2020). On 30 September 2021, Cruise (and Waymo) received a permit to offer rides to their passengers in robotaxis in

San Francisco (Waymo with a safety driver, Cruise without a safety driver) (Lyons, 2021b) (Hawkins, 2021a).

In January 2020, Cruise, GM and Honda revealed the fully autonomous Cruise Origin shuttle to the public in San Francisco, but it is years away according to the article (Baldwin, 2020). A Video of the presentation and an interview with Dan Ammann can be found here: (Cruise, 2020) (Bloomberg Technology, 2020). In June 2021, it was reported that Cruise starts pre-production of the Cruise Origin shuttle thanks to a USD 5 billion credit from GM (Hawkins, 2021b); they build 100 pre-production vehicles, help Honda to bring new mobility services (MaaS) to Japan [based on the Cruise Origin shuttle], and plan to expand self-driving operations to Dubai[34] in 2023 (Korosec, 2021c) (Szymkowski, 2021) (Wayland, 2021a).

GM CEO Mary Barra[35] wants to sell personal autonomous vehicles using Cruise's self-driving tech by 2030. Quote of Mary Barra: "I believe we will have personal autonomous vehicles […] to really be well positioned to delight the customers" (Korosec, 2021d).

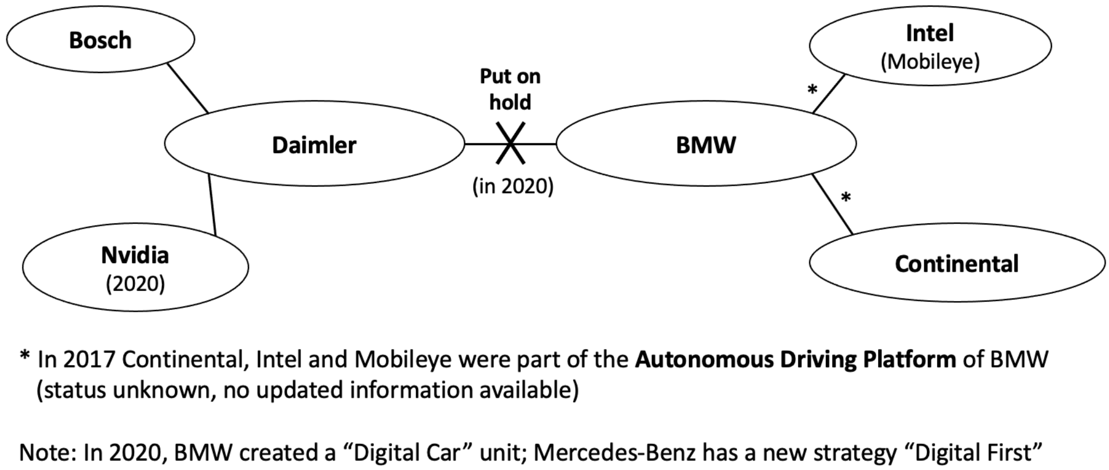
The current valuation of Cruise is close to USD 30 billion (similar to Waymo's valuation that was once thought to be close to USD 200 billion) (Abuelsamid, 2020) (Jin & Mehta, 2021).

[34] "Cruise signed an agreement with Dubai's roads and transport authority to be the exclusive provider for self-driving taxis and ride-hailing services" (Wayland, 2021a).
[35] In 2020, GM announced the commitment of **USD 27 billion** in investments in electric and autonomous vehicle technologies through 2025. Source: Annual Report / 10-K Form (SEC Filings) (General Motors, 2021)

5.3 BMW/Daimler

Figure 4

Ecosystem of Daimler and BMW (non-exhaustive list of partnerships)



On 4 July 2019, it was announced that BMW and Daimler would cooperate on the development of autonomous driving up to SAE Level 4 (BMW Group, 2019). It was supposed to be a long-term, strategic partnership, where 1'200 experts would have worked on the technologies for a rapid introduction to the market as of 2024.

Daimler and BMW both have a long history of developing cars and advanced driver assistance systems together with their partners (Daimler with Bosch and BMW with Continental among others). Bosch has been working an anti-lock braking systems (ABS) since 1969, and it debuted in a Mercedes-Benz S-Class in 1978 (Bosch, 2019). The *Daimler and Benz Stiftung* has even published a book "Autonomes Fahren" / "Autonomous Driving" in 2015/2016 (Maurer et al., 2016). According to their own statement, the BMW Group works since 2006 on highly automated driving (BMW Group, 2019).

BMW opened the "Autonomous Driving Campus" in Unterschleissheim near Munich in 2017/2018 (BMW Group, 2021) (NewGadgets.de, 2018) and built the "Autonomous Driving Platform" with Mobileye, Intel and Continental since 2016/2017 (BMW Group, 2016) (Boeriu, 2017). In 2019, BMW had around 70 test vehicles around the world and in an interview

Alejandro Vukotich, then Head of Autonomous Driving at BMW, said they will bring the autopilot (for a speed of up to 130 km/h on the highway) to the market in 2021 and also start a pilot fleet of robotaxis in 2021 (Dahlmann, 2019)[36].

Similarly, a product brochure "Introducing DRIVE PILOT" of Mercedes-Benz shows that they excel at autonomous driving on the highway; however Renata Jungo Brüngger (Member of the Board of Management of Daimler AG for Integrity and Legal Affairs) argued that the legal framework needs to be international, since the car does not stop at the border (or change the features available of its autonomous system)[37] (Mercedes-Benz, 2021) (Daimler, 2017) . In 2019, Daimler together with Bosch planned their first pilot project for an automated ride hailing service in San José - according to the latest sources it has now been stopped (Daimler, 2019a) (ADAC, 2021).

On 22 June 2020, the cooperation between BMW and Daimler was put on hold "due to the expense involved in creating a shared technological platform, as well as the current business and economic conditions, especially in the wake of coronavirus, the timing simply is not right for the implementation of the cooperation" ("Both explicitly wished to emphasise that [the] cooperation may be resumed at a later date") (Daimler, 2020b) (Autovista Group, 2020).

On 23 June 2020, Daimler announced a cooperation for the development of its next generation vehicle architecture with Nvidia (Daimler, 2020a) (Shapiro, 2020). They want to build a "Software-Defined Computing Architecture for Automated Driving". This should also make it possible for Daimler to update the car software "over the air" and release autonomous driving features. They claim the new S-class - introduced in 2021 - is ready for automated driving up to SAE-Level 4. As with the introduction of the Audi A8 in 2017 we remain cautious whether

[36] It is not clear, whether BMW still works with Intel, Mobileye (Intel acquired Mobileye in 2017). The ADAC mentioned that Intel and Mobileye announced a cooperation with Sixt (at the IAA in Munich) and want to introduce a ride-hailing service in Munich and Tel-Aviv by 2022 (ADAC, 2021).

[37] Frank Weber, Head of Development at BMW, claims in an interview that they master autonomous driving just as well as Tesla (Fasse & Hubik, 2020). He also informs that in the US the driver can take away the hands from the steering wheel for a longer period of time (Level 2 assistant system).

the new features will be made available to the public. The new car provides “over-the-air” updates and if the law changes, the Drive Pilot program is pre-programmed to operate at higher speeds, an ability that can be unlocked via wireless update[38] (Daimler, 2019b) (Mercedes-Benz, 2021) (Johnson, 2020).

The new Head of Development at BMW, Frank Weber, is much more cautious (the new iX does not offer those features at the launch) and says that the steering wheel will stay for a long time to come (Fasse & Hubik, 2020). BMW plans to develop a new operating system for the introduction to the market with the new electric car iX in 2021 (Fasse, 2020). For this BMW has a new unit called “Digital Car” with 4000 software engineers where the new operating system is developed. Already with OS7 (the current operating system) - introduced in 2018 - BMW can do software updates “over the air” for currently around 750’000 vehicles. I want to remark that the new iX was released without a Lidar, whereas the new S-Class has a Lidar sensor built in (and BMW itself claims Lidar is required for autonomous driving, even for L3).

Mercedes-Benz has a new strategy “Digital First” and Dr. Michael Hafner, former Head of Automated Driving and Active Safety at Mercedes-Benz is now Head of MB.OS Base Layer (Operating System) and MBUX (User Experience). In an interview he mentions that “Mercedes-Benz AG is hiring around 1,000 software developers at its Sindelfingen site. Another 2,000 jobs are to be created in the global R&D network in the Tech Hubs such as Berlin, Tel Aviv, Seattle, Sunnyvale, Beijing, Tokyo, Seoul and Bangalore.” (Daimler, 2020d) (Daimler, 2021b).

In May 2021, I had a personal conversation with an expert on autonomous driving in Germany, and he mentioned that the automotive manufacturers changed their strategy. They

[38] The UN regulations on automated driving (SAE Level 3) allow Automated Lane Keeping Systems (ALKS) that can be activated under certain conditions (e.g. no pedestrians and cyclists allowed, physical separation between traffic in opposite directions). The regulation currently limits the operational speed to a maximum of 60 km/h (UNECE, 2020). The government of Japan and Germany co-led the drafting of the regulation (it will enter into force in January 2021). The German government is actively participating in extending the UN regulations to extend the operational speed to 130 km/h and that lane changes (of the system) are permitted (BMVI, 2021a).

focus on SAE Level 3 features for private passenger cars (lane keeping on the motorway, automatic parking features). The reasons are twofold: First of all, the development of autonomous driving features L4 costs billions (and it is not clear when the technology will come to the market, hence there is not business perspective in the short term). Second, in the luxury segment many people still want to own their vehicle (and the luxury segment is growing), on top of that the technology for the ride-sharing services (Waymo, Cruise) is currently so expensive, that probably an Uber driver costs less (Financial Times, 2021).

From what can be observed the German car manufacturers (BMW, Audi, Daimler) mostly focus on the highly automated driving on highways (Fraunhofer-Institut, 2015). Even though the ADAC mentions, that the legislation is more advanced in the US and in China, so that autonomous driving is first developed and commercialized there (ADAC, 2021) the BMVI touts that "Germany will be the world leader in autonomous driving"[39]. Maybe this is true for automated driving on the highway (SAE Level 3). According to Frank Weber the "official statements on the conditions to drive autonomously in urban areas will only be available in the next decade" (translated from German) (Fasse & Hubik, 2020). Finally, Dr.-Ing. Christian Müller at the German Research Center for Artificial Intelligence writes on his homepage "Although Germany holds more than 50% of the world's patents for autonomous driving[40], it shows deficits in practical implementation compared to other countries." (DFKI, 2021).

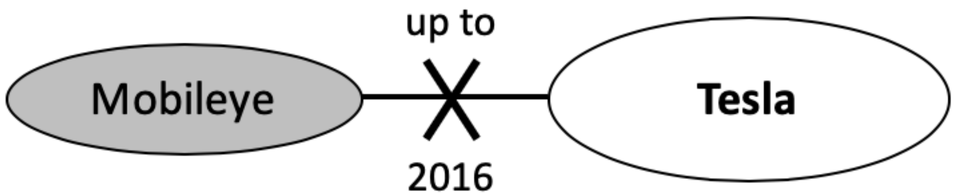
[39] The BMVI (Federal Ministry of Transport and Digital Infrastructure) in Germany mentions that the laws are there - and "the automotive industry is to intensify its efforts with regard to autonomous driving. […] the industry will systematically use the trialling opportunities in Germany so that people can experience automated and autonomous vehicles at first hand" (BMVI, 2021b). It remains to be seen what will happen until 2023.

[40] This statement is based on a patent analysis of applications from 2010-2016 (Bardt, 2017), a newer patent analysis (based on connectivity and 5G technology) might lead to different results.

5.4 Tesla

Figure 5

Ecosystem of Tesla (suppliers are not considered)[41]



Tesla was founded as Tesla Motors in 2003 and is headquartered in Palo Alto, California. Elon Musk, who contributed most of the funding in early days, is CEO since 2008. Tesla began production of their first car model, the Roadster, in 2009. This was followed by the Model S in 2012 and further models in 2015, 2017 (Model 3) and 2020. The company had 70’000 employees and produced 510’000 cars in 2020 (*Wikipedia - Tesla, Inc.*, 2021).

In 2014 Tesla released the Autopilot HW 1 developed together with the Israeli company Mobileye[42] (camera supplied by Mobileye, forward looking radar supplied by Bosch) as an option for its Tesla Model S (*Wikipedia - Tesla Model S*, 2021). After a fatal accident in 2016, Tesla started to develop its Autopilot HW 2 (October 2016) and 3 (2019) inhouse - and stopped the cooperation with Mobileye. HW 2 includes eight cameras, twelve ultrasonic sensors and a forward-facing radar (*Wikipedia - Tesla, Inc.*, 2021). HW 3 includes an upgraded and more powerful computer. Elon Musk claims that the cars are ready for full self-driving (FSD) in the future and there will be 1 million robotaxis on the road by 2020 (TopSpeed, 2019).

Even though Tesla has an impressive track record (close to 1 million vehicles with Autopilot hardware delivered by 2020, almost 500’000 vehicles delivered in 2020 alone) the Autopilot does not qualify as a Level 4 system - and is even not as close to a Level 3 system, as

[41] Since 2016 Tesla develops its autonomous driving hardware and software independently.
[42] Mobileye was acquired by Intel in March 2017 (*Wikipedia - Mobileye*, 2021).

Elon Musk's promise would suggest (Street signals including speed signs and traffic lights cannot be detected reliably and during construction works on the motorway there may be malfunctions) - from a legal standpoint Tesla's autopilot is an SAE Level 2 system that needs permanent supervision (of the Driver) (Fridman, 2020) (Statista, 2021) (Kolodny, 2021).

According to many industry experts, including former CEO of Waymo (John Krafcik) Tesla will never reach full autonomy - however "they are developing a really good driver-assistance system" (Lee, 2021) (Wilkes, 2021). There are other proponents, who believe ADAS (Advanced Driver-Assistance Systems) will one day deliver full autonomy - also in cities, but clearly there is a long way to go (Financial Times, 2021). Where Tesla is leading is in terms of customer perception[43] and the way it collects data[44]; since the hardware is built-in and the Autopilot is running in a "Shadow Mode" (even if not activated by the driver) algorithms can be improved by the team working at Tesla based on real-life data collected by the customers (TopSpeed, 2019).

Tesla builds the whole stack from hardware (including processors) to the software (AI algorithms). Therefore, they can optimally train their neural networks - which might be an advantage, even though we trust industry sources that full autonomy cannot be reached without additional sensors, e.g. Lidar[45] (*Wikipedia - Tesla Autopilot*, 2021) (Knight, 2021) (Dickson, 2021a)[46].

[43] Of course, this can be disputed, Tesla has also many legal complaints (see 2.1 and 2.3) - mostly the marketing regarding Autonomous Driving called 'Full Self Driving' is misleading (Mitchell, 2021b). However, Tesla gets approval for its cars also in Europe and they can charge an extra amount for those features/services (Financial Times, 2021). A colleague from Norway mentioned, that Autopilot is not allowed to be activated there.
[44] It is rumoured that Tesla with its 800'000 cars collects more data than Volkswagen with its 100 million cars around the world (Rasch, 2021).
[45] The problem lies in the system's reliability, measured in failures per hundreds of miles driven, as pointed out by Prof. Amnon Shashua (CEO of Mobileye). Even though Elon Musk has a valid point that human beings also have only eyes the weather conditions (e.g. driving at night, during bad weather or visibility, etc.) are far too challenging so that machine learning based on vision alone needs much more progress - especially at high speeds (Intel Newsroom, 2021a) (Financial Times, 2021).
[46] NIO is a Chinese startup (backed by the Government) that plans to bring the ET7, an electric sedan, to Europe in 2022 (first Norway and Germany). They claim their car has much better computing power than a Tesla - indeed they have high-resolution sensors built-in on top of the car (like a watch tower) and ultralong-range LiDAR - however, it remains to be seen how they develop their algorithms for autonomous driving (NIO, 2021) (O'Kane, 2020a).

6 Comparison of the Innovation Strategies

This chapter compares the different innovation strategies of the automotive manufacturers / innovation ecosystems and what kind of cooperations develop (i.e. which partners the established players choose for the development of autonomous driving).

First, we consider all forms of cooperations (since companies that cooperate with Waymo will be a great competition in the future) before we compare the strategies of our four cases.

We found the following forms of cooperations:

- Some companies cooperate with Waymo (e.g. Renault-Nissan-Mitsubishi[47], Fiat Chrysler[48]), this is not part of the cases (Hawkins, 2019) (Wayland, 2020a)
- Some companies cooperate with or buy startups (e.g. GM, Ford/Volkswagen)
- Some automotive companies partner and put their research activities together (BMW and Daimler[49], Ford and Volkswagen[50])
- Some companies develop autonomous driving on their own (e.g. Tesla)

Next, we compare the innovation strategies of the four cases and what kind of cooperations (e.g. ecosystems) develop (see Table 1). Thereafter, we describe the strategy change that we observed (see Table 2).

[47] Original Source: (Renault Nissan Mitsubishi, 2019)
[48] Original Source: (Fiat Chrysler Automobiles, 2020)
[49] Even though the partnership was put on hold (in 2020) we want to keep this as a potential scenario - it might be that the cooperation gets activated again in the future (BMW and Daimler cooperate on different topics) (Reuters, 2020a).
[50] Only for commercial vehicles

Table 1

Comparison of the innovation strategies and what kind of cooperations develop

Automotive Manufacturer / Innovation Ecosystem	**Description of the innovation strategies**	**What kind of cooperations develop?**
Ford/Volkswagen (Argo AI)	Ford and Volkswagen cooperate on the MEB (Modularer Elektrobaukasten) (Volkswagen, 2019b) and also have a cooperation regarding the development of autonomous shuttles together with their jointly owned Argo AI; however, it remains to be mentioned that Volkswagen develops the new software for its passenger vehicles on its own (up to SAE Level 3).	There is an international cooperation between established automotive manufacturers – as has already been the case in the past; for now it is limited to commercial trials with shuttles (equipped with technology of Argo AI), whether later this technology will be integrated into passenger cars and the cooperation extended remains to be seen; currently this is not the case and Volkswagen independently develops the new operating system (thereby establishing their own platform/ecosystem that they later want to sell to other car manufacturers). Whether this strategy is successful and they can compete with Waymo and the like remains to be seen.

GM (Cruise)	GM’s Cruise is the only company (among our 4 cases) that is seriously working on autonomous driving Level 4. For this they have investors from different sectors, incl. GM and Honda, SoftBank and Microsoft. They plan to rollout vehicles (the Cruise Origin Shuttle) in different parts of the world and currently have a pre-production of 100 vehicles. Next to Waymo they hold the most autonomous miles driven in California (in 2020).	This seems to be the only real ecosystem related to Autonomous Driving SAE Level 4 that develops (among our cases); there are other examples like Mobileye or Waymo – but they are not analyzed here. Even though it is investments in a startup, GM and Honda want to implement this technology not only in shuttles, but also in their passenger cars (at least Mary Barra, GM CEO, says so). Interesting is that also technology companies and venture capital funds participate.
BMW/Daimler	The cooperation between Daimler and BMW (related to automated driving up to SAE Level 4) is put on hold. It could not be verified whether the “Autonomous Driving Platform” of BMW still exists (e.g. the cooperation with Mobileye); Daimler has a new cooperation with Nvidia. The new iX of BMW does not feature a Lidar sensor – so it will never be able for autonomous driving SAE Level 3 on the motorway. Daimler as well as BMW develop the software of their new cars on their own – even though BMW CEO Oliver Zipse claims this is not ideal (Hubik et al., 2021).	Currently, BMW and Daimler still develop their technologies on their own (There is no ecosystem yet, except the established supplier relationships). A potential cooperation, for example with Volkswagen, might be possible. Note: It remains to be mentioned that Daimler with Bosch has a strong history in the development of driving assistance systems (and now they also cooperate with Nvidia for computing power) so they have good chances to stay in the lead with automated driving (up to SAE Level 3).

Tesla	Tesla stopped the cooperation with Mobileye (in 2016) and now develops all the technology inhouse (including processors, and algorithms). Tesla collects a lot of data of its vehicles, which can be used to improve the full self-driving features.	Tesla does the development on their own (and has a high vertical integration), however it remains to be seen whether Tesla can keep its promises regarding Autopilot and Full Self-Driving (currently the beta seems to be overwhelmed in the city) (CNN, 2021).

For a description of the Table see the summary below.

Tesla, Volkswagen, BMW and Daimler now develop their new operating systems (which form the basis for the driver assistance systems) on their own. They partly cooperate with suppliers for this. The goal is to have a share of 60% of the software developed inhouse in the future (Volkswagen as well as Daimler). Only Volkswagen, who plans some trials with SAE Level 4 vans together with Argo AI (co-owned by Ford and Volkswagen), and Cruise are working on autonomous shuttles, while GM plans to integrate the technology into passenger vehicles in the future. Even though VW CEO Herbert Diess said "It's clear that we will soon see driverless cars of various types on the streets." (Volkswagen, 2018) they do not see this as a priority for 2030. Cruise is the only company in our sample developing autonomous shuttles for the city. Consequently, Cruise has signed a contract for such services in Dubai.

According to statements from Daimler and BMW there is a long way to go until we see such automated driving features (for the city) in our private cars. We want to note here that there are other companies also working on SAE Level 4 technology, e.g. Motional (Hyundai-Aptiv); Toyota currently develops their new vehicle OS[51] together with Apex.ai which should form the basis for autonomous driving (Apex.AI, 2021). Waymo will become a serious competitor in the future[52] and Baidu is one of the leading players in terms of kilometers driven in China (see Appendix A); they plan to have robotaxis in 100 cities by 2030 (Liao, 2021a).

As a preliminary conclusion regarding our research questions it becomes clear that, at least so far, there is no such thing as the most promising innovation strategy. We consider the first two research questions to be answered by Table 1 and the summary. After the following description of the strategy change we proceed to the Discussion regarding the recommendations for the improvement of existing strategies.

[51] Operating System

[52] Mobileye is also working on driverless shuttles (Mobileye, 2021b) and plans robotaxis operated by Sixt in Munich as of 2022 (Mobileye, 2021a).

Table 2

Comparison of the strategies related to Autonomous Driving SAE Level 3 and 4

	Autonomous Driving SAE Level 3	Autonomous Driving SAE Level 4
Ford/Volkswagen (Argo AI)	✓ (on their own)	(✓) Argo AI
GM (Cruise)	GM has a system called 'Super Cruise'	✓
BMW/Daimler	✓ (on their own)	–
Tesla	(✓) No Test License for Level 3	–
Others (e.g. Mobileye with Sixt)		(✓) Planned

Note: Currently all those systems are authorized for SAE Level 2 only; Waymo and startups in the US and China are testing robotaxis (without a driver at the wheel)

What we also observed is a strategy change of the established automotive manufacturers at least in Germany: They changed their focus away from autonomous driving SAE Level 4 (robotaxis) to the more realistic automated driving on the motorway and some automated parking in specifically equipped parkings, at least for the 2030 timeframe. Much of the later discussion, mostly in comparison with the startups and technology companies, will focus on this strategic difference (GM with Cruise is here an exception). It can be argued that autonomous driving SAE Level 3 can be reached with suppliers and the established cooperations the German car manufacturers already have. Clearly, SAE Level 4 (autonomous driving in the city, without a driver at the wheel) is another challenge and might require different forms of cooperations. We are stunned that no European company is seriously working on this[53].

[53] Issues related to capital markets (and different mindsets with resp. to risk culture) have been analyzed, however this is out of scope. We mention it as recommendations for further research with regard to innovation management.

7 Discussion[54]

McKinsey predicts that by 2040 over 60% of passenger kilometers could be traveled by autonomous vehicles such as shared services and private cars in China (Möller et al., 2019); we are careful with such predictions, but it shows where the future goes. Waymo started over a decade ago to invest billions annually and still has no commercial breakthrough (Financial Times, 2021). The future of the private autonomous vehicle probably does not come from the established automotive companies – but they will be able to integrate the technology if suppliers like Mobileye or Waymo will provide the technology at scale and for the terms that the established car manufacturers can accept. It will be interesting to see how initial cooperations with Waymo will play out; established car manufacturers will probably not feature in robotaxis in the city, except if they provide their vehicles for integration at the startups. Baidu will most probably cooperate with Chinese car manufacturers, however it remains to add that Volvo is owned by Geely and that Geely owns 10% of shares in Daimler (Daimler, 2021c) (Jourdan & Shirouzu, 2018).

Based on this and other discussions we have had with experts in the automotive industry we split the market in two different use cases:

- Robotaxis (operated by Waymo, Cruise or any other company)[55]
- Private Car Ownership (can be a luxury car, but can also be a Toyota Prius or Honda Civic for an Uber driver)

The Figure below visualizes this concept.

[54] The Discussion is influenced by 'The Oxford Handbook of Innovation Management' (2014) and 'Managing Innovation' of Joe Tidd and John Bessant. Individual Passages are not cited, but the reading of the former is higly recommended (especially the chapter on Innovation Ecosystems, Innovation, Strategy and Hypercompetion, and Collaboration and Innovation Management). It is clear that the future of a manager is more on alliance building (and cooperation) than traditional competition within an industry as illustrated in Porter's Framework. Therefore, the concept of ecosystems is important if it helps managers to open up toward the wider industry.
[55] Based on a statement of BMW CEO Oliver Zipse they are not an "airline" but produce cars, they are strong as "system integrator"; therefore, it can be assumed that they do not want to operate fleets of vehicles (Fasse, 2019).

Figure 6

Predictions of different use cases for the 2030 to 2060 timeframe (own chart)

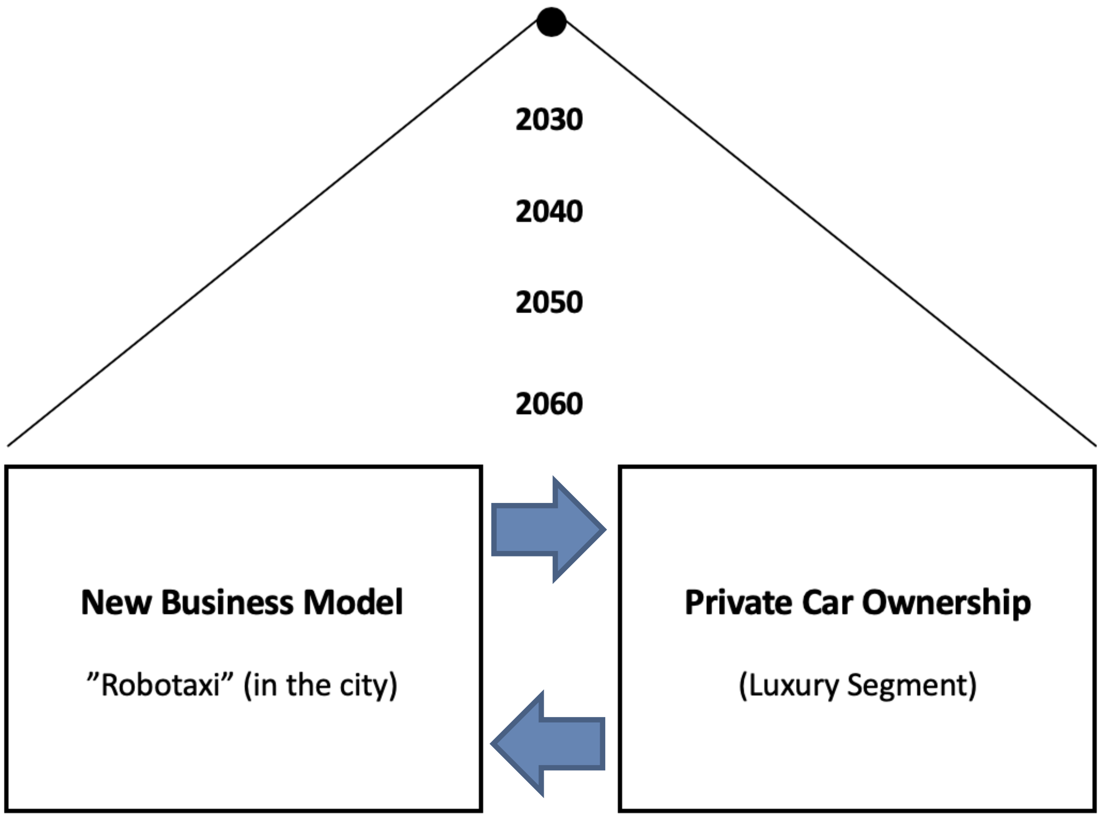


Figure 6 visualizes the development of the two markets/technologies over a longer timeframe. While we agree that the market for robotaxis is probably max 15% in terms of cars or kilometers driven by 2030, we assume the prediction of McKinsey might become true latest in 2050; which would mean that by then 60% of passenger kilometers driven could be completed in robotaxis (at least in cities and densely populated areas). Let's extrapolate to 2060 and this figure could increase to 80%, by then private cars should also provide this functionality and manually driven cars might even be forbidden in certain areas.

A general trend that we can observe is that the established automotive manufacturers are up to a decade behind startups (electro mobility, wireless updates, autonomous driving features), this is just an observation and doesn't mean that they are not on track. But according to investors they face billions in restructuring costs[56], not only when changing their production facilities from gasoline engines to electric cars, but also for digitalization and ultimately the development of autonomous driving features. Since we believe Tesla is not on track regarding autonomous driving at least in the city, the comparison here to be drawn is with the startups and technology companies (e.g. Waymo). Clearly, Cruise is a good example where an established automotive manufacturer has set up or bought a company that competes head-on for autonomous driving SAE Level 4. The other automotive manufacturers have decided to wait and see; this probably depends on their planning horizon that does not span ahead of 2030. According to an established manager in a big corporation that is already a long planning horizon for a strategy. The problem lies in the fact, that innovations might take more than 10 years to materialize themselves, as can be seen in the case of Tesla who was not profitable for the first decade. Nevertheless, their market capitalization proofs them right. So, the question is what established companies can do to develop really new products and markets without just buying or investing in startups. We will further explore that in the implications for practice that follow. It is not directly related to the concept of ecosystems, nevertheless also cooperations require long-term planning. We believe changing partners every two years is fruitless, because the technology development requires a minimum of 5 years. Hence the long-term strategy horizon and the set up of cooperations for the long term go hand in hand and the automotive industry already masters supplier relationships. We believe Autonomous Driving SAE Level 3 can be reached with this approach (maybe also limited assistance for city-driving), SAE Level 4 requires a different approach. We believe also Waymo cannot afford to map all the cities in the world with Lidar sensors and sell this technology with worldwide applicability to the estab-

[56] "From an investor perspective, traditional players face billions of dollars in restructuring costs as they transform product lines and factories to move away from internal combustion technology" according to the following article (Taylor et al., 2020).

lished companies. Even though Mobileye tries such an approach. This leads us to the conclusion that Robotaxi companies will be a local phenomenon, until they manage to cooperate with volume car manufacturers and roll out affordable sensors worldwide, so that the technology can be improved and the algorithms be trained on a global scale. The OEMs are the best integrators (as is correctly argued by Boston Consulting Group), ultimately someone must be responsible for the product - also in legal terms (Pidun et al., 2019). In their own words: "For example, the production of an iPhone from its components (main I/O, battery, display, camera, and so on) is characterized by low modularity and must be done by the OEM (in this case in a hierarchical supply chain)". This is a nice conclusion, because it shows even if Google is very good at improving their algorithms, to integrate, develop and homologate a series car is another business. They best would partner with established car manufacturers and just focus on training the algorithms, on the other hand how to choose and integrate the sensors must be done in cooperation with the automotive companies (because only then this can be done at reasonable cost so that the technology allows worldwide commercialization). We do only see this cooperation starting right now (with for example Volvo building robotaxis with Waymo). From a negotiation point of view it is right that the German car manufacturers develop their own operating system, even if they should do it in collaboration (and not each of them alone)[57].

Before we move on we want to cite a conclusion of the Chapter 'Cooperative Strategy: Strategic Alliances and Networks' in (Faulkner & Campbell, 2003, p. 154): "Cooperative strategy, whether in the close form of strategic alliances or the more loosely coupled form of networks, requires attitudes and approaches to management quite distinct from those found in hierarchies. It generally emerges when one company finds itself unable to cope with a global or other challenge, because of limitations in its resources and competences, and seeks an ally

[57] It is interesting to see that this is an ongoing topic in the German media (whether they should cooperate to fend off competitors like Google and the startups) (Hubik et al., 2021).

to reduce its vulnerabilities. Where this new mode of organizing its business is approached flexibly and sensitively by the partners, enduring, successful, and mutually beneficial relationships can be created and maintained. Indeed there are grounds for believing that the future of these more flexible organizational forms […] is likely to be bright. Such arrangement will not survive, however, if partners play power politics with each other, show lack of commitment, distrust, and lack of integrity and do not make very positive steps to deal with the cultural differences between the partners that will almost inevitably exist. It is these latter mishandled situations that have led to the reported 50% failure rate of recent alliances. The need is to understand the key factors for success in managing alliances as competently as the lessons from management theory in handling integrated hierarchical corporations. They are as different as the contrast between giving orders from a position of authority compared with developing a consensus for action in a community of equals. Only when this difference is appreciated and translated into changed behaviour will the failure rate of cooperative arrangements begin to decline."

7.1 Implications for Theory

The following recommendations for future research concentrate on the basic findings of this study. As opposed to the fragmented theories we have to focus on core implications. Porter and Fuller about 'Coalitions and Global Strategy' (Porter, 1986, p. 342): "Coalitions should be approached with a full view of their costs as well as their benefits. We believe that coalitions in the most vital activities of a firm's value chain should be resorted to only rarely. A firm must ultimately master such activities itself if it is to sustain a competitive advantage in its industry." Interestingly, David Faulkner cited Porter and Fuller for the motivations behind cooperation (Faulkner & Campbell, 2003, p. 128): „The most common motivations behind the development of cooperation between companies as suggested by Porter and Fuller (1986) are: (1) to achieve with one's partner, economies of scale and of learning; (2) to get access to the benefits of the other firm’s assets, be they technology, market access, capital, production capacity, products, or manpower; (3) to reduce risk by sharing it, notably in terms of capital requirements, but also often R&D; (4) to help shape the market, e.g. to withdraw capacity in a mature market.“

Our analysis showed that: Contrary to the expectation that ecosystems would arise, this was only the case for Cruise (with autonomous shuttles for SAE Level 4). The strategy(ies) changed and the Boston Consulting Group concludes why cooperations for SAE Level 3 are less important and there needs to be one system integrator. The ecosystems concept is overly vague and we assume that it gained popularity recently because of some software platforms like Apple’s iOS or Google’s Android, where the intermediary profits based on the central link between customer and content provider. Driving functions are safety relevant, therefore a third-party app would hardly be allowed to control the car. Most other apps can already be accessed through the mobile phone, therefore the ecosystems concept did not apply so far.

We conclude and recommend the following:

1) Cooperation as the general concept is sufficient. The definition of the term ecosystem is too vague to be of practical value for management. The concept overlaps with networks and platforms and on top of that cooperations are not something new in the industry. Hierarchical supplier relationships and also R&D cooperations with peers have been managed for decades. Lessons learned from those experiences should be incorporated. The conclusion cited at the end of the introduction to the Discussion stipulates that more research into management of cooperations and internal operating procedures is important, but is currently under-researched.

2) We propose a long-term cross-industry study instead of developing individual theories for each case study separately. Researchers should observe an industry over a longer timeframe (10+ years) and look at distinct industries (i.e. automotive, semiconductors, biotechnology,

pharmaceuticals, financial services, etc.). It would be interesting to develop theories that have general applicability and this should be checked in different industries. A synopsis of different theories should be pursued.

3) The authors about ‘Innovation, Strategy and Hypercompetition’ write “Finally, competitors are increasingly viewed as potential alliance partners in facilitating and extending innovations” (Dodgson et al., 2015, p. 411); however, according to other studies there is no empirical evidence whether cooperations between former competitors would enhance innovation and firms’ performance as a result (Martinez-Noya & Narula, 2018). As shown in 3.4.1 and 3.4.2 there are advantages and disadvantages of cooperations; we propose to better understand the decision making process including the analysis of psychological factors. It is important to understand the factors that make cooperations successful (Martinez-Noya & Narula, 2018).

Our contribution was to shed light on the current status of cooperations in the automotive industry regarding autonomous driving (SAE Level 3 and 4). We will show the limitations of our research in 7.3.

7.2 Implications for Practice

The implications for practice are based on the analysis of the cases and other observations in the field of autonomous driving (e.g. articles about startups/technology companies and other discussions with experts). Some recommendations, e.g. standards, have been derived from books about innovation management and cases in other industries (we cite those references).

One main consideration was whether long-term cooperations (e.g. between Daimler and Bosch that developed ABS together, and wrote books about “Autonomous Driving”) have an advantage compared to startup companies like Tesla that started with a software-mindset in Silicon Valley. While the latter operate at faster speed and take greater risks, the former should focus on developing standards (also in cooperation with Governments) – this requires testing of new functionalities in the real world. The Financial Times points out correctly, that Waymo was also not able to commercialize the service so far (McGee, 2021)[58].

There seems to be some misconception about what Artificial Intelligence can do and what it cannot. At the moment deep learning mostly trains on datasets (recognizes patterns, models correlations and calculates probabilities); however, it lacks causal relationships and therefore cannot extend its application towards new situations (Dickson, 2021b). This means if a flowerpot is falling from a balcony, the car does not know how to react if it was not part of its training. Also for a human there is no predetermined solution, but we can assume there is awareness of the surroundings and a creative solution can be found based on judgement (ranging from a full stop if there is no car right behind, an avoidance maneuver if there is no risk for collision, or ultimately colliding with the object and finding a stopping location in order to find the culprit and file an insurance report). This kind of reasoning is not embedded in machine learning for the moment – indeed the understanding of the real world seems to be very limited. On the other hand algorithms perform much better at repetitive tasks and many accidents could be avoided if the human driver would not be part of the driving task anymore. We believe standards need to be developed, those will be followed by regulations. Only testing in the real world allows development of de facto standards in cooperation with society. Accidents may happen – as is already the case with human drivers every day. Legal aspects need to be considered, society would benefit by less road accidents.

This background is required to better understand the following recommendations.

[58] Waymo's former CEO, John Krafcik, dismissed Tesla's strategy regarding self-driving many years ago (Lee, 2021).

Recommendation 1: Digitalization of the car is a must, but spend IT-resources diligently

Description: Currently, the automotive manufacturers are about to become software companies[59]. From our point of view, the operating system is not a differentiating characteristic[60], it is mostly based on Linux (Topgear Autoguide, 2020). However, the driving functionalities and user interface can be a competitive advantage[61]. Wireless updates of a car (improvement of driving characteristics, user interface, entertainment system) are a must, however we do not expect much monetization from those services – simply because we get most services and apps for free on our mobile phones (and via internet). Software developers are scarce, and standards like AUTOSAR (AUTOSAR, 2022) or Ethernet are used in the automotive world. Currently, there is no standard operating system, safety and security is important. The automotive manufacturers should focus on driving characteristics and improvement of user interface. Additionally, interaction with traffic infrastructure (e.g. timing of traffic lights) and communication between cars would enhance customer experience. It would make sense to cooperate on those developments, one example might be to locate and pay for a parking spot. OEMs should focus on value-added services.

Rationale: Limited resources, economies of scale (R&D unit cost); operating system itself is not a differentiating characteristic, however the driving functionalities and user interface can lead to competitive advantage.

[59] This is not a novel conclusion. Already in 2019 there were articles in tech magazines (Hetzner, 2019) - and since then many (German) CEOs of car companies have proclaimed that they will become tech or software companies. Quote of Herbert Diess: "Volkswagen needs to change: From a collection of valuable brands to a digital company that reliably operates millions of mobility devices worldwide" (Diess, 2020).

[60] We talked to an experienced executive in the industrial world in Europe and he mentioned that the development of operating systems (and becoming software companies) is a temporary trend, since in the end it is the embeddedness of hardware and software that is important. Historically, the (German) car manufacturers have outsourced a lot of the development to suppliers - but currently the value chains (and profit pools) of the future are not clear.

[61] This was supported by a discussion with an expert on Autonomous Driving in the US (who has also a German background). He argued that it is a "Wettbewerbsvorteil" if they have the better driving assistance systems (incl. user interface). Therefore, he can understand that the German car manufacturers (or car manufacturers on a global scale) do not cooperate on the development of the technology.

Recommendation 2: Add additional sensors to the cars and collect data in order to improve the algorithms

Description: Artificial Intelligence (AI) is a hot topic. The established automotive manufacturers should integrate the required sensors into production cars and start collecting data from customer vehicles (with permission and anonymized of course). We do not believe that machine learning alone will solve the problem of autonomous driving (especially in cities)[62]. However, collecting data with 100-200 test cars is not adapt to the problem of automated driving in cities all around the world, which needs massive scale of data to improve the algorithms. Not every company must be an expert in analyzing data, but the algorithms must be proven to work also in challenging situations and the limitations of the altorithms must be demonstrated. Table 3 shows potential partnerships for cooperation; the data can even be given into the open domain to improve the algorithms in a concerted effort, researchers might work on improving the algorithms. The infrastructure requirements and the limitations of the system must be transparent, before the software is released to the public. The responsibility can gradually shift away from the driver and some customers might volunteer as test drivers.

Rationale: Machine learning (deep neural networks) currently lack rationality, e.g. they cannot interfere in nor handle new situations, therefore certain boundary conditions must be met. Nevertheless, collecting data is key to improve the autonomous driving features of the future on a global scale. OEMs must collect data, if they want to be part of this development.

[62] Another aspect seems to be infrastructure; not only 5G but depending on the road conditions (markings, cones, barriers) an autonomous car seems not to be able to improvise based on those non-standard conditions. Certainly, infrastructure aspects need to be considered when allowing autonomous cars – currently not separating cars, bicycles and even slow-moving scooters pose great challenges to even human drivers – and if then pedestrians or officers authorized to give traffic signals intervene it gets chaotic. This means some more digitalization is also required on their side, and infrastructure must have certain minimal standards. Security of the system is paramount.

Recommendation 3: Develop standards together with startups and technology companies

Description: The established automotive manufacturers are really good at integrating technology at high volumes, relatively low cost and exceptional quality. They should keep developing SAE Level 4 technology in cooperation with startups or technology companies. It is not clear when autonomous driving in the city will become reality, but one day it will be regulated and customers also expect this technology in their private cars. It is important to develop standards for automated driving, how those cars should interact with infrastructure and human beings[63]. To be clear: To develop those standards needs testing in the real world. Strategic locations can be chosen (e.g. Germany, Israel, Silicon Valley, Japan, Chinese cities), only then the established automotive manufacturers can ensure to stay at the forefront of the technological development. For example Argo AI is developing standards for how self-driving cars should act around cyclists (Bellan, 2021a). Ethics professionals agree that the systems can be released to the public if there is an overall positive risk balance overall (i.e. the systems perform better than human drivers in average) (BMVI, 2017).

Rationale: Only companies doing tests in the real world can establish standards how those cars/systems should behave in certain situations. Currently the law prohibits excessive risk taking by the established companies[64]. Trials must be done in different cities/places around the world. Only startups and technology companies are currently doing this kind of exploration.

[63] Setting standards can lead to considerable competitive advantage: "de facto" standards are established based on diffusion and "market power" (as for example VHS), establishing "de jure" standards invevitably involves collaboration (for example the development of the LTE standards almost took 10 years) (*Wikipedia - LTE*, 2022). Intellectual Property is a topic of its own (see for example 'Intellectual Property Rights, Standards, and the Management of Innovation' in (Dodgson et al., 2015)).

[64] Herbert Diess points out correctly that "self-driving cars must perform 100 to 1'000 times better than humans to gain social acceptance" (he argues with the fatality rates) (Volkswagen, 2018). On the other hand, he mentions the risk culture, which we have seen may be delaying the rollout of SAE Level 3 functionalities in Europe and worldwide (Diess, 2020). Another European manager mentioned liability issues regarding product development, which can lead to criminal prosecution. Certification of vehicles seems to be different in the US; according to our understanding it is not so much regulation that prevents autonomous vehicles, but the law regarding autonomous

Recommendation 4: Keep your investment horizon long-term – even though investors favour short-term gains

Description: A word regarding investors/capital markets: Ultimately, it is the long-term survival of the company that matters. Without investing in the future, a company might have a hard time to survive[65]. Companies like Cruise (or Waymo) are funded by outside sources of capital – but still controlled by their parent. It might be an option to start an own venture, and get risk capital for that. Not having technology being tested and developed in Europe leaves a risk that the established car industry might get marginalized. Robotaxis will take market share.

We understand that a strategy horizon of 2030 is quite advanced, however real innovations (including new business models) require up to 10 years to generate profits. Entrepreneurs take more risk and invest in the long-term future.

Rationale: Many investors are short-term oriented; Chinese investors (e.g. Geely) seem to follow a long-term strategy. Equivalently, the development of autonomous driving SAE Level 4 requires a long-term perspective (it is not clear, when the robotaxi market will become profitable).

systems (Wagner, 2019). Society needs to have a certain risk-tolerance, if they want the improvement such systems promise. Complete digitalization is another way, ultimately China will go ahead – and also pedestrians have to follow the rules. Whoever will be able to provide clean infrastructure, can reap the benefits of the technology. The RAND Corporation argues that by not introducing the technology as soon as it is better than a human driver we have unnecessary accidents and deaths and the technology will not evolve as fast as possible (Bauman, 2017).

[65] There is a difference between venture-funded and revenue-funded companies (as has been discussed with several experts). While the former can burn money on commercial exploration (and there is a return for the investors if the company goes public or gets acquired), the latter must finance their innovations and product development from on-going operations that must be profitable.

Recommendation 5: Cooperations can be beneficial, but must be considered with care (Managers should be trained in alliance management)

Description: Competition as well as cooperation has its value in the automotive industry (Co-opetition is the term coined by Adam Brandenburger and Barry Nalebuff in 1996 that quite well describes the observation). Given the fact that many cooperations fail, we tried to come up with a recommendation whether and with whom to cooperate for specific areas relevant for autonomous driving SAE Level 4 (see Table 3). Obviously, the task of autonomous driving SAE Level 4 is too big for one company to tackle it alone. Besides regional differences there are also infrastructure constraints. Not even talking about social and legal issues. Standards might be developed which help technology adoption on a global scale. We see the biggest obstacles in infrastructure requirements and the mindset regarding product liability (the law needs to allow autonomous systems on the streets so that insurances can pay for damages).

As Brandenburger & Nalebuff mentioned even if cooperation is a win-win, dividing the pie is still a zero-sum game (Brandenburger & Nalebuff, 2021). Recommendations must be based on an individual benefit and cost analysis. In order to succeed the rationale for the corporation must be clear, besides other aspects like value appropriation and organizational aspects. We believe cooperations have high potential to deliver superior outcomes in solving real-world problems. Table 3 shows the multitude of potential cooperation partners. Risks must be managed properly and management must have the appropriate mindset. Hence behavioural aspects of management, incl. setting the right incentives, are important.

Conclusion: Managers should be trained in alliance management to stay flexible to cooperate with competitors or technology companies/startups. The partners need to operate on equal terms and show common interests. There likely will be divergence in objectives. Market power plays an important role.

7.3 Limitations of Current Research

The limitations of the current research are its limited timeframe. 2019 – 2021 has been observed mostly, there will be further progress in the coming years, with VW promising the new operating system as of 2024, we expect some advancement until 2026. The outcome regarding autonomous driving SAE Level 3 and 4 is not yet clear – and there is still a lot of opportunity for cooperation. Only four cases have been analyzed in this study – a thorough analysis would need to include Asian players and the technology companies known to be working on this. For startups there is not much known about the progress, regarding worldwide rollout of the technology they can be neglected for the moment. Most promising for autonomous driving SAE Level 4 are cooperations between Waymo and Geely, owner of Volvo Cars. Lessons learned from other industries (e.g. biotechnology) have not been integrated, since it was not clear to what extent they apply in the automotive industry. Besides capital market aspects (i.e. what the shareholders expect from the board and management) and cultural differences regarding innovation (e.g. China, Silicon Valley, Europe) also psychological factors should be considered. For this and a better understanding of management decisions researchers should attend board meetings, because even interviews can be misleading when the outcome is later rationalized. Questionnaires regarding innovation culture or risk appetite would be interesting on different levels of the organization, but we believe ultimately it is the board who decides and management can try to convince while lawyers might have a different opinion. Clearly, there are differences between established companies and startup companies, but they can be explained. Cooperations can only be fully understood by analyzing the internal processes and considering managerial aspects in daily operation; power play might be an important factor. Those human aspects must be considered when making recommendations.

8 Conclusion

We started with the ecosystems concept and analysed whether the concept applies to the automotive industry in an innovative case study regarding autonomous driving. Four cases have been analyzed and the outcome has shown that cooperation in the automotive industry is not a new concept. However, to make cooperations successful more research is needed to analyze psychological factors and management behaviour in strategic decision making as well as in day-to-day operations. So far companies prefer to operate on their own, since risks are manageable. We argue that for autonomous driving SAE Level 4 different types of cooperations are required, since so many parties all around the world are involved (infrastructure, jurisdictions, society). Research into the previously mentioned can make valuable contributions.

Acknowledgements

Special thanks go to an anonymous expert, for his insights into the industry, to Sven Beiker, for challenging the wisdom of the established players, and to Carlos Haertel to give a critical view on what strategies big companies can follow or not.

The chart in Appendix B is reproduced with permission of SAE International; the following copyright must be added:

Additional Tables

Table 3

Potential cooperations in the field of autonomous driving SAE Level 4

	Operating System	Collecting Data	Hardware (Sensors)	Infrastructure
Competitors	(✓) no core competency	(✓) depends on sensors	(✓) costs	✓ influence together, set standards
Own	(✓) no competency yet	(✓) analyzing not core competency	✓	– depends, e.g. parking
Technology Companies	✓ complementary skills	(✓) value appropriation	(✓)	(✓)
Startups	–	✓	(✓)	(✓)
Suppliers	(✓) no standard yet	–	✓	– indirect requirements
Research Institutes		✓		(✓)
Standardization	(✓) depends on the customization		(✓)	✓
Open Source	✓ Linux	(✓) release data	–	– security is an issue
Infrastructure provider	–	–	– maybe via suppliers	✓
Governments	– avoid monopoly power	(✓) regulatory		✓

✓ Recommended (✓) Optional – Not recommended

Table 3 shows potential cooperation partners for different areas (specific disciplines) relevant for autonomous driving. There exists huge potential for cooperations regarding autonomous driving SAE Level 4. Important is that each specific cooperation with an individual company must be analyzed for its benefits and risks, incl. cultural aspects.

Table 4

Miles Driven in the Autonomous Vehicle Tester Program in California (2020)

Company[1]	**Miles driven in California** (2020)	**Miles driven per disengagement**
Waymo (US)	628’839	29’945
Cruise (US)	770’049	28’520
AutoX (China)	40’734	20’367
Pony.ai (China)	225’496	10’738
Argo AI (US)	21’037	10’519
WeRide (China)	13’014	6507
DiDi (China)	10’401	5201
Nuro (US)	55’370	5034
DeepRoute (China)	10’018	3339
Zoox[2] (US)	102’521	1627
QCraft (China)	7582	474
Aurora (US)	12’208	330
Lyft[3] (US)	32’731	266
Gatik (US)	2352	214
Apple (US)	18’805	145
Nissan (Japan)	395	99
BMW (Germany)	122	41
Aimotive (Hungary)	2987	26
Mercedes (Germany)	29’984	26
NVIDIA (US)	3033	24
Qualcomm (US)	1727	19
SF Motors (US)	875	14
EasyMile (France)	424	3
Toyota (Japan)	2875	2
Ridecell (US)	148	1

[1] Companies with less than 100 miles driven are excluded
[2] bought by Amazon (in 2020)
[3] bought by Toyota (in 2021)

Source: https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/disengagement-reports/

In 2014, the California DMV (Department of Motor Vehicles) developed the Autonomous Vehicle Tester Program to allow manufacturers to test autonomous vehicles with a human driver in the seat (DMV, 2020). Table 4 shows a list of companies which had miles driven in the year 2020. According to the rules they must report the miles driven and the number of disengagements (when the driver must take manual control or the autonomous technology failed) (Sun, 2021).

It can be seen that Waymo and Cruise lead the miles driven per disengagement. Even though there is some controversy about the data (some claim the Disengagement Reports are "effectively meaningless") we use it for two reasons: First of all, it is the only (public) source that allows the comparison of different actors – even though only in California – and second, the data allows to see the progress of the companies towards autonomous driving SAE Level 4 (since Level 3 still requires a driver as a fallback; see also Table 5 for a list of the companies that hold a permit to test without a test driver). It is clear, that the weather in California might not be representative of cities all over the world, but there is no equivalent testing taking place (except in some districts/cities/industrial parks in China) (Hawkins, 2020b) (Krämer, 2021).

Note: Tesla does not show up in the list, since its system is "officially" classified as an SAE Level 2 system. This has already led to some confusion and some communication with the regulator (Baldwin, 2021) (Kolodny, 2021). For SAE Level 3 a test permit is also required.

Table 5

Permit Holders Autonomous Vehicle Driverless Tester Program in California (2021)

Permit Holders (Driverless Testing) in California (as of 21 May 2021)	
Waymo (US)	1
Nuro (US)	2
AutoX (China)	3
Zoox[1] (US)	4
Cruise (US)	5
Baidu (China)	6
WeRide (China)	7
Pony.ai (China)	8

[1] bought by Amazon (in 2020)

Source: https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-testing-permit-holders/

In 2018, the California DMV (Department of Motor Vehicles) established the Autonomous Vehicle Driverless Tester Program (DMV, 2020). Currently (as of 21 May 2021), eight companies have a driverless test permit from the California DMV: Waymo, Nuro, AutoX, Zoox, Cruise, Baidu, WeRide and Pony.ai (DMV, 2021). Note: The order of the companies is the order in which the companies received the test permit. Cruise was for example the fifth company in the state that received a driverless test permit. Four of the companies are Chinese.

Table 6

Company Data

	General Motors	Ford Motor Company	Volkswagen Group	Daimler AG	BMW	Tesla, Inc.
Founded	1908*	1903	1937	1926**	1916	2003
Headquarters	Detroit, Michigan, U.S.	Dearborn, Michigan, U.S.	Wolfsburg, Germany	Stuttgart, Germany	Munich, Germany	Palo Alto, California, U.S.
Key People	Mary Barra (Chairperson & CEO) Mark Reuss (President)	Jim Farley (President & CEO) William Clay Ford Jr. (Executive Chairman)	Herbert Diess (CEO) Hans Dieter Poetsch (Supervisory Board)	Ola Kaellenius (CEO) Bernd Pischetsrieder (Supervisory Board)	Oliver Zipse (CEO) Norbert Reithofer (Supervisory Board)	Elon Musk (CEO) Robyn Denholm (Chairwoman)
Products	Automobiles Commercial vehicles	Automobiles Commercial vehicles	Automobiles Commercial vehicles Motorcycles etc.	Automobiles Commercial vehicles	Automobiles Motorcycles	Automobiles Batteries Solar panels and roofs
Production output / Unit sales	6'830'000 vehicles (2020)	4'187'000 vehicles (2020)	8'900'000 vehicles (2020)	2'840'402 vehicles (2020)	2'255'637 cars (2020) 168'104 motorcycles (2020)	509'737 vehicles (2020)
Revenue	USD 122.49 billion (2020)	USD 127.144 billion (2020)	EUR 222.884 billion (2020)	EUR 154.309 billion (2020)	EUR 98.990 billlion (2020)	USD 31.536 billion (2020)
Operating Income	USD 6.634 billion (2020)	USD -4.408 billion (2020)	EUR 11.667 billion (2020)	EUR 6.603 billion (2020)	EUR 5.222 billion (2020)	USD 1.994 billion (2020)
Net Income	USD 6.247 billion (2020)	USD -1.276 billion (2020)	EUR 8.334 billion (2020)	EUR 4.009 billion (2020)	EUR 3.857 billion (2020)	USD 0.721 billion (2020)
R&D Expenses	USD 6.2 billion (2020)	USD 7.1 billion (2020)	EUR 13.885 billion (2020)	EUR 8.614 billion (2020)	EUR 6.279 billion (2020)	USD 1.491 billion (2020)
Number of employees	155'000 (2020)	186'000 (2020)	662'600 (2020)	288'481 (2020)	120'726 (2020)	70'757 (2020)
Website	gm.com	ford.com	volkswagenag.com	daimler.com	bmwgroup.com	tesla.com

* original company, 2009 present company

** original foundation of Daimler-Benz

Sources: Wikipedia, Company Homepage, Annual Reports (10-K forms)

The company data has mostly been compiled to see the financial strength of the companies (based on vehicles sold/produced and revenue and operating/net income). Also, the R&D expenses have been compiled, even though we were cautioned not to make a comparison between e.g. Tesla and Volkswagen (because the latter has many more models in its product pipeline that generate high costs for development and testing).

References

Abuelsamid, S. (2020). *Waymo's $30 Billion Valuation Shows The New Reality Of Automated Driving Is Sinking In*. Retrieved 6 March 2020 from https://www.forbes.com/sites/samabuelsamid/2020/03/06/waymos-30b-valuation-shows-the-new-reality-of-automated-driving-is-sinking-in/

ADAC. (2021). *Autonomes Fahren: Digital entspannt in die Zukunft*. Retrieved 29 March 2021 from https://www.adac.de/rund-ums-fahrzeug/ausstattung-technik-zubehoer/autonomes-fahren/technik-vernetzung/aktuelle-technik/

Apex.AI. (2021). *Customer Success Story Toyota's Woven Planet*. Retrieved 3 Nov 2021 from https://www.apex.ai/toyota-woven-planet

Apollo. (2021a). *Ecological Partners*. Retrieved 29 May 2021 from https://apollo.auto/about/ecological_partner.html

Apollo. (2021b). *Smart Transportation Solution*. Retrieved 13 May 2021 from https://apollo.auto/

Argo AI. (2021). *We're Building Self-Driving Technology You Can Trust.* Retrieved 31 May 2021 from https://www.argo.ai/

Attias, D. (2017). The Autonomous Car, a Disruptive Business Model? In D. Attias (Ed.), *The Automobile Revolution*. Springer, Cham.

Attias, D., & Mira-Bonnardel, S. (2017). Extending the Scope of Partnerships in the Automotive Industry Between Competition and Cooperation. In D. Attias (Ed.), *The Automobile Revolution*. Springer, Cham.

Aurora. (2021). *The Aurora Driver, delivering the benefits of self-driving to the world*. Retrieved 18 May 2021 from https://aurora.tech

AUTOSAR. (2022). *The standardized software framework for intelligent mobility*. Retrieved 3 Jan 2022 from https://www.autosar.org/

Autovista Group. (2020). *BMW and Mercedes-Benz autonomous driving partnership on hold*. Retrieved 23 March 2021 from https://autovistagroup.com/news-and-insights/bmw-and-mercedes-benz-autonomous-driving-partnership-hold

AutoX. (2021). *Democratizing Autonomy*. Retrieved 2 June 2021 from https://www.autox.ai/en/index.html

Baidu. (2020). *Baidu looks into making its own electric cars, holding talks with Geely, GAC, FAW, sources say*. Retrieved 5 Nov 2021 from https://www.scmp.com/tech/big-tech/article/3113994/baidu-looks-making-its-own-electric-cars-holding-talks-geely-gac-faw

Baidu Inc. (2020). *Baidu Apollo Showcases Fully Automated Driving Capability at Baidu World 2020*. Retrieved 29 May 2021 from https://www.prnewswire.com/news-releases/baidu-apollo-showcases-fully-automated-driving-capability-at-baidu-world-2020-301131252.html

Baidu Inc. (2021). *Baidu Receives Green Light to Demonstrate Commercialized Autonomous Driving, Test Driverless Vehicles in Cangzhou*. Retrieved 6 June 2021 from https://www.prnewswire.com/news-releases/baidu-receives-green-light-to-demonstrate-commercialized-autonomous-driving-test-driverless-vehicles-in-cangzhou-301247206.html

Baldwin, R. (2021). *Tesla Tells California DMV that FSD Is Not Capable of Autonomous Driving*. Retrieved 21 March 2021 from https://www.caranddriver.com/news/a35785277/tesla-fsd-california-self-driving/

Bardt, H. (2017). Autonomous Driving – a Challenge for the Automotive Industry. *Intereconomics*, *52*.

https://www.intereconomics.eu/contents/year/2017/number/3/article/autonomous-driving-a-challenge-for-the-automotive-industry.html
Barringer, B. R., & Harrison, J. S. (2000). Walking a Tightrope: Creating Value Through Interorganizational Relationships. *Journal of Management*, *26*(3), 367-403.
Bauman, M. (2017). *Why Waiting for Perfect Autonomous Vehicles May Cost Lives*. Retrieved 22 March 2021 from https://www.rand.org/blog/articles/2017/11/why-waiting-for-perfect-autonomous-vehicles-may-cost-lives.html
BBC. (2017). *Intel buys driverless car technology firm Mobileye*. Retrieved 2020-09-02 from https://www.bbc.com/news/business-39253422
BBC. (2020). *Nuro set to be California's first driverless delivery service*. Retrieved 18 May 2021 from https://www.bbc.com/news/technology-55438969
Bellan, R. (2021a). *Argo releases standards for how self-driving cars should act around cyclists*. Retrieved 4 Jan 2022 from https://techcrunch.com/2021/12/06/argo-releases-standard-for-how-self-driving-cars-should-act-around-cyclists/
Bellan, R. (2021b). *Waymo self-driving vehicles will begin mapping NYC's streets*. Retrieved 4 November 2021 from https://techcrunch.com/2021/11/03/waymo-self-driving-vehicles-are-headed-to-nyc-for-a-mapping-operation/
Bellon, T., & Yamamitsu, E. (2021). *Toyota to buy Lyft unit in boost to self-driving plans*. Retrieved 29 May 2021 from https://www.reuters.com/business/autos-transportation/lyft-sells-self-driving-tech-unit-toyota-550-mln-moves-up-profit-timeline-2021-04-26/
Beresford, C. (2020). *Toyota Invests $400 Million in Chinese Self-Driving Startup Pony.ai*. Retrieved 2 April 2021 from https://www.caranddriver.com/news/a31115985/toyota-investment-pony-self-driving/
Birkinshaw, J. (2019). *Ecosystem Businesses Are Changing the Rules of Strategy*. Retrieved 17 Nov 2021 from https://hbr.org/amp/2019/08/ecosystem-businesses-are-changing-the-rules-of-strategy
Bloomberg Technology. (2020). *GM Shows Off Autonomous Shuttle With No Pedals or Steering Wheel*. Retrieved 19 Oct 2021 from https://www.youtube.com/watch?v=tV1aRN9TOSw
BMVI. (2017). *ETHIK-KOMMISSION AUTOMATISIERTES UND VERNETZTES FAHREN*. Retrieved 19 May 2021 from https://www.bmvi.de/SharedDocs/DE/Publikationen/DG/bericht-der-ethik-kommission.pdf?__blob=publicationFile
BMVI. (2021a). *Deutschland wird international die Nummer 1 beim autonomen Fahren*. Retrieved 27 March 2021 from https://www.bmvi.de/SharedDocs/DE/Artikel/DG/gesetz-zum-autonomen-fahren.html
BMVI. (2021b). *Germany will be the world leader in autonomous driving*. Retrieved 18 Oct 2021 from https://www.bmvi.de/SharedDocs/EN/Articles/DG/act-on-autonomous-driving.html
BMW Group. (2016). *BMW Group, Intel and Mobileye Team Up to Bring Fully Autonomous Driving to Streets by 2021*. Retrieved 18 Oct 2021 from https://www.press.bmwgroup.com/africa-dom-easteurope/article/detail/T0261660EN/bmw-group-intel-and-mobileye-team-up-to-bring-fully-autonomous-driving-to-streets-by-2021?language=en
BMW Group. (2019). *Vertragsunterzeichnung erfolgt: BMW Group und Daimler AG starten langfristige Entwicklungskooperation für automatisiertes Fahren*. Retrieved 17 June, 2020 from https://www.press.bmwgroup.com/deutschland/article/attachment/T0298266DE/434525

BMW Group. (2021). *WELCOME TO THE BMW GROUP AUTONOMOUS DRIVING CAMPUS.* Retrieved 18 Oct 2021 from https://www.bmwgroup.com/en/innovation/technologies-and-mobility/autonomes-fahren/campus.html

Boeriu, H. (2017). *Continental joins autonomous driving platform from BMW, Intel and Mobileye*. Retrieved 18 Oct 2021 from https://www.bmwblog.com/2017/06/20/continental-joins-autonomous-driving-platform-bmw-intel-mobileye/

Bosch. (2019). *History Safe Braking: 50 years start of developing Bosch's anti-lock braking system ABS*. Retrieved 1.10.2020 from https://www.bosch.com/stories/beginnings-of-abs/

Boyle, A. (2020). *Elon Musk starts another catfight with Jeff Bezos after Amazon buys Zoox self-driving car venture*. Retrieved 13 May 2021 from https://www.geekwire.com/2020/elon-musk-starts-another-catfight-jeff-bezos-amazon-buys-zoox-self-driving-car-venture/

Brandenburger, A., & Nalebuff, B. (2021). *The Rules of Co-opetition*. Retrieved 26 Jan 2022 from https://hbr.org/2021/01/the-rules-of-co-opetition

Brennan, T., Ernst, P., Katz, J., & Roth, E. (2020). *Building an R&D strategy for modern times*. Retrieved 23 Nov 2021 from https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/building-an-r-and-d-strategy-for-modern-times

Burns, M. (2018). *GM's Cruise gets $2.25B from SoftBank's Vision Fund, $1.1B from GM*. Retrieved 19 May 2021 from https://techcrunch.com/2018/05/31/gms-cruise-gets-2-25b-from-softbanks-vision-fund-1-1b-from-gm/

CARIAD. (2021). *We transform automotive mobility.* Retrieved 13 May 2021 from https://cariad.technology/

CNBC. (2021). *5. Didi Chuxing*. Retrieved 25 May 2021 from https://www.cnbc.com/2021/05/25/didi-chuxing-disruptor-50.html

CNBC Television. (2019). *GM Cruise CEO Dan Ammann on its autonomous rideshare project*. Retrieved 18 May 2021 from https://www.youtube.com/watch?v=X1g_Y4hwpRI

CNN. (2021). *CNN tried Tesla's 'full self-driving' mode on NYC streets. It didn't go great*. Retrieved 26 Nov 2021 from https://edition.cnn.com/videos/business/2021/11/17/tesla-3-full-self-driving-mode-test-mc-zw-orig.cnn-business/video/playlists/business-tesla/

Cruise. (2020). *Introducing the Cruise Origin*. Retrieved 19 Oct 2021 from https://www.youtube.com/watch?v=TGe4sOHYiXc

Cruise. (2021). *Driving cities forward*. Retrieved 30 May 2021 from https://www.getcruise.com/

Crunchbase. (2021). *Momenta (Company Profile)*. Retrieved 30. April 2021 from https://www.crunchbase.com/organization/momenta-ai

Crunchbase - AutoX. (2021). Retrieved 2 June 2021 from https://www.crunchbase.com/organization/autox-ac12

Crunchbase - Didi. (2021). Retrieved 25 May 2021 from https://www.crunchbase.com/organization/didi-dache

Crunchbase - Pony.ai. (2021). Retrieved 1 June 2021 from https://www.crunchbase.com/organization/pony-ai

Crunchbase - WeRide. (2021). Retrieved 30 May 2021 from https://www.crunchbase.com/organization/werideai

Dahlmann, D. (2019). *Alejandro Vukotich von BMW: „Wir starten 2021 unsere Robotaxis“*. Gruenderszene. Retrieved 2020-08-25 from https://www.gruenderszene.de/automotive-mobility/bmw-robotaxi-vukotich-autonomes-fahren

Daimler. (2017). *Automated and Autonomous Driving. Legal Framework*. Retrieved 01.10.2020 from https://www.daimler.com/innovation/case/autonomous/legal-framework.html

Daimler. (2019a). *Daimler and Bosch. Start of the San José pilot project for automated ride-hailing service*. Retrieved 28 March 2021 from https://www.daimler.com/innovation/case/autonomous/pilot-city-san-jose.html

Daimler. (2019b). *DRIVE PILOT*. Retrieved 21 March 2021 from https://www.daimler.com/innovation/case/autonomous/drive-pilot-2.html

Daimler. (2019c). *Safety First for Automated Driving*. Retrieved 19 May 2021 from https://www.daimler.com/documents/innovation/other/safety-first-for-automated-driving.pdf

Daimler. (2020a). *Mercedes-Benz and NVIDIA: Software-Defined Computing Architecture for Automated Driving Across Future Fleet*. Retrieved 22 March 2021 from https://www.daimler.com/innovation/product-innovation/autonomous-driving/mercedes-benz-and-nvidia-plan-cooperation.html

Daimler. (2020b). *Partners reach joint decision: BMW Group and Mercedes-Benz AG put development cooperation in automated driving temporarily on hold – may be resumed later*. Retrieved 18 Oct 2021 from https://media.daimler.com/marsMediaSite/en/instance/ko/Partners-reach-joint-decision-BMW-Group-and-Mercedes-Benz-AG-put-development-cooperation-in-automated-driving-temporarily-on-hold--may-be-resumed-later.xhtml?oid=46637056

Daimler. (2020c). *Strategic partnership. Daimler Trucks and Waymo*. Retrieved 16 Oct 2021 from https://www.daimler.com/investors/reports-news/financial-news/20201027-dt-and-waymo.html

Daimler. (2020d). *“We’re making autonomous driving safe.” An interview about progress in development work*. Retrieved 01.10.2020 from https://www.daimler.com/innovation/case/autonomous/interview-hafner-2.html

Daimler. (2021a). *Annual Report 2020*. Retrieved 13 Mai 2021 from https://www.daimler.com/documents/investors/reports/annual-report/daimler/daimler-ir-annual-report-2020-incl-combined-management-report-daimler-ag.pdf

Daimler. (2021b). *MB.OS is the "Next Big Thing" - Interview with Dr. Michael Hafner*. Retrieved 18 Oct 2021 from https://www.daimler.com/career/about-us/mercedes-benz-operating-system/michael-hafner.html

Daimler. (2021c). *Overview of Daimler shareholders*. Retrieved 14 Dec 2021 from https://www.daimler.com/investors/share/shareholder-structure/

Davies, A. (2019). *Amazon Dives Into Self-Driving Cars With a Bet on Aurora*. Retrieved 29 March 2021 from https://www.wired.com/story/amazon-aurora-self-driving-investment-funding-series-b/

Denso. (2018). *Toyota Research Institute-Advanced Development (TRI-AD) Established in Tokyo To Provide Fully-Integrated, Production-Quality Software For Automated Driving*. Retrieved 18 May 2021 from https://www.denso.com/global/en/news/newsroom/2018/20180302-g01/

DFKI. (2021). *AUTONOMOUS DRIVING*. Retrieved 29 March 2021 from https://www.dfki.de/en/web/research/competence-centers/autonomous-driving/

Dickson, B. (2021a). *Tesla AI chief explains why self-driving cars don't need lidar*. Retrieved 25 Oct 2021 from https://venturebeat.com/2021/07/03/tesla-ai-chief-explains-why-self-driving-cars-dont-need-lidar/

Dickson, B. (2021b). *Why machine learning struggles with causality*. Retrieved 2 Jan 2022 from https://bdtechtalks.com/2021/03/15/machine-learning-causality/

Diess, H. (2020). *How we transform Volkswagen*. https://www.linkedin.com/pulse/how-we-transform-volkswagen-herbert-diess/

Diess, H. (2021). *Diess spricht LIVE: mit Philipp Westermeyer*. Retrieved 14 Oct 2021 from https://www.linkedin.com/video/live/urn:li:ugcPost:6840309137142759424/

DMV. (2020). *AUTONOMOUS VEHICLES*. Retrieved 2 April 2021 from https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/

DMV. (2021). *AUTONOMOUS VEHICLE TESTING PERMIT HOLDERS*. Retrieved 16 May 2021 from https://www.dmv.ca.gov/portal/vehicle-industry-services/autonomous-vehicles/autonomous-vehicle-testing-permit-holders/

Dodgson, M., Gann, D. M., & Phillips, N. (2015). *The Oxford Handbook of Innovation Management*. Oxford University Press.

DPCcars. (2021). *Nuro Self Driving Vehicle*. Retrieved 13 May 2021 from https://www.youtube.com/watch?v=MzsSO1RVPME

Dyer, J. H., & Nobeoka, K. (2000). Creating and Managing A High-Performance Knowledge-Sharing Network: The Toyota Case. *Strategic Management Journal*, *21*, 345-367.

Edelman, G. (2021). *A New Antitrust Case Cuts to the Core of Amazon's Identity*. Retrieved 1 Dec 2021 from https://www.wired.com/story/amazon-antitrust-lawsuit-cuts-to-core-of-identity/

European Commission. (2015). *Antitrust: Commission opens formal investigation against Google in relation to Android mobile operating system*. Retrieved 1 Dec 2021 from https://ec.europa.eu/commission/presscorner/detail/en/MEMO_15_4782

European Commission. (2019). *Antitrust: Commission opens investigation into possible anti-competitive conduct of Amazon*. Retrieved 1 Dec 2021 from https://ec.europa.eu/commission/presscorner/detail/en/ip_19_4291

Farhadi, N. (2019). *Cross-Industry Ecosystems*. Springer Gabler.

Fasse, M. (2019). *BMW-Chef Oliver Zipse geht in die Offensive*. Retrieved 10 Dec from https://www.handelsblatt.com/unternehmen/industrie/autobauer-flugzeugbauer-und-keine-airline/25049514-2.html

Fasse, M. (2020). *BMW will Tesla und Google mit neuem Betriebssystem Paroli bieten*. Retrieved 21 March 2021 from https://www.handelsblatt.com/unternehmen/industrie/neue-software-einheit-bmw-will-tesla-und-google-mit-neuem-betriebssystem-paroli-bieten/26726248.html

Fasse, M., & Hubik, F. (2020). *BMW-Vorstand zum autonomen Fahren: „Das können wir genauso wie Tesla“*. Retrieved 28 March 2021 from https://www.handelsblatt.com/unternehmen/industrie/interview-mit-frank-weber-bmw-vorstand-zum-autonomen-fahren-das-koennen-wir-genauso-wie-tesla/26609266.html?ticket=ST-380833-wSG39REbOqTIonJXbDdc-ap6

Fasse, M., Hubik, F., Krolle, H., Menzel, S., & Tyborski, R. (2021). *Wer beim Wettlauf um das beste Auto-Betriebssystem vorn liegt*. Retrieved 29 May 2021 from https://www.handelsblatt.com/unternehmen/innovationweek/industrie-gegen-techkonzerne-wer-beim-wettlauf-um-das-beste-auto-betriebssystem-vorn-liegt/27151616.html?ticket=ST-5224562-f9lRIVPeg5L9hOFxNiTH-ap2

Faulkner, D. O., & Campbell, A. (2003). *The Oxford Handbook of Strategy* (Vol. II). Oxford University Press.

Fiat Chrysler Automobiles. (2020). *FCA and Waymo Further Expand Autonomous Driving Technology Partnership and Sign Exclusive Agreement for Light Commercial Vehicles*. Retrieved 15 May 2021 from https://www.fcagroup.com/en-US/media_center/fca_press_release/2020/july/Pages/fca_and_waymo_further_expand_autonomous_driving_technology_partnership.aspx

Financial Times. (2021). *Robotaxis: have Google and Amazon backed the wrong technology?* Retrieved 25 Oct 2021 from https://www.ft.com/content/46ff4fe4-0ae6-4f68-902c-3fd14d294d72

Fraunhofer-Institut. (2015). *Hochautomatisiertes fahren auf Autobahnen - Industriepolitische Schlussfolgerungen*. Retrieved 29 March 2021 from https://www.bmwi.de/Redaktion/DE/Downloads/H/hochautomatisiertes-fahren-auf-autobahnen.pdf

Fridman, L. (2020). *Tesla Vehicle Deliveries and Autopilot Mileage Statistics*. Retrieved 28 March 2021 from https://lexfridman.com/tesla-autopilot-miles-and-vehicles/

GitHub - Apollo. (2021). Retrieved 7 June 2021 from https://github.com/ApolloAuto/apollo

Global Times. (2021). *Baidu's self-driving bus, Robobus, is on cusp of commercial operation*. Retrieved 29 May 2021 from https://www.globaltimes.cn/page/202104/1220826.shtml

Granstrand, O., & Holgersson, M. (2020). Innovation ecosystems: A conceptual review and a new definition. *Technovation*, *90-91*.

Green Car Congress. (2020). *Volvo robotaxis roll out in suburban Shanghai*. Retrieved 25 May 2021 from https://www.greencarcongress.com/2020/07/20200706-shanghai.html

Green Car Congress. (2021). *Baidu Apollo to launch fully driverless ride-hailing services in Beijing; health code scan to enter*. Retrieved 1 June 2021 from https://www.greencarcongress.com/2021/05/20210501-baidu.html

Greeven, M. J. (2019). *Is it the end of strategy in business ecosystems?* Retrieved 17 Nov from https://www.imd.org/research-knowledge/articles/Is-it-the-end-of-strategy-in-business-ecosystems/

Hawkins, A. J. (2019). *Waymo strikes a deal with Nissan-Renault to bring driverless cars to Japan and France*. Retrieved 29 March 2021 from https://www.theverge.com/2019/6/20/18692764/waymo-nissan-renault-self-driving-car-japan-france

Hawkins, A. J. (2020a). *Cruise gets the green light to test fully driverless cars in California*. Retrieved 2 April 2021 from https://www.theverge.com/2020/10/15/21517833/cruise-driverless-cars-test-permit-california-dmv

Hawkins, A. J. (2020b). *Everyone hates California's self-driving car reports*. Retrieved 1 June 2021 from https://www.theverge.com/2020/2/26/21142685/california-dmv-self-driving-car-disengagement-report-data

Hawkins, A. J. (2020c). *Volvo will use Waymo's self-driving technology to power a fleet of electric robotaxis*. Retrieved 13 May 2021 from https://www.theverge.com/2020/6/25/21303324/volvo-waymo-l4-deal-electric-self-driving-robot-taxi

Hawkins, A. J. (2020d). *Waymo and Daimler are teaming up to build fully driverless semi trucks*. https://www.theverge.com/2020/10/27/21536048/waymo-daimler-driverless-semi-trucks-cascadia-freightliner

Hawkins, A. J. (2021a). *Cruise gets the green light to give driverless rides to passengers in San Francisco*. Retrieved 20 Oct 2021 from https://www.theverge.com/2021/9/30/22702962/cruise-waymo-california-dmv-autonomous-vehicle-permit

Hawkins, A. J. (2021b). *Cruise starts pre-production of its autonomous shuttle thanks to $5 billion from GM*. Retrieved 20 Oct 2021 from https://www.theverge.com/2021/6/15/22534945/gm-credit-cruise-autonomous-vehicle-origin-production

Hawkins, A. J. (2021c). *Toyota teams up with Aurora and Denso on robotaxi development*. Retrieved 18 May 2021 from https://www.theverge.com/2021/2/9/22274640/toyota-aurora-denso-self-driving-car-robotaxi

Hawkins, A. J. (2021d). *Volvo and Aurora team up on fully autonomous trucks for North America*. Retrieved 23 May 2021 from https://www.theverge.com/2021/3/30/22358005/volvo-aurora-autonomous-truck-partnership

Hawkins, A. J. (2021e). *VW will start testing its Argo AI-powered self-driving vans in Germany this summer*. Retrieved 19 May 2021 from https://www.theverge.com/2021/5/12/22430813/vw-argo-autonomous-delivery-ride-pooling-germany

HBS. (2021). *The Five Forces*. Retrieved 17 Nov 2021 from https://www.isc.hbs.edu/strategy/business-strategy/Pages/the-five-forces.aspx

Henßler, S. (2019). *VW ID.3 führen massive Softwareprobleme zu verspäteter Auslieferung?* Retrieved 22 March 2021 from https://www.elektroauto-news.net/2019/vw-id-3-massive-softwareprobleme-verspaetete-auslieferung

Hetzner, C. (2019). *How Germany's giants are transforming into tech companies*. Retrieved 29 March 2021 from https://www.autonews.com/technology/how-germanys-giants-are-transforming-tech-companies

Horwitz, J. (2016). *Uber's merger with Didi shows just how hard it is for a foreign company to compete in China*. QUARTZ. Retrieved 25 May 2021 from https://qz.com/747013/uber-shows-just-how-hard-it-is-for-foreign-companies-to-compete/

Hubik, F., Fasse, M., & Menzel, S. (2021). *Die Software-Frage spaltet die deutschen Autohersteller*. Retrieved 18 Nov 2021 from https://www.handelsblatt.com/unternehmen/industrie/handelsblatt-auto-gipfel-2021-die-software-frage-spaltet-die-deutschen-autohersteller/27787642.html?ticket=ST-5574708-GxPwajL1NyNasayheuOe-cas01.example.org

Intel Newsroom. (2021a). *2021 CES: Under the Hood with Prof. Amnon Shashua*. Retrieved 30. April 2021 from https://www.youtube.com/watch?v=B7YNj66GxRA

Intel Newsroom. (2021b). *CES 2021: Amnon Shashua Shares that Mobileye's AVs are on the 'Go' Around the World*. Retrieved 23 May 2021 from https://www.youtube.com/watch?v=N5pJMMO6i4w

Jacobides, M. G. (2019). *In the Ecosystem Economy, What's Your Strategy?* Retrieved 25 Nov 2021 from https://hbr.org/2019/09/in-the-ecosystem-economy-whats-your-strategy

Jacobides, M. G., & Lianos, I. (2021). Ecosystems and competition law in theory and practice. *Industrial and Corporate Change*. https://academic.oup.com/icc/advance-article/doi/10.1093/icc/dtab061/6428760

Jaguar Land Rover. (2018). *WAYMO AND JAGUAR LAND ROVER ANNOUNCE LONG-TERM PARTNERSHIP, BEGINNING WITH SELF-DRIVING JAGUAR I-PACE*. Retrieved 19 Nov 2021 from https://media.jaguarlandrover.com/en-us/news/2018/03/waymo-and-jaguar-land-rover-announce-long-term-partnership-beginning-self-driving-0

JAYDIAZ2013. (2016). *INCREMENTAL, BREAKTHROUGH AND RADICAL INNOVATION: DECIPHERING THE DIFFERENCES| BY |EMMA MUCKERSIE.*

Retrieved 17 Nov 2021 from https://technopreneurph.wordpress.com/2016/08/04/incremental-breakthrough-and-radical-innovation-deciphering-the-differences-by-emma-muckersie/
Jin, H., & Mehta, C. (2021). *Alphabet's Waymo raises $2.5 billion in first fresh funding in a year*. Retrieved 20 Oct 2021 from https://www.reuters.com/article/us-waymo-funding-idCAKCN2DS1EQ
Johnson, E. (2020). *The 2021 Mercedes-Benz S-Class Is Ready For Our Autonomous Future*. Retrieved 27 March 2021 from https://www.motortrend.com/news/2021-mercedes-s-class-level-3-level-4-drive-pilot-automated-autonomous-driving/
Jourdan, A., & Shirouzu, N. (2018). *How Geely's Li Shufu spent months stealthily building a $9 billion stake in Daimler*. Retrieved 2021 from https://www.reuters.com/article/us-daimler-geely-shell-insight-idUSKCN1GD5ST
Kharpal, A. (2021). *Chinese driverless car start-up WeRide raises $310 million in funding as competition heats up*. Retrieved 30 May 2021 from https://www.cnbc.com/2021/01/14/chinese-driverless-car-start-up-weride-raises-310-million-in-funding.html
Knight, W. (2021). *Why Tesla Is Designing Chips to Train Its Self-Driving Tech*. Retrieved 25 Oct 2021 from https://www.wired.com/story/why-tesla-designing-chips-train-self-driving-tech/
Kölling, M. (2019). *Toyota holt sich für autonomes Fahren Starthilfe aus dem Silicon Valley*. Retrieved 13 June, 2020 from https://www.handelsblatt.com/unternehmen/industrie/autobauer-toyota-holt-sich-fuer-autonomes-fahren-starthilfe-aus-dem-silicon-valley/23926948.html
Kölling, M. (2021). *Kampfansage an VW, Tesla und Google: Toyota will eigenes Betriebssystem entwickeln*. Retrieved 4 June 2021 from https://www.handelsblatt.com/unternehmen/industrie/software-im-auto-kampfansage-an-vw-tesla-und-google-toyota-will-eigenes-betriebssystem-entwickeln/26864432.html
Kolodny, L. (2021). *Tesla can't promise driverless cars in 2021, engineer tells California DMV*. Retrieved 16 May 2021 from https://www.cnbc.com/2021/05/07/tesla-engineer-to-california-dmv-self-driving-may-not-come-this-year.html
Korosec, K. (2019a). *VW invests $2.6 billion in self-driving startup Argo AI as part of Ford alliance*. Retrieved 16 Oct 2021 from https://techcrunch.com/2019/07/12/vw-invests-2-6-billion-in-self-driving-startup-argo-ai-as-part-of-ford-alliance/
Korosec, K. (2019b). *VW's partnership with self-driving car startup Aurora has ended*. Retrieved 23 March 2021 from https://techcrunch.com/2019/06/11/vws-partnership-with-self-driving-car-startup-aurora-has-ended/
Korosec, K. (2020a). *Autonomous vehicle startup AutoX lands driverless testing permit in California*. Retrieved 16 May 2021 from https://techcrunch.com/2020/07/17/autonomous-vehicle-startup-autox-lands-driverless-testing-permit-in-california/
Korosec, K. (2020b). *AutoX and Fiat Chrysler are teaming up on a robotaxi for China*. Retrieved 28 March 2021 from https://techcrunch.com/2020/01/07/autox-and-fiat-chrysler-are-teaming-up-on-a-robotaxi-for-china/
Korosec, K. (2020c). *The Station: Bird spikes Circ in the Middle East, Kitty Hawk folds Flyer, Cruise attemps a hiring coup*. Retrieved 22 March 2021 from https://techcrunch.com/2020/06/07/the-station-bird-spikes-circ-in-the-middle-east-kitty-hawk-folds-flyer-cruise-attempts-a-hiring-coup/
Korosec, K. (2020d). *Uber sells self-driving unit Uber ATG in deal that will push Aurora's valuation to $10B*. Retrieved 18 May 2021 from

https://techcrunch.com/2020/12/07/uber-sells-self-driving-unit-uber-atg-in-deal-that-will-push-auroras-valuation-to-10b/

Korosec, K. (2021a). *Aurora strikes deal with Toyota, Denso to develop, test self-driving Sienna minivans*. Retrieved 18 May 2021 from https://techcrunch.com/2021/02/09/aurora-to-strikes-deal-with-toyota-denso-to-develop-test-self-driving-sienna-minivans/

Korosec, K. (2021b). *Chinese startup Pony.ai can now test driverless vehicles in three California cities*. Retrieved 1 June 2021 from https://techcrunch.com/2021/05/21/chinese-startup-pony-ai-can-now-test-driverless-vehicles-in-three-california-cities/

Korosec, K. (2021c). *Cruise secures $5B credit line to buy electric, autonomous Cruise Origin vehicles from GM*. Retrieved 20 Oct 2021 from https://techcrunch.com/2021/06/15/cruise-secures-5b-credit-line-to-buy-electric-autonomous-cruise-origin-vehicles-from-gm/

Korosec, K. (2021d). *GM CEO Mary Barra wants to sell personal autonomous vehicles using Cruise's self-driving tech by 2030*. Retrieved 19 May 2021 from https://techcrunch.com/2021/05/05/gm-ceo-mary-barra-wants-to-sell-personal-autonomous-vehicles-using-cruises-self-driving-tech-by-2030/

Korosec, K. (2021e). *Intel's Mobileye takes its autonomous vehicle testing program to New York City*. Retrieved 4 November 2021 from https://techcrunch.com/2021/07/20/intels-mobileye-takes-its-autonomous-vehicle-testing-program-to-new-york-city/

Korosec, K. (2021f). *Microsoft invests in Cruise in new $2 billion round*. Retrieved 29 March 2021 from https://techcrunch.com/2021/01/19/microsoft-invests-in-cruise-in-new-2-billion-round/

Korosec, K. (2021g). *Motional to begin testing autonomous vehicles in LA as part of California expansion plan*. Retrieved 4 November 2021 from https://techcrunch.com/2021/08/10/motional-to-begin-testing-autonomous-vehicles-in-la-as-part-of-california-expansion-plan/

Korosec, K., & Harris, M. (2020). *Anthony Levandowski sentenced to 18 months in prison as new $4B lawsuit against Uber is filed*. Tech Crunch. Retrieved August 17, 2020 from https://techcrunch.com/2020/08/04/anthony-levandowski-sentenced-to-18-months-in-prison-as-new-4b-lawsuit-against-uber-is-filed/

Krämer, U. M. (2021). *Auf Reisen im Silicon Valley: Es ist die Denkweise, die Unternehmer dort erfolgreicher macht*. Retrieved 30 April 2021 from https://www.digitale-exzellenz.de/reisen-im-silicon-valley/

Lambert, F. (2019). *Tesla unveils 'Robotaxi' plan for self-driving ride-sharing network next year*. electrek. Retrieved August 17, 2020 from https://electrek.co/2019/04/22/tesla-robotaxi-network-self-driving-fleet-ride-sharing-cars/

Lee, J. L., & Vengattil, M. (2021). *Baidu gets California nod for testing empty self-driving cars*. Retrieved 21 March 2021 from https://www.reuters.com/article/us-baidu-autonomous-idUSKBN29W2OT

Lee, T. B. (2021). *Waymo CEO dismisses Tesla self-driving plan: "This is not how it works"*. Retrieved 25 October 2021 from https://arstechnica.com/cars/2021/01/waymo-ceo-tesla-is-not-a-competitor-at-all/

Leswing, K. (2020). *Apple's 'monopoly power' over iPhone app distribution gives it outsized profits, antitrust committee says*. Retrieved 10 Feb 2022 from https://www.cnbc.com/2020/10/06/house-antitrust-subcommittee-apple-has-monopoly-power.html

Liao, R. (2019). *How China's first autonomous driving unicorn Momenta hunts for data*. Retrieved 21 March 2021 from https://techcrunch.com/2019/06/13/momenta-profile/
Liao, R. (2020a). *AutoX becomes China's first to remove safety drivers from robotaxis*. Retrieved 21 March 2021 from https://techcrunch.com/2020/12/02/autox-removes-safety-drivers/
Liao, R. (2020b). *Chinese autonomous driving startup WeRide bags $200M in funding*. Retrieved 30 May 2021 from https://techcrunch.com/2020/12/22/weride-200-million-funding/
Liao, R. (2021a). *Baidu's robotaxi service aims to be in 100 cities by 2030*. Retrieved 26 Nov 2021 from https://techcrunch.com/2021/11/17/baidu-robotaxi-2030/
Liao, R. (2021b). *Betting on China's driverless future, Toyota, Bosch, Daimler jump on board Momenta's $500M round*. Retrieved 30. April 2021 from https://techcrunch.com/2021/03/18/momenta-500-million-fundraise/
Liao, R. (2021c). *China's autonomous vehicle startups AutoX, Momenta and WeRide are coming to TC Sessions: Mobility 2021*. Retrieved 2 June 2021 from https://techcrunch.com/2021/05/13/chinese-autonomous-driving-tc-sessions-mobility-2021/
LinkedIn - Alejandro Vukotich. (2021). Retrieved 23 May 2021 from https://www.linkedin.com/in/alejandro-vukotich/
LinkedIn - WeRide.ai. (2021). Retrieved 30 May 2021 from https://www.linkedin.com/company/werideai/
Loizos, C. (2019). *Aurora co-founder and CEO Chris Urmson on the company's new investor, Amazon, and much more*. Retrieved 17 June, 2020 from https://techcrunch.com/2019/02/10/aurora-cofounder-and-ceo-chris-urmson-on-the-companys-new-investor-amazon-and-much-more/
Lyons, K. (2021a). *Chinese startup Pony.ai gets approval to test driverless vehicles in California*. Retrieved 1 June 2021 from https://www.theverge.com/2021/5/22/22449084/chinese-startup-pony-ai-autonomous-vehicles-california
Lyons, K. (2021b). *Cruise gets permit from California to provide passenger test rides in driverless vehicles*. Retrieved 20 Oct 2021 from https://www.theverge.com/2021/6/5/22520227/cruise-permit-california-driverless-autonomous-vehicles
MacRumors. (2021). *Apple Car*. Retrieved 15 May 2021 from https://www.macrumors.com/roundup/apple-car/
Martin, R. L. (2015). *There Are Still Only Two Ways to Compete*. Retrieved 17 Nov 2021 from https://hbr.org/2015/04/there-are-still-only-two-ways-to-compete
Martinez-Noya, A., & Narula, R. (2018). What more can we learn from R&D alliances? A review and research agenda. *BRQ Business Research Quarterly (2018)*(21), 195 - 212.
Matousek, M. (2019). *Tesla and rivals like Waymo and GM are locked in a battle over the future of self-driving cars*. Business Insider. Retrieved August 17, 2020 from https://www.businessinsider.com/tesla-rivals-waymo-locked-in-battle-over-self-driving-cars-2019-12
Maurer, M., Gerdes, J. C., Lenz, B., & Winner, H. (2016). *Autonomous Driving*. Cham Springer Berlin Heidelberg.
McGee, P. (2021). *Robotaxis: have Google and Amazon backed the wrong technology?* Retrieved 3 November 2021 from https://www.ft.com/content/46ff4fe4-0ae6-4f68-902c-3fd14d294d72
Menzel, S. (2019). *„Smartphones auf vier Rädern" – VW bündelt die Softwareentwicklung in neuer Gesellschaft*. Retrieved 21 March 2021 from

https://www.handelsblatt.com/unternehmen/industrie/car-software-org-smartphones-auf-vier-raedern-vw-buendelt-die-softwareentwicklung-in-neuer-gesellschaft/25227140.html?ticket=ST-5772297-fSOTozFdXGV0ZXaCmf0e-ap6
Menzel, S. (2020). *VW will die Software-Probleme rasch lösen – ID.3 kommt im Spätsommer*. Retrieved 22 March 2021 from https://www.handelsblatt.com/technik/thespark/volkswagen-vw-will-die-software-probleme-rasch-loesen-id-3-kommt-im-spaetsommer/25904772.html?ticket=ST-6156799-diF0OMjNXgMYu3xCTzTd-ap6
Menzel, S. (2021). *Volkswagen will mit Tesla gleichziehen: E-Auto-Software soll künftig per Funk erneuert werden*. Retrieved 21 March 2021 from https://www.handelsblatt.com/unternehmen/industrie/updates-over-the-air-volkswagen-will-mit-tesla-gleichziehen-e-auto-software-soll-kuenftig-per-funk-erneuert-werden/26970668.html?ticket=ST-5818317-FYMswSzibWd1ze64044K-ap6
Mercedes-Benz. (2021). *Driving assistance systems in S-Class: Intelligent Drive Next Level*. Retrieved 27 March 2021 from https://www.mercedes-benz.com/en/innovation/autonomous/the-new-s-class-intelligent-drive-next-level/
Metz, C., & Conger, K. (2020). *Uber, After Years of Trying, Is Handing Off Its Self-Driving Car Project*. The New York Times. Retrieved March 14, 2021 from https://www.nytimes.com/2020/12/07/technology/uber-self-driving-car-project.html
Microsoft. (2021). *Volkswagen Group teams up with Microsoft to accelerate the development of automated driving*. Retrieved 24 May 2021 from https://news.microsoft.com/2021/02/10/volkswagen-group-teams-up-with-microsoft-to-accelerate-the-development-of-automated-driving/
Minchin, J. (2021). *China set to join the autonomous vehicle race with new law drafted*. Retrieved 30. April 2021 from https://www.intelligenttransport.com/transport-news/114787/china-autonomous-vehicle-laws/
Mitchell, R. (2021a). *DMV probing whether Tesla violates state regulations with self-driving claims*. Retrieved 31 May 2021 from https://www.latimes.com/business/story/2021-05-17/dmv-tesla-california-fsd-autopilot-safety
Mitchell, R. (2021b). *Tesla touts self-driving to consumers. To the DMV, it tells a different tale*. Retrieved 21 March 2021 from https://www.latimes.com/business/story/2021-03-09/elon-musk-wants-it-both-ways-with-telsas-full-self-driving
Mobileye. (2021a). *Launching our Self-Driving Robotaxi in Germany*. Retrieved 24 Nov 2021 from https://www.mobileye.com/blog/self-driving-robotaxi-sixt-germany-iaa/
Mobileye. (2021b). *Mobileye Self-Driving Mobility Services*. Retrieved 24 Nov 2021 from https://www.mobileye.com/mobility-as-a-service/
Mobileye. (2021c). *Road Experience Management*. Retrieved 31 May 2021 from https://www.mobileye.com/our-technology/rem/
Möller, T., Padhi, A., Pinner, D., & Tschiesner, A. (2019). *The future of mobility is at our doorstep*. Retrieved 26 Nov 2021 from https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-future-of-mobility-is-at-our-doorstep?cid=app
Momenta. (2021). *Better AI, Better Life*. https://www.momenta.cn/
Moore, J. F. (1999). Predators and Prey: A New Ecology of Competition. *Harvard business review*, *71*, 75-86.
Nakayama, S. (2019). *Toyota launches second Silicon Valley investment fund*. Retrieved 19 May 2021 from https://asia.nikkei.com/Business/Companies/Toyota-launches-second-Silicon-Valley-investment-fund
NewGadgets.de. (2018). *BMW Autonomous Driving Campus*. Retrieved 01.10.2020 from https://www.youtube.com/watch?v=D_0sbTUZwQA

NIO. (2021). *NIO Autonomous Driving (NAD)*. Retrieved 25 Oct 2021 from https://www.nio.com/nad
Nuro. (2021). *Less Driving. More Thriving.* Retrieved 18 May 2021 from https://www.nuro.ai/
O'Kane, S. (2018a). *Former Google self-driving wiz will help Volkswagen and Hyundai build fully autonomous cars*. Retrieved 16 Oct 2021 from https://www.theverge.com/2018/1/4/16846526/aurora-chris-urmson-volkswagen-hyundai-self-driving-cars
O'Kane, S. (2018b). *Toyota starts a new $2.8 billion company to develop self-driving software*. Retrieved 18 May 2021 from https://www.theverge.com/2018/3/2/17070828/toyota-research-institute-tri-ad-tokyo
O'Kane, S. (2020a). *Nio's future depends more on the Chinese government than ever*. Retrieved 25 Oct 2021 from https://www.theverge.com/2020/6/5/21274457/nio-q1-earnings-deliveries-chinese-government-investment-bailout
O'Kane, S. (2020b). *Zoox unveils a self-driving car that could become Amazon's first robotaxi*. Retrieved 26 May 2021 from https://www.theverge.com/2020/12/14/22173971/zoox-amazon-robotaxi-self-driving-autonomous-vehicle-ride-hailing
O'Kane, S. (2021a). *Apple reportedly wants to launch a self-driving EV in 2025 with a custom chip*. Retrieved 28 Nov 2021 from https://www.theverge.com/2021/11/18/22789615/apple-self-driving-car-project-titan-custom-processor-ev
O'Kane, S. (2021b). *Foxconn reveals three 'Foxtron'-branded electric vehicle prototypes*. Retrieved 5 Nov 2021 from https://www.theverge.com/2021/10/18/22732897/foxconn-electric-vehicles-foxtron-platform-evs
Ohnsman, A. (2017). *Mobileye Wants To Teach Your Robotic Car To Merge In Heavy Boston Traffic*. Retrieved 13 May 2021 from https://www.forbes.com/sites/alanohnsman/2017/01/13/mobileye-wants-to-teach-your-robotic-car-to-merge-in-heavy-boston-traffic/?sh=5fe0b3841b42
Ovans, A. (2015). *What Is Strategy, Again?* Retrieved 17 Nov 2021 from https://hbr.org/2015/05/what-is-strategy-again
Ovide, S. (2021). *The Big Deal in Amazon's Antitrust Case*. Retrieved 1 Dec 2021 from https://www.nytimes.com/2021/05/25/technology/amazon-antitrust-lawsuit.html
Pandaily. (2021). *Baidu's Apollo Robobus - The Future of Smart Transportation?* Retrieved 9 Nov 2021 from https://www.youtube.com/watch?v=wH1ZhKGEf0k
Pidun, U., Reeves, M., & Knust, N. (2021). *How Do You Manage a Business Ecosystem?* Retrieved 17 Nov 2021 from https://www.bcg.com/publications/2021/how-to-manage-business-ecosystem
Pidun, U., Reeves, M., & Schüssler, M. (2019). *Do You Need a Business Ecosystem?* Retrieved 25 Nov 2021 from https://www.bcg.com/publications/2019/do-you-need-business-ecosystem
Pidun, U., Reeves, M., & Schüssler, M. (2020). *Why Do Most Business Ecosystems Fail?* Retrieved 25 Nov 2021 from https://www.bcg.com/publications/2020/why-do-most-business-ecosystems-fail
Pluta, W. (2021). *VW testet autonomen Bulli in München*. Retrieved 26 May 2021 from https://www.golem.de/news/autonomes-fahren-vw-testet-autonomen-bulli-in-muenchen-2105-156459.html
Pony.ai. (2020). *Pony.ai Raises $400 Million from Toyota to Accelerate Autonomous Driving Development*. Retrieved 1 June 2021 from https://www.globenewswire.com/news-

release/2020/02/26/1990586/0/en/Pony-ai-Raises-400-Million-from-Toyota-to-Accelerate-Autonomous-Driving-Development.html
Pony.ai. (2021). *Autonomous Mobility Everywhere*. Retrieved 1 June 2021 from https://pony.ai/en/index.html
Porter, M. E. (1979). *How Competitive Forces Shape Strategy*. Retrieved 17 Nov 2021 from https://hbr.org/1979/03/how-competitive-forces-shape-strategy
Porter, M. E. (1986). *Competition in Global Industries*. Harvard Business School Press.
Powell, W. W. (1990). Neither Market Nor Hierarchy: Network Forms of Organization. *Research in Organization Behavior*, *12*, 295-336.
Ramey, J. (2021). *China's First Robotaxi Service Launches in Beijing ahead of the Olympics*. Retrieved 16 May 2021 from https://www.autoweek.com/news/technology/a36354137/beijing-olympics-robotaxi-china/
Randazzo, R. (2021). *Are you ready to ride in a car without a driver? Waymo vans going public in the East Valley*. Retrieved 30 April 2021 from https://eu.azcentral.com/story/money/business/consumers/2020/10/08/waymo-driverless-program-metro-phoenix-open-public/5913106002/
Renault Nissan Mitsubishi. (2019). *GROUPE RENAULT AND NISSAN SIGN EXCLUSIVE ALLIANCE DEAL WITH WAYMO TO EXPLORE DRIVERLESS MOBILITY SERVICES*. Retrieved 29 March 2021 from https://www.alliance-2022.com/news/groupe-renault-and-nissan-sign-exclusive-alliance-deal-with-waymo-to-explore-driverless-mobility-services/
Reuters. (2020a). *BMW, Mercedes put automated driving alliance on hold*. Retrieved 29 March 2021 from https://www.reuters.com/article/us-daimler-bmw-autonomous-idUSKBN23Q23Q
Reuters. (2020b). *China's autonomous vehicle company WeRide starts driverless testing*. Retrieved 30 May 2021 from https://www.reuters.com/article/us-china-autonomous-weride-idUSKBN24B03Q
Reuters. (2020c). *EXCLUSIVE China search giant Baidu considers making own electric vehicles -sources*. Retrieved 5 Nov 2021 from https://www.reuters.com/business/autos-transportation/exclusive-china-search-giant-baidu-considers-making-own-electric-vehicles-2020-12-15/
Reuters. (2021a). *Autonomous driving startup Momenta raises $500 million from SAIC, Toyota, others*. https://www.reuters.com/article/us-momenta-autonomous-fundraising-idUSKBN2BB08W
Reuters. (2021b). *China's Didi raises $300 million for autonomous driving unit*. Retrieved 1 June 2021 from https://www.reuters.com/article/us-didi-chuxing-autonomous-idUSKBN29X0YO
Reuters. (2021c). *VW plans to challenge Google with own AV software*. Retrieved 21 March 2021 from https://europe.autonews.com/automakers/vw-plans-challenge-google-own-av-software
Roberts, A., & McLain, S. (2018). *Honda to Invest $2.75 Billion in GM's Self-Driving Car Unit*. Retrieved 19 May 2021 from https://www.wsj.com/articles/honda-to-invest-in-gms-self-driving-car-unit-gm-cruise-1538569503
SAE International. (2019). *SAE Standards News: J3016 automated-driving graphic update*. SAE International. Retrieved August 17, 2020 from https://www.sae.org/news/2019/01/sae-updates-j3016-automated-driving-graphic
Said, C. (2020). *Cruise deploys true robot cars in S.F. - no backup drivers behind the wheel*. Retrieved 23 March 2021 from https://www.sfchronicle.com/business/article/Cruise-deploys-true-robot-cars-in-S-F-no-15788555.php

Schramm, W. (1971). Notes on case studies of instructional media projects. *Working paper for the Academy for Educational Development, Washington, DC.*
Shapiro, D. (2020). *Mercedes-Benz, NVIDIA Partner to Build the World's Most Advanced, Software-Defined Vehicles*. Retrieved 22 March 2021 from https://blogs.nvidia.com/blog/2020/06/23/mercedes-benz-nvidia-software-defined-vehicles/
Shu, C. (2019). *Didi Chuxing's autonomous driving unit is now an independent company*. Retrieved 4 Dec 2021 from https://techcrunch.com/2019/08/04/didi-chuxings-autonomous-driving-unit-is-now-an-indepedent-company/
Silver, D. (2021). *Baidu Launches Self-Driving Cars, Shuttles, Buses, Vending And Even Police Robots*. Retrieved 29 May 2021 from https://www.forbes.com/sites/davidsilver/2021/02/12/baidu-launches-self-driving-cars-shuttles-buses-vending-and-even-police-robots/?sh=2e6cf3cd28c7
Statista. (2021). *Number of Tesla vehicles delivered worldwide from 1st quarter 2016 to 3rd quarter 2021*. Retrieved 25 October 2021 from https://www.statista.com/statistics/502208/tesla-quarterly-vehicle-deliveries/
Statt, N. (2017). *Ford is giving Google and Uber veterans $1 billion to build a self-driving car brain*. Retrieved 16 Oct 2021 from https://www.theverge.com/2017/2/10/14579126/ford-argo-ai-one-billion-investment-self-driving-cars
Stone, T. (2021). *China's Baidu Apollo get permit to test AVs without an in-car safety driver in California*. Retrieved 9 April 2021 from https://www.traffictechnologytoday.com/news/autonomous-vehicles/chinas-baidu-apollo-gets-california-permit-to-test-avs-without-a-safety-driver.html
Sugiura, E. (2021). *Honda launches world's first level 3 self-driving car*. https://asia.nikkei.com/Business/Automobiles/Honda-launches-world-s-first-level-3-self-driving-car
Sun, N. (2021). *China guides its self-driving startups into the fast lane*. Nikkei Asia. Retrieved March 14, 2021 from https://asia.nikkei.com/Business/Business-Spotlight/China-guides-its-self-driving-startups-into-the-fast-lane
Szymkowski, S. (2021). *GM and Cruise lend a hand to Honda's self-driving mobility service*. Retrieved 19 May 2021 from https://www.cnet.com/roadshow/news/honda-gm-cruise-self-driving-car-test-japan/
Taylor, E., Shirouzu, N., & White, J. (2020). *How Tesla defined a new era for the global auto industry*. Retrieved 4 June 2021 from https://www.reuters.com/article/us-autos-tesla-newera-insight/how-tesla-defined-a-new-era-for-the-global-auto-industry-idUSKCN24N0GB
Tidd, J., & Bessant, J. (2018). *Managing Innovation: Integrating Technological, Market and Organizational Change* (Sixth Edition ed.). Wiley.
Topgear Autoguide. (2020). *Car Operating Systems From Tesla, Google, Daimler, BMW Or VW*. Retrieved 3 Jan 2022 from https://topgear-autoguide.com/category/traffic/car-operating-systems-from-tesla-google-daimler-bmw-or-vw1607935498
TopSpeed. (2019). *Tesla Autonomy Day 2019 - Full Self-Driving Autopilot - Complete Investor Conference Event*. TopSpeed. Retrieved August 17, 2020 from https://www.youtube.com/watch?v=-b041NXGPZ8
Toyota. (2018). *Toyota Research Institute-Advanced Development (TRI-AD) Established in Tokyo To Provide Fully-Integrated, Production-Quality Software For Automated Driving*. Retrieved 18 May 2021 from https://global.toyota/en/newsroom/corporate/21315381.html

UNECE. (2020). *UN Regulation on Automated Lane Keeping Systems is milestone for safe introduction of automated vehicles in traffic*. Retrieved 27 March 2021 from https://unece.org/transport/press/un-regulation-automated-lane-keeping-systems-milestone-safe-introduction-automated

Vijayenthiran, V. (2021). *Foxconn launches Foxtron EV brand with trio of vehicles including 750-hp sedan*. Retrieved 5 Nov 2021 from https://www.motorauthority.com/news/1133893_foxconn-launches-foxtron-ev-brand-with-trio-of-vehicles-including-750-hp-sedan

Volkswagen. (2018). *The race toward autonomous driving - In an interview with Herbert Diess*. Retrieved 22 March 2021 from https://www.volkswagenag.com/en/news/stories/2018/11/the-race-toward-autonomous-driving.html

Volkswagen. (2019a). *The Car.Software organization*. Retrieved 25 May 2021 from https://www.volkswagen-newsroom.com/en/images/detail/the-car-software-organization-31910

Volkswagen. (2019b). *Ford und Volkswagen weiten weltweite Kooperation auf autonomes Fahren und Elektrifizierung aus*. Retrieved 26 Nov 2021 from https://www.volkswagen-newsroom.com/de/pressemitteilungen/ford-und-volkswagen-weiten-weltweite-kooperation-auf-autonomes-fahren-und-elektrifizierung-aus-5188

Volkswagen. (2019c). *Volkswagen strengthens new software organization*. Retrieved 13 May 2021 from https://www.volkswagenag.com/en/news/2019/11/volkswagen-strengthens-new-software-organization.html#

Volkswagen. (2020). *Markus Duesmann takes charge of Car.Software organization at the Volkswagen Group*. Retrieved 21 March 2021 from https://www.volkswagenag.com/en/news/2020/07/Car_Software_organization.html

Volkswagen Group. (2021). *Annual Report 2020*. Retrieved 22 March 2021 from https://www.volkswagenag.com/presence/investorrelation/publications/annual-reports/2021/volkswagen/Y_2020_e.pdf

Wagner, P. D. G. (2019). *Produkthaftung für autonome Systeme*. https://www.rewi.hu-berlin.de/de/lf/oe/rdt/pub/working-paper-no-3

Wayland, M. (2017). *GM lets its autonomous unit be autonomous*. Retrieved 21 March 2021 from https://www.autonews.com/article/20170619/MOBILITY/170619761/gm-lets-its-autonomous-unit-be-autonomous

Wayland, M. (2020a). *Fiat Chrysler and Waymo sign exclusive deal on self-driving commercial vehicles*. Retrieved 29 March 2021 from https://www.cnbc.com/2020/07/22/fiat-chrysler-and-waymo-sign-deal-on-self-driving-commercial-vehicles.html

Wayland, M. (2020b). *GM's self-driving unit Cruise to cut 8% of staff*. Retrieved 20 Oct 2021 from https://www.cnbc.com/2020/05/14/gms-self-driving-unit-crusie-to-cut-8percent-of-staff.html

Wayland, M. (2021a). *General Motors-backed Cruise is set to expand self-driving operations to Dubai in 2023*. Retrieved 20 Oct 2021 from https://www.cnbc.com/2021/04/12/gm-backed-cruise-to-expand-self-driving-operations-to-dubai-in-2023.html

Wayland, M. (2021b). *Microsoft is investing and partnering with GM's Cruise on self-driving cars*. Retrieved 29 March 2021 from https://www.cnbc.com/2021/01/19/microsoft-invests-partners-with-gms-cruise-on-self-driving-cars.html

Waymo. (2020a). *Waymo Driver*. https://waymo.com/tech/

Waymo. (2020b). *We're building the World's Most Experienced Driver*. Retrieved 16 May 2021 from https://waymo.com/
Waymo. (2021a). *Download the Waymo app*. Retrieved 30. April 2021 from https://waymo.com/apply/
Waymo. (2021b). *Waymo Driver*. Retrieved 29 April 2021 from https://waymo.com/waymo-driver/
WeRide. (2021a). *Transform Mobility with Autonomous Driving*. Retrieved 30 May 2021 from https://www.weride.ai/en/
WeRide. (2021b). *WeRide Robovan, China's first Level 4 self driving cargo van*. Retrieved 16 Oct 2021 from https://www.youtube.com/watch?v=HLFAkGWf7wU
WeRide. (2021c). *WeRide Robovan, China's first Level 4 self driving cargo van*. Retrieved 9 Nov 2021 from https://www.youtube.com/watch?v=HLFAkGWf7wU
WeRide.ai. (2021). *WeRide receives California permit to test driverless vehicles and releases 2-hour non-stop driverless test video with no intervention*. Retrieved 4 June 2021 from https://werideai.medium.com/weride-receives-california-permit-to-test-driverless-vehicles-and-releases-2-hour-non-stop-c6898375b355
Wiggers, K. (2019). *Baidu releases Apollo 5.0 with upgrades for 'complex' road scenarios*. Retrieved 29 May 2021 from https://venturebeat.com/2019/07/01/baidu-releases-apollo-5-0-with-upgrades-for-complex-road-scenarios/
Wiggers, K. (2020). *Waymo's autonomous cars have driven 20 million miles on public roads*. Retrieved 1 June 2021 from https://venturebeat.com/2020/01/06/waymos-autonomous-cars-have-driven-20-million-miles-on-public-roads/
Wiki - AutoX. (2020). Retrieved 2 June 2021 from https://golden.com/wiki/AutoX_(company)-99996BW
Wikipedia - Argo AI. (2021). Retrieved 22 March 2021 from https://en.wikipedia.org/wiki/Argo_AI
Wikipedia - Case study. (2021). Retrieved 16 May 2021 from https://en.wikipedia.org/wiki/Case_study
Wikipedia - Chris Urmson. (2021). Retrieved 18 May 2021 from https://en.wikipedia.org/wiki/Chris_Urmson
Wikipedia - Cruise (autonomous vehicle). (2020). Retrieved 17 June, 2020 from https://en.wikipedia.org/wiki/Cruise_(autonomous_vehicle)
Wikipedia - DiDi. (2021). Retrieved 13 May 2021 from https://en.wikipedia.org/wiki/DiDi
Wikipedia - Here Technologies. (2021). Retrieved 30. April 2021 from https://en.wikipedia.org/wiki/Here_Technologies
Wikipedia - LTE. (2022). Retrieved 5 Jan 2022 from https://en.wikipedia.org/wiki/LTE_(telecommunication)
Wikipedia - Mobileye. (2021). Retrieved 28 March 2021 from https://en.wikipedia.org/wiki/Mobileye
Wikipedia - Momenta. (2021). Retrieved 30. April 2021 from https://en.wikipedia.org/wiki/Momenta
Wikipedia - Nuro. (2021). Retrieved 15 May 2021 from https://en.wikipedia.org/wiki/Nuro
Wikipedia - Pony.ai. (2021). Retrieved 1 June 2021 from https://en.wikipedia.org/wiki/Pony.ai
Wikipedia - Self-driving car. (2021). Retrieved 29 March 2021 from https://en.wikipedia.org/wiki/Self-driving_car
Wikipedia - Tesla Autopilot. (2021). Retrieved 29 March 2021 from https://en.wikipedia.org/wiki/Tesla_Autopilot
Wikipedia - Tesla Model S. (2021). Retrieved 21 March 2021 from https://en.wikipedia.org/wiki/Tesla_Model_S

Wikipedia - Tesla, Inc. (2021). Retrieved 22 March 2021 from https://en.wikipedia.org/wiki/Tesla,_Inc.
Wikipedia - Triangulation. (2021). Retrieved 7 Dec 2021 from https://en.wikipedia.org/wiki/Triangulation_(social_science)
Wikipedia - Waymo. (2021). Retrieved 19 May 2021 from https://en.wikipedia.org/wiki/Waymo
Wikipedia - Zoox (company). (2021). Retrieved 13 May 2021 from https://en.wikipedia.org/wiki/Zoox_(company)
Wilkes, W. (2021). *Tesla's Autopilot Won't Achieve Full Autonomy, Waymo CEO Says*. https://www.bloomberg.com/news/articles/2021-01-22/tesla-s-autopilot-won-t-achieve-full-autonomy-waymo-ceo-says
woven planet. (2020). *Toyota Research Institute - Advanced Development, Inc. announces it will expand and improve its operations by forming Woven Planet Holdings and two new operating companies, Woven Core and Woven Alpha*. Retrieved 5 Nov 2021 from https://www.woven-planet.global/en/news-release/20200728/KbVAuy5jsKGMvBa9Hjs2i
Yin, R. K. (2017). *Case Study Research and Applications: Design and Methods* (6th ed.). SAGE Publications.
Ziegler, C. (2016). *GM aims to speed up self-driving car development by buying Cruise Automation*. Retrieved 20 Oct 2021 from https://www.theverge.com/2016/3/11/11195808/gm-cruise-automation-self-driving-acquisition
Zoox. (2021). *The future is for riders*. Retrieved 13 May 2021 from https://zoox.com/

Appendix A Cooperations Autonomous Driving SAE Level 4

List of Cooperations in the field of Autonomous Driving mostly related to Autonomous Driving SAE Level 4.

A.1 Waymo (Renault-Nissan-Mitsubishi, Jaguar Land Rover, Stellantis)

Waymo is building the "World's Most Experienced Driver" (Waymo, 2020b). An extensive history about Waymo, which started as Google's Self-Driving Car Project in 2009 can be found on Wikipedia (*Wikipedia - Waymo*, 2021). They have a commercial self-driving car service called "Waymo One" in the Phoenix metropolitan area (end of November 2019 it was the first service worldwide operating autonomous vehicles without a safety driver in the car). They are probably the leader in accumulated miles[66] and have the least disengagements per miles driven in California (see Table 4). It is probably not the goal of Google to roll out the service all over the world, but they want to partner with automakers and license their technology to them. Currently, there are the following partnerships/cooperations:

- Renault-Nissan has an exclusive alliance deal to explore driverless mobility services in France and Japan (Hawkins, 2019) (Renault Nissan Mitsubishi, 2019)
- Fiat Chrysler has an autonomous driving technology partnership (Fiat Chrysler Automobiles, 2020)
- Volvo will use Waymo's self-driving technology to power a fleet of electric robotaxis (Hawkins, 2020c)
- Waymo and Daimler are teaming up to develop a fully driverless Freightliner truck (Hawkins, 2020d)

[66] They have millions of miles on public roads (and billions of miles in simulation) (Waymo, 2021b).

A.2 Cruise (GM, SoftBank, Honda, Microsoft)

Cruise is one of the companies / ecosystems we have a look at in this work.

For a description of GM (Cruise) see section 5.2.

Sources: (Cruise, 2021) (*Wikipedia - Cruise (autonomous vehicle)*, 2020)

A.3 AutoX (Alibaba, Dongfeng Motor, SAIC Motor, Stellantis)

AutoX is a startup backed by Alibaba, MediaTek and Shanghai Motors and is the first autonomous driving company in China removing safety drivers from robotaxis in downtown Shenzhen, China (Liao, 2020a).

AutoX was the first Chinese company that held a driverless test permit in the state of California (Korosec, 2020a). In January 2020, it was announced that Fiat Chrysler and AutoX would team up on a robotaxi for China (Korosec, 2020b).

According to the following article, AutoX is backed by Chinese state-owned automakers Dongfeng Motor and SAIC Motor (Liao, 2021c).

Sources: (AutoX, 2021) (*Crunchbase - AutoX*, 2021) (*Wiki - AutoX*, 2020)

A.4 Pony.ai (Toyota, Sequoia Capital)

Toyota invested USD 400 million in the Chinese self-driving startup Pony.ai in February 2020 (Pony.ai, 2020). Pony.ai is the eighth company in the state of California to receive a driverless test permit (Korosec, 2021b). According to the article Pony.ai has cooperations with Bosch, Hyundai and Toyota. It’s robotaxis should be ready for customers in 2023 (Lyons, 2021a).

Sources: (Pony.ai, 2021) (*Crunchbase - Pony.ai*, 2021) (*Wikipedia - Pony.ai*, 2021)

A.5 Argo AI (Ford, Volkswagen)

Ford/Volkswagen (Argo AI) is one of the ecosystems we have a look at in this work (we mostly focus on Volkswagen).

For a description of Argo AI see section 5.1.

Source: (Argo AI, 2021) (*Wikipedia - Argo AI*, 2021)

A.6 WeRide (Renault-Nissan-Mitsubishi, SenseTime, IDG)

WeRide also received a license to test driverless vehicles in California (WeRide.ai, 2021) (DMV, 2021). In 2021, they revealed the WeRide Robovan, China's first Level 4 self-driving cargo van (WeRide, 2021b).

WeRide, a Chinese autonomous vehicle startup backed by Renault-Nissan-Mitsubishi, was the first company to start fully driverless vehicle testing in Guangzhou, China (Reuters, 2020b). WeRide raised USD 200 million in a Series B round end of 2020 (Liao, 2020b), and another USD 300 million in January 2021 (Kharpal, 2021).

Sources: (WeRide, 2021a) (*Crunchbase - WeRide*, 2021) (*LinkedIn - WeRide.ai*, 2021)

A.7 DiDi Chuxing (SoftBank, IDG)

Didi Chuxing is the Uber of China ("it has over 550 million users and tens of millions of drivers"). The company was founded by Wei Cheng (CEO) and Bo Zhang (CTO) in 2012 and has its headquarter in Beijing. In 2016, Didi acquired Uber's China division. In 2019, the company spun off its autonomous driving unit. The last investment round in Didi's autonomous driving division was led by SoftBank. The Chinese-owned Swedish carmaker Volvo provides cars to Didi for its self-driving test fleet. "[The] XC90 SUVs [are] equipped with backup steering and braking systems." Already in 2020, Volvo robotaxis were rolling out in suburban Shanghai as part of a pilot program (currently, there is still a human driver at the wheel to take over in unexpected situations). The company plans "to gradually roll out its on-demand autonomous service over a larger area in Jiading, [which is] Shanghai's main autonomous driving zone". They have dispatched over 100 self-driving taxis in several places around the globe, including California[67].

Sources: (*Wikipedia - DiDi*, 2021) (*Crunchbase - Didi*, 2021) (Horwitz, 2016) (CNBC, 2021) (Green Car Congress, 2020) (Shu, 2019) (Reuters, 2021b)

A.8 Nuro

Nuro is set to be California's first driverless delivery service (BBC, 2020) (Nuro, 2021). The company was founded in 2016 by engineers of Google's self driving car project Waymo and has its headquarters in Mountain View, California (*Wikipedia - Nuro*, 2021). It has more than 800 employees and received money (in 2019) from the SoftBank Group and the C-Series funding round (in 2020) was led by T. Rowe Price. A video of the delivery vehicle can be found at (DPCcars, 2021).

A.9 Zoox (bought by Amazon)

After Amazon invested in Aurora in 2019 (Davies, 2019), they bought the self-driving company Zoox in 2020, most probably with the interest to automate delivery services (Elon Musk reacted/responded with a tweet that Jeff Bezos is a "Copy Cat [icon]" (Boyle, 2020)).

Similarly to GM Cruise's Origin shuttle and Volkswagen's ID Buzz vans (equipped with hardware and software developed by Argo AI), Zoox unveiled a self-driving car in December 2020 that could become Amazon's first robotaxi (O'Kane, 2020b).

Sources: (Zoox, 2021) (*Wikipedia - Zoox (company)*, 2021)

[67] There is an interesting quote of Yang Ming, an autonomous vehicle expert at Shanghai Jiao Tong University: "The goal of robotaxis is to eliminate the need for human drivers, which is how we can cut costs and make profits. But currently, no company can do this." According to a report from China EV100 the cost of an unmanned taxi is currently USD 100'000 more than a regular taxi (sensors, etc.) (Green Car Congress, 2020).

A.10 Aurora (Hyundai, Byton, Fiat Chrysler, Toyota, Volvo Trucks)

Aurora was co-founded by Chris Urmson, who led Google's Self-Driving Car Project, in 2017 and has offices in Palo Alto, Pittsburgh and San Francisco. As of December 2019, the company had almost 400 employees (*Wikipedia - Chris Urmson*, 2021) (Aurora, 2021). They build the 'Aurora Driver' - a self-driving stack - that should power self-driving passenger or commercial vehicles.

Aurora had a successful Series B financing round in 2019 (Amazon, Sequoia Capital) and partnerships with Fiat Chrysler, Hyundai/Kia Motors and Volkswagen (Loizos, 2019). The partnership with Volkswagen ended in 2019 (Korosec, 2019b).

In 2020, Aurora acquired Uber's Advanced Technologies Group (Korosec, 2020d) "which spun out from Uber in 2019 after the unit raised USD 1 billion in funding from Toyota, Denso and SoftBank's Vision Fund" (Korosec, 2021a). Toyota, Denso and Aurora will now develop a fleet of robotaxis based on the Sienna minivans (Hawkins, 2021c)[68].

Aurora and Volvo Trucks signed a partnership to develop fully autonomous trucks for North America in 2021 (Hawkins, 2021d). It is not clear, whether Hyundai, Fiat Chrysler and even Toyota are still a partner since it seems Aurora will shift to develop a self-driving semi-truck (*Wikipedia - Chris Urmson*, 2021) citing (Metz & Conger, 2020).

A.11 Lyft (sold division to Toyota)

Lyft, like Uber, sold its autonomous driving division to Toyota in 2021 (Hawkins, 2021a).

[68] Shortly afterwards Toyota bought Lyft's autonomous car division for USD 550 million in 2021 (Hawkins, 2021a). Toyota sold the stake in Uber's Advanced Technologies Group (Bellon & Yamamitsu, 2021).

A.12 Momenta (Tencent, Daimler)

Toyota, Bosch and SAIC Motor invested in Momenta in a USD 500 million investment round. Financial investors were the Singaporean sovereign fund Temasek and Alibaba founder Jack Ma's Yungfeng Capital. Further investors included Xiaomi founder Lei Jun's Shunwei Capital, Tencent, Cathay Capital and Mercedes-Benz. According to Liao "It's rare to see Tencent and Alibaba (or their affiliates) co-invest." (Liao, 2021b).

Momenta is the first autonomous driving unicorn of China and has its own headquarter in Suzhou, China (Liao, 2019). The startup is backed by Baidu rival Tencent and has announced plans for robotaxi tests in Beijing in 2020 (Green Car Congress, 2020).

Sources: (Momenta, 2021)[69] (Crunchbase, 2021) (*Wikipedia - Momenta*, 2021)

A.13 Baidu Apollo (Baidu, FAW Group, Weltmeister, Ford, Geely)

Apollo is an open-source project started by Baidu in 2017 - according to other sources Baidu has been investing in autonomous driving since 2013. Baidu released Apollo 5.0 and according to an article in 2020 Weltmeister should be the first in China to incorporate Apollo's L4 autonomous valet parking technology in 2021.

"Baidu Apollo recently announced the completion of more than 10 million kilometers of road testing for autonomous driving" (Green Car Congress, 2021). According to its own homepage Apollo has 210 global partners, including BMW, VW, Toyota, Hyundai, Honda, PSA, Daimler, Ford, Volvo (OEMs) and many others (Tier 1).

Baidu has 500 self-driving cars mostly in China and has a license to test empty self-driving cars in Beijing, China (Lee & Vengattil, 2021). Baidu also got a permit in 2021 to test empty self-driving cars (without a driver behind the wheel) as the sixth company in the state of California (Lee & Vengattil, 2021).

[69] The company homepage is only in Chinese.

Baidu also tests self-driving buses with local government support (the test track is about 10 kilometers and the base is operational for more than 2 years). According to (Sun, 2021) Apollo "holds most Chinese permits for operating robotaxis".

Sources: (Baidu Inc., 2020) (Apollo, 2021b) (Apollo, 2021a) (Silver, 2021) (Baidu Inc., 2021) (Stone, 2021) (*GitHub - Apollo*, 2021) (Wiggers, 2019) (Global Times, 2021)

A.14 Mobileye (Partners: Volkswagen, BMW, Nissan, Sixt)

Mobileye is an Israelian company which was bought by Intel in 2017. Its CEO is Amnon Shashua and in 2017 Mobileye, BMW and Intel announced that they were developing a test fleet of autonomous vehicles. Mobileye builds its own sensors (hardware and software) that should power autonomous driving of the future. Currently, they target 2025 for Level 4 autonomy.

In 2017, Audi wanted to introduce its "Traffic Jam Pilot" (a Level 3 System) which was developed together with Mobileye. At that time Alejandro Vukotich was Vice President R&D Automated Driving and Driver Assistance Systems at Audi in Ingolstadt. He later was Senior Vice President Fully Automated Driving and Driver Assistance at BMW. Currently, he is Vice President, Automotive Product Development at Qualcomm. Audi abandoned its plan in 2020 and the promised functionality of the car never came to the market.

The partners / customers of Mobileye are not fully known. In 2017, Audi was a partner according to Prof. Amnon Shashua (CEO of Mobileye) and there is a Joint Venture for the deployment with Volkswagen in Israel, other customers are in France, South Korea and Japan. However, we could not verify whether the world's first level 3 self-driving car of Honda in Japan is powered by Mobileye's system (Sugiura, 2021). Mobileye collects data for its REM[70] Maps and known partners are Volkswagen, Nissan and BMW (starting 2018). Those are High-

[70] Road Experience Management to facilitate autonomous driving anywhere in the world (Mobileye, 2021c).

Definition Maps - not Video - where 10 kByte of data per km are transmitted. According to Mobileye's own statement 8 million km of road are sent every day and 6 car makers are involved (by 2024 they should have 1 billion km of road sent daily).

Whether the strategy of the Israelian company Mobileye will be successful[71] we will only see in the future. In 2021, it was announced that Mobileye together with Sixt would introduce a ride-hailing service in Munich and Tel-Aviv by 2022 (at the IAA in Munich) (ADAC, 2021).

Sources: (*Wikipedia - Mobileye*, 2021) (BBC, 2017) YouTube Video in the following Article (Ohnsman, 2017) (Intel Newsroom, 2021a) (Intel Newsroom, 2021b) (*LinkedIn - Alejandro Vukotich*, 2021) (Fasse & Hubik, 2020)

A.15 Trucks

Volvo Trucks is partnering with Aurora (Hawkins, 2021d) and Daimler Trucks has an own 'Autonomous Technology Group' (Daimler, 2021a) and is at the same time also partnering with Waymo on the Freightliner Trucks (Hawkins, 2020d). The goal of Waymo and Daimler is to deploy "SAE L4 trucks" (Daimler, 2020c). For a definition of the SAE Levels see Appendix B.

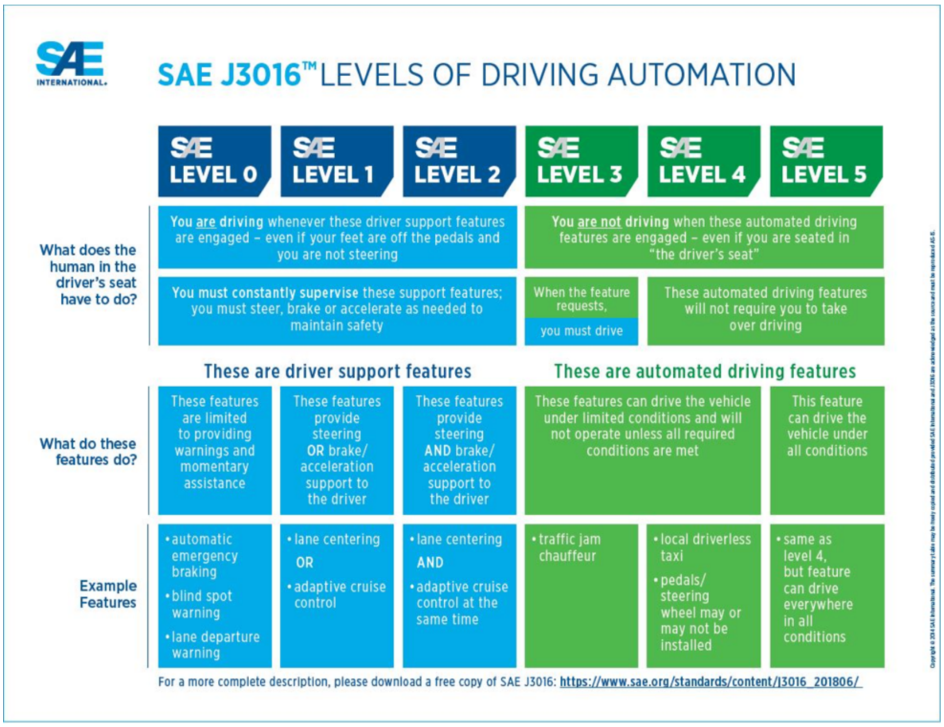
[71] Mobileye is quite aggressive with its targets (they want to remove the steering wheel by 2025). Frank Weber, Head of Development at BMW, responds to that statement that the steering wheel will stay for a long time to come (and certain providers already promised autonomous driving for 2015 and in 2019 it was still not the case) (Fasse & Hubik, 2020).

Appendix B Levels of Driving Automation (SAE J3016)

SAE International, previously known as the Society of Automotive Engineers defines the levels of driving automation as follows in the SAE J3016 (see Figure 7).

Figure 7

Levels of Driving Automation (SAE J3016)



Source: (SAE International, 2019)

We refer to SAE Level 4 as "highly autonomous vehicles" and SAE Level 5 as "fully autonomous vehicles". SAE Level 2 requires permanent driver attention (and is the feature currently rolled out by Tesla, and approved by regulators). SAE Level 3 allows some autonomous driving, but the driver must be able to take over the driving - if requested - at any point in time[72]. Interesting is SAE Level 4, where autonomous driving is possible for example on highways (geofenced, restricted areas) and during this time the driver does not need to take control. SAE Level 5 does not require a driver anymore, the car is fully autonomous.

[72] The Germans call SAE Level 3 "highly automated driving" and SAE Level 4 and 5 "fully automated driving" (Daimler, 2020d).