CHALMERS
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The Future of Autonomous Cars

A Scenario Analysis of Emergence and Adoption

Master’s thesis in Management and Economics of Innovation

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CHALMERS UNIVERSITY OF TECHNOLOGY
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"The horse is here to stay, but the automobile is only a novelty – a fad,"

Stated by the president of the Michigan Savings Bank while advising Henry Ford's lawyer not to invest in Ford Motor Co. Something the lawyer did nonetheless which earned him the fortune of his life.

Acknowledgments

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I also owe a large appreciation to Berg Insight and in particular Johan Fagerberg who made this study possible through a combination of good advice, access to extensive amount of data as well as a beautiful office to work in with an excellent coffee machine. For anyone interested in reading a market research analysis version of this study I refer to the title *The Future of Autonomous Cars* available at Berg Insight.

Abstract

Despite the substantial evolution of exterior and interior appearance as well as technology performance in cars ever since the development of the model T, one thing has remained constant - cars have always had a driver. The concept of dislodging the driver from controlling the vehicle opens up for new potential applications as well as business models. In fact, the removal of the driver is arguably the most significant and transformative innovation ever faced by the automotive industry. This transition will impact not only the automotive industry but also entire societies in several ways.

Cars are severely under-utilized as they are standing still during the majority of their life-time. In addition, many people spend a significant time of their life in the driver seat of their car. To imagine that this time could be spent on something else, something more value adding, opens up for interesting ideas.

The benefits with autonomous cars are many and the questions about when they will come and how fast people will adopt them are therefore relevant. This study aims to answer both of these questions based on forecasting techniques. A crucial point in forecasting is the recognition that they most of the time turn out to be wrong. That is a natural consequence of the vast amount of random events that can occur - irregular events and pure chance is an integral part of our world. With that in mind, it is not farfetched to question the usefulness of forecasting. However, the alternative – to simply sit and wait for the future to happen – is even worse.

In order to account for the uncertainty in forecasting new technology this study is based on three different scenarios. This includes a base-line scenario following an extrapolation on the current development along with a pessimistic scenario and an optimistic scenario. These scenarios provide boundaries within which autonomous cars of various levels are highly likely to emerge and be adopted. This study finds that autonomous cars will emerge between 2018 and 2025 and reach an adoption rate of between 1 and 77 million annual sales in 2030.

Contents

1 Introduction

This chapter introduces the background to the study and the purpose along with the research questions. Some of the limitations of the study are discussed followed by a description of the layout of this report.

1.1 Background

The concept of autonomous cars is an area that has gained a lot of attention over the last couple of years. However, the idea of self-driving cars is not new; already in the 1960s General Motors envisioned a future with cars running automatically along designated highways with magnetic sensors able to guide the vehicle without the need of an attentive driver. Such an application has so far failed to materialize but today, several factors seem to point to that autonomous cars are on the verge to emerge within a few years. These cars will likely also be able to negotiate not only specially designed highways but most types of roads.

The hype around self-driving cars is tremendous and one of the most frequently asked questions today is when these cars will emerge on the global market and what impact they will have on the automotive industry. Some advocate that a few actors have already launched self-driving cars – which is to some extent true, but it depends on how the terms "self-driving" or "autonomous" are defined as we shall see.

There are several studies indicating the size of a potential future market for autonomous cars and different automakers or other actors continuously feed the media with estimation of dates for when autonomous cars will emerge. However, these estimates are often different among different actors and also ambiguous to their nature since what each actor define as autonomous is not always clear.

1.2 Purpose and research questions

This study aims to bring clarity to the future of autonomous cars by formally defining various levels of autonomy and through a scenario analysis forecast when these cars will emerge as well as by what rate they will be adopted by the global market. This narrows down to the following research questions:

1) When will autonomous cars emerge?

2) At what rate will autonomous cars be adopted by the global market?

1.3 Limitations

An aspect that complicates a forecast of autonomous cars is the fact that this technology will exist in a society and thus in relation to people as well as several other technologies. This study has attempted to deal with this complexity by taking a wide approach and looking at several different factors that might influence the emergence and adoption of autonomous cars. However, many aspects have had to been omitted. For instance, this study only focuses on the passenger car market, disregarding heavy trucks or other types of transportation. Furthermore, many actors that are active in the development of autonomous technology have been omitted; only the most active ones have been analyzed.

1.4 Layout of research study

The theoretical framework for this thesis revolves around the three intertwined areas of technology forecasting methods, factors that influence technology adoption and methods for scenario analysis. The analysis of the empirical data follows the scenario analysis method but in addition incorporates important aspects of the technology emergence and adoption areas.

The method chapter highlights the researcher's specifically chosen path in accordance to the methods described in the theoretical framework. The method chapter also clarifies the different contents of the study and what purpose each chapter fills.

2 Theoretical Framework

The theoretical framework for this study revolves around the topic of forecasting technology from three different angles. The first section focuses on different methods to forecast technological change. The second part deals with technology adoption and what factors influence the rate of adoption. Finally, the third part describes a method for using scenario analysis as a tool for forecasting.

2.1 Forecasting Technological Change

The major reason for making forecasts is according to Martino (1993) as a basis for decision making. It is easy to believe that a forecasts value can only be measured in terms of its precision in predicting future events. Martino (ibid) argues that this is wrong and that the major benefit with a forecast is the possibility to use it for decision making. Thus, the success of a forecast should not be measured by its precision but rather by the impact it has on decisions. Quinn (1967) further argues that technological forecasts are important as they paint a better picture of future opportunities and threats. According to Quinn it is unrealistic to demand absolute precision from a forecast. He argues that forecasting is useful as long as the operations of the organization are more successful with than without them.

Meredith and Mantel (1995) argue that forecasting technology is more useful when it comes to forecasting technological capabilities, attributes and parameters rather than how the technology actually works.

There are several methods for forecasting technological change. Meredith and Mantel (1995) broadly categorize the various methods into numeric and judgmental techniques. This chapter presents some of the more prominent techniques of both kinds.

2.1.1 Delphi

The Delphi method for forecasting relies on expert opinion. A disadvantage with the Delphi method is that it is affected by people's subjective beliefs. However, when it comes to new technology, there is often an apparent lack of historical data and Martino (1993) states that this implies that expert opinion is necessary. Moreover, Martino argues that for new technology which external forces are likely to have a larger impact on the innovation compared to the aspects that previously governed the initial development of the technology, expert opinion can be more important than historical data.

The Delphi procedure seeks to attain the advantages with a panel group while at the same time minimizing the related disadvantages, according to Martino (1993). According to Brown (1968), the Delphi procedure is performed in the following steps. First, each individual in a group of experts is asked (preferably through a questionnaire) to anonymously share their opinions and ratifications regarding a certain matter, such as a technology forecast. A facilitator then summarizes all the answers and shows the summary to each individual respondent. The respondents are then able to change their opinions through a new round of anonymous questions. This process can go on for as many iterations as wanted until the panel has reached a reasonably precise estimation. The idea is that the different opinions should guide the experts to converge towards a unanimous answer.

The anonymity among the respondents is key in the Delphi procedure since it reduces the impact of negative peer pressure or biases. Martino (1993) argues that it is easier for people to change their opinions based on others' arguments when they do not risk losing their faces publicly.

An advantage with the Delphi procedure is according to Martino (ibid) that it includes both the extreme points and the more central opinions and that the degree of disagreement can be determined statistically. However, according to Kelly et. al. (1975, pp. 126, 436-438) the procedure has some disadvantages including the fact that it requires a lot of work to gather all experts and furthermore assumes that collective judgment is stronger than individual judgment, which might not always be the case for new technology.

2.1.2 Forecasting by Analogy

Analyzing the future based on a comparable historical event is known as forecasting by analogy. According to Martino (1993) analogies are often used in everyday life and the basis for inductive inference (i.e. how people make general conclusions based on specific examples). Martino also points out that using analogies is a qualitative method and can never produce any numbers for the forecast. Analogies are regularly used in discussions about environmental issues and in particular in educational situations. For instance, the story of the people who once populated the Easter Island before going extinct as a result of their own short sighted decisions has been used as a comparison to today's global climate crisis. In research however, analogies can be used as more than frightening examples. Analogies are typically used to analyze how difficult a new project will be compared to a known project (with respect to the restraints at the time of the historical project).

By using a well-structured approach, Martino (ibid) argues that analogies can be used to forecast the future outcome of a specific technology better than relying on pure unstructured judgment about the new technology. By comparing a "model" historical situation to the current situation the outcome of the current situation could be forecasted. If the model situation is sufficiently similar to the current situation the forecast will be that the current situation will have a similar outcome as the model situation.

Using a historical event to forecast a future situation is thus dependent on a certain degree of similarity between the two situations. To ensure that the specific analogy is suitable, a way to compare different situations is therefore necessary. The comparison should arguably focus on the most important factors and identify how similar these factors are. With that said, identifying the most important factors and deciding how to measure similarity are certainly not elementary tasks. Martino (ibid) provides a framework for how to do this using a set of nine dimensions that historically have shown a strong connection to the advancements in technology by either favoring or resisting innovation. The nine dimensions are the following:

1. Technological
2. Economic
3. Managerial
4. Political
5. Social
6. Cultural
7. Intellectual
8. Religious-ethical
9. Ecological

Technology is in itself an important factor influencing technological change as no technology exists in its own vacuum. New inventions build on old ones (a car is the result of combining older inventions such as engines, gears and even the wheel itself. Moreover, different technologies can be used to solve the same problem. There might be alternative technologies that compete with the technology that will be forecasted. When comparing a new technology with an old one, competing technologies in both cases should also be compared to get evaluate if the analogy matches well with the technology to be forecast.

The **Economic** dimension is important as people's willingness to pay differ for different technologies. There are two types of costs that should be considered and compared with the analogy: the entire cost for developing and deploying the technology and the cost that the end customer will pay for it.

The **Managerial** dimension relates to how projects or technological change is managed. By how many people and what roles they have.

The **Political** dimension takes into account how different political ambitions, goals and power may influence the technological change. Some groups benefit from new technology and some suffer. Depending on the relative strengths of the groups on each side, the project may take different directions. Another aspect of the political dimension is the laws that apply where the technology is being developed and deployed.

The S**ocial** and **Cultural** dimensions regard for the people that are introduced to the new technology. The social dimension focuses on the people's institutions, traditions and customs while the cultural aspect is more related to values, attitudes and goals in the society.

The **Intellectual** dimension deals with the intellectual leaders of the people being introduced to the new technology. These can be decision makers for both public and private organizations as well as people representing media. Important for the analogy is whether the intellectual leaders are supportive or opposed the technology and whether they have a strong influence on the people.

The **Religious-Ethic** dimension is important since people usually judge things as right or wrong based on some standard set of beliefs. This dimension can be further divided into two factors: the actual set of beliefs that guide people's judgments and the institutions that formulate or otherwise influence these beliefs. Different religions may have different opinions on specific innovations.

Finally the **Ecological** dimension is important has nowadays become important as people today are more sensitive to the potential environmental impact a new technology might have.

Martino further stress that for a specific technology or project there might be other dimensions that are more important indicators of similarity than the nine listed above. Regardless, identifying the most important dimensions is necessary to find a relevant analogy. The next step is to identify the similarity between the technologies looking at these dimensions. Although it is possible to compare numbers from one technology to another (sales figures, developing costs etc.), there is no quantitative way to make a final judgment between the technologies and an analogous forecast will thus always be qualitative to its nature.

2.1.3 Trend Extrapolation and Growth Curves

Meredith and Mantel (1995) identify trend extrapolation as the major numeric method for forecasting technology. In general this method relies on the idea to use historical data for some parameter of the technology to predict the future outcome of the same parameter. Meredith and Mantel further divide trend extrapolation into four subcategories:

1. **Statistical curve fitting** is suitable to forecast the future functional capabilities of the technology such as speed, efficiency or a similar output parameter. The idea is to use historic data for a functional parameter and extrapolate future outcome through some mathematical function. The function is normally linear, logarithmic, Fourier or exponential.
2. **Limit Analysis** is simply a way of taking into consideration the fact that most functional parameters are, either theoretically or practically, bound by limits. Meredith and Mantel bring up the example of the lowest temperature achieved in a laboratory. That parameter is bound by the fact that there is an ultimately lowest temperature at 0 Kelvin. What Meredith and Mantel advocate is that when a technology approaches its limit, extrapolation based on historical data may not be reasonable as it is likely that this overestimate future capabilities.
3. **Trend Correlation** acknowledges that sometimes a technology is dependent on a specific preceding technology. This relationship can be used to extrapolate future performance. If the preceding technology develops in a certain direction it is likely that the new will follow a similar pattern. Meredith and Mantel take the development in speed at combat and transport aircrafts as an example. The speed in combat aircrafts have kept a linear progression over the last 100 years and maintained roughly the same relative advantage to transport aircraft speeds.
4. **Multivariate Trend Correlation** is basically an extension of trend correlation taking into account that some technologies are dependent on several precursor technologies. The result is that the new technology is dependent on both performance of preceding technologies as well as how they are combined.

Meredith and Mantel state that one of the advantages with trend extrapolation is that it permits an objective approach to forecasting. At the same time, they argue that this method has serious limitations. If the researcher makes a mistake in choosing the historical data it might completely disrupt the forecast. Furthermore, if some environmental aspect about the condition for the technology is about to change, the historical data might be irrelevant.

According to Martino (1993) the development in capability of a technology has historically shown a tendency to follow an S-shaped curve. Due to these curves resemblance to biological growth (for example human's growth in weight and height as a function of time) they have also become known as growth curves. Martino explains the S-shape of the growth curve by the fact that growth is usually slow in the beginning due to initial difficulties. Once these are overcome, the growth is much quicker. Then, when the technology approaches its maximum performance each increase in capacity becomes more difficult and the growth again slows down. Martino also describes that in some cases a new breakthrough might significantly increase the upper limit of the capacity. In such circumstances a new S-curve might result and the technology associated with that the new standard.

Martino (ibid) describes some different methods of extrapolating an S-curve based on initial data of the technology. Linear regression (minimizing the mean squared error between the data and the fitted curve) is the most common way of fitting data to a curve. Martino also states three assumptions that most hold for the extrapolation to be relevant:

1. *The upper limit to the growth curve must be known*

2. *The chosen growth curve to be fitted to the historical data is the correct one.*
3. *The historical data gives the coefficients of the chosen growth curve formula correctly*

2.1.4 Measures of Technology

Martino (1993) advocates that it is important to find suitable measures for an emerging technology. Since new technologies tend to be complex, the parameters to measure the technology should preferably be independent and focus on important aspects of the technology.

Martino (ibid) also argues that technical and functional parameters should be separated. Functional parameters measure the direct utility a user gets from the technology while technical parameters are integral factors that measure different attributes of the technology. Technical parameters can be altered by the designer to change the resulting functional parameters. For instance, the top acceleration of a sports car is a functional parameter (it has direct value to the user) while the volume of the cylinders is a technical parameter (it is relevant to the designer who wants to achieve a certain top acceleration value). Technical parameters are according to Martino more suitable as measures in R&D projects while functional parameters are often better as measures in marketing planning.

2.1.5 Correlation Methods

In situations where the functional capacity of a technology is difficult to forecast directly, Martino (1993) argues that it can be beneficial to look at some other correlating parameter that is easier to measure or forecast. Martino lists a few types of correlation factors that can be used but also advocates that these factors are not exhaustive and that each forecast calls for a unique analysis of what correlating factors can be used.

Most technologies do not exist in a vacuum but rather follows on other technologies. In some cases the development of a technology can follow the development of a direct precursor. In such circumstanced the development of the second technology can be forecasted by measuring the development of the first technology and adding some time for the lag in between. The idea is that a functional parameter measuring the technologies capacities will have a similar development for both technologies (for instance, follow a growth curve or a linear trend). A typical case for this is how high performing technology is first applied in experimental vehicles before being applied in racing cars or luxury vehicles and then gaining widespread use in mass-market vehicles. According to Martino, the difficult part is often to estimate the lag time. Having some data for the second use case makes this task easier but it is no guarantee that the lag will be constant as there might be ways to adopt the technology in the preceding use case faster in the following use case.

Another correlation method highlighted by Martino is the economic situation. The advancement of some technologies can sometimes be directly derived from a country’s economic development. Especially technologies related to communication or transportation tend to correlate with the wealth of countries according to Martino. The relation between telephones per capita and GNP per capita is on example of this. However, an inherent problem with this forecasting technique is that the forecaster then needs to estimate the economic development instead of the technology. This might prove to be just as big a challenge as forecasting the original technology development.

Another way to forecast technology development is to look at the number of patents being filed for the technology. However, although increased patent activity can indicate a technology shift, Martino argues that the lead time (from a patent is filed until the technology reaches the market) is often quite short and thus it is difficult to forecast over a longer time.

Yet another typical correlating factor for a technology's advancement is according to Martino the cumulative production of the technology. The more that is produced, the higher capacity the technology achieves. This method has a similar problem as the technique that relies on economic progress (mentioned above). To forecast technological development the forecaster needs first to estimate the progress of production.

2.1.6 Causal Models

Martino (1993) discuss causal models as a method of technology forecasting. Forecasting techniques that involve extrapolation inherently have some flaws. In particular, in situations where the development of a specific technology is bound to take a new direction due to some known circumstance, the historical data is unlikely to give a good indication of the future. The reason for this is that these techniques do not take into account what causal factors are affecting the technology. Rather, they simply assume that whatever is causing the change will continue in a similar manner.

Causal models rely on an analysis of what factors are causing the technology to develop. These factors are then fitted to a mathematical model. If the factors used are either technological or economic or both, the model can be what Martino calls a "closed-form analytical model". These models express the cause-effect relations through an equation or a set of equations. If social factors (such as politics or cultures for instance) are added it usually calls for a simulation model to deal with the complexity that follows.

A disadvantage with causal models is according to Martino that the causality does not occur as presumed in the modeling. Even if past data indicates causality between two factors, the future behavior might not show the same causality. On the other hand, an advantage with causal models is that the analysis of different factors gives a hint of what different policies could result in. To look at causal models could thus generate insight outside the value of the forecast itself.

2.1.7 Normative Methods

According to Porter et al. (2003) future analysis of technology can happen in two ways, either through exploratory methods or through normative methods. Exploratory methods rely on extrapolation of currently available technological capabilities. Normative methods on the other hand start by identifying perceived future needs before analyzing what technological development is necessary to achieve this. Porter et al. (ibid) also states that methods can be both exploratory and normative depending on how the technique is set-up (the Delphi method is an example of this).

Martino (1993) describes how relevance trees, morphological models and mission flow diagrams can be used to break down a forecast problem in a normative way. These methods all are based on identifying the future state and then (through somewhat different approaches) analyzing and listing what steps are necessary to get there. These steps can often produce different alternatives. According to Martino, one of the risks with the normative approach is that the forecaster misses to account for some step which might significantly change the validity of the forecast. Martino also states that the major benefit with the normative approach lies in the structure it can provide to the forecast problem.

According to Quinn (1967), excess technological capacity is seldom the major driver of technological change. Rather, clearly perceived demand is the primary force behind technological development. If there is no need for a certain technology, it will not be utilized. This implies that an actor might be better off by first identifying future needs and then asses how to get there technology-wise (a normative approach) rather than simply developing technology in the hopes that a future utility will emerge (exploratory). Quinn (ibid) also advocates that if the anticipated demand is sufficiently high it will motivate humans to solve the technological problems to reach the required capabilities. Moreover, he argues that incumbent institutions may change if the perceived need for the new technology is strong enough. Porter et al. (ibid) argues that for making operational decisions (such as investing in a new technology or not), exploratory methods are not sufficient as the decision often requires more detailed information. On the other hand, when a certain desired future state is not readily apparent, an exploratory approach could provide some directions.

2.1.8 Environmental Monitoring

Apart from the more technical methods described above, Martino (1993) also emphasizes the need for environmental monitoring when forecasting technology. The idea is that no technology is developed without precursors or initial signs about the breakthrough about to happen. This means that a forecaster needs to pay good attention to what initiatives are going on in the field of the technology. Early signs should be mapped into possible patterns of change. To find this signs, the forecaster can look in various fields – Martino mentions the technological, economic, managerial, political, social, cultural, intellectual, religious-ethical and the ecological sector as possible environments to monitor for signs of a technology change.

2.2 Technology adoption

Technology adoption describes how consumers acquire a specific technology over time. This chapter aims to describe the scientific view on how technology is adopted over time as well as what impact the rate of adoption.

2.2.1 Diffusion of Innovations

How people and organizations attain innovations and in particular at what rate they do it are known as the diffusion of innovations, a subject heavily researched by Everett Rogers. Rogers (1995) points out four main elements that influence the diffusion of a new innovation:

- **The innovation itself** – its relative advantage compared to other alternatives, usability etc. will have an impact on the diffusion of the innovation.
- **Communication channels** – since diffusion takes place among people, some kind of communication channels between these people are necessary for the diffusion to occur.
- **Time** – Innovations are very rarely adopted immediately (in fact there is usually a rather strong resistance to change) and thus the passage of time is necessary for diffusion to occur.
- **Social System** – This factor deals with how potential individual adopters are influenced by other people and organizations in their surroundings (e.g. opinion leaders, mass media and governmental leaders).

The underlying reason why these four elements are most important stems from the fact that they together make up the actual parts of a diffusion process. An **innovation** is spread through **communication channels, over time** among people in a **social system**.

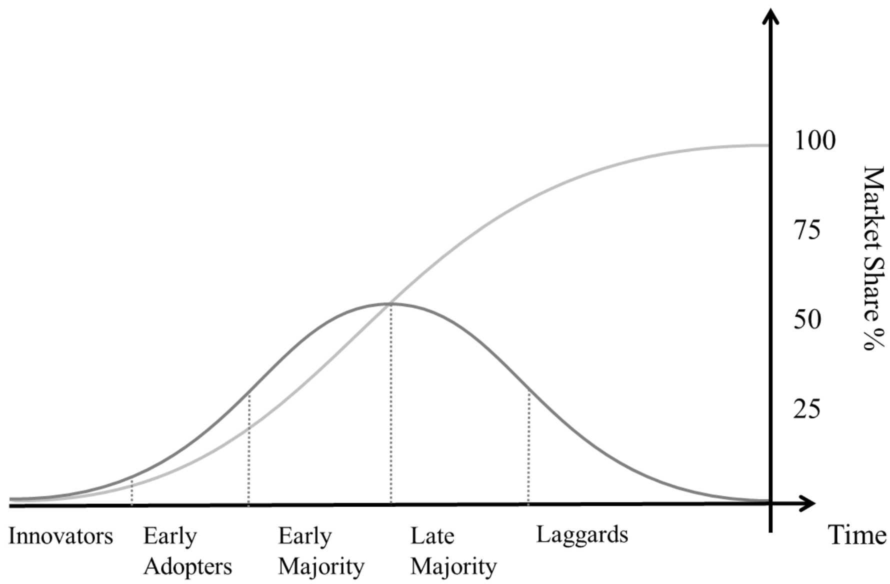
According to Martino (1993), all technology propagates through stages of innovation before achieving widespread use. The stages can be defined from the usefulness or practicability of the technology device. These stages can be divided into:

1. Scientific Findings
2. Laboratory Feasibility
3. Operating Prototype
4. Commercial Introduction or Operational Use
5. Widespread Adoption
6. Diffusion To Other Areas
7. Social and Economic Impact

Rogers (ibid) defines five categories of adopters based on their time of adoption and thereby their relative interest in new innovations:

- **Innovators** – Are characterized by risk taking individuals of high social status with strong financial capacity and close relationship to the scientific community.
- **Early Adopters** –Are similar to innovators with a high social status and financial power but are slightly more selective in choosing innovations to adopt. This group normally consists of the main opinion leaders for the following adopters.
- **Early Majority** – Is a group characterized by people with above average social status but these people are still slower than innovators and early adopters to react to the new innovations. They are heavily influenced by early adopters but hold no significant opinion leadership.
- **Late Majority –** Are skeptical to new innovations and only adopt after most others already have started to use the innovation. This group has below average social status and financial means and very low opinion leadership.
- **Laggards** – Are typically seen as traditionalists who are reluctant to change and show virtually none opinion leadership. These people are usually of the lowest social status and have the lowest financial power.

Figure 1. Innovation Adopters



As is observable in the picture, the adoption of technology follows a similar S-shaped pattern as the development of a technology's capability, discussed in chapter 2.1. Martino (1993) argues that the substitution from an old technology to a new can be forecast through the use of a growth curve. According to Martino, the Pearl and the Gompertz curves are most often used for this purpose. Martino also states that the upper limit to a substitution curve should be based on the total market share possible for the substitution of the new technology.

2.2.2 Disruptive Innovations

The term disruptive innovation was coined by Clayton M Christensen in his "The Innovators Dilemma" in 1997. According to Christensen (1997) a disruptive innovation is an innovation that is so radically different from existing solutions that it provides a completely new value to the consumer resulting in a new market which disrupts existing markets and companies.

Christensen (ibid) argues that disruptive innovations can greatly affect even responsive companies with high customer attention and well-functioning research and development departments. That is because disruptive innovations tend to be of rather low value to consumers in the beginning. This means that even if the innovation is well known by the incumbent companies, it is deemed as not profitable enough to sustain the company's operations. Thus a disruptive innovation is often launched by a start-up and slowly adopted by consumers. The start-ups then are first to reach the state where the advantages with the new technology over the old (for instance in terms of capacity or cost efficiency) become evident. At that point it can be too late for the large incumbent firm to switch to the new technology. Even if they do, the transition is slow and a lot of the market share will be lost to new entrants. This process is what characterizes this type of innovations as disruptive.

2.3 Scenario Analysis

Scenario analysis has emerged as a method to deal with the complexity of forecasting the future. According to Kosow and Gaßner (2008), the word "scenario" is often defined along these lines:

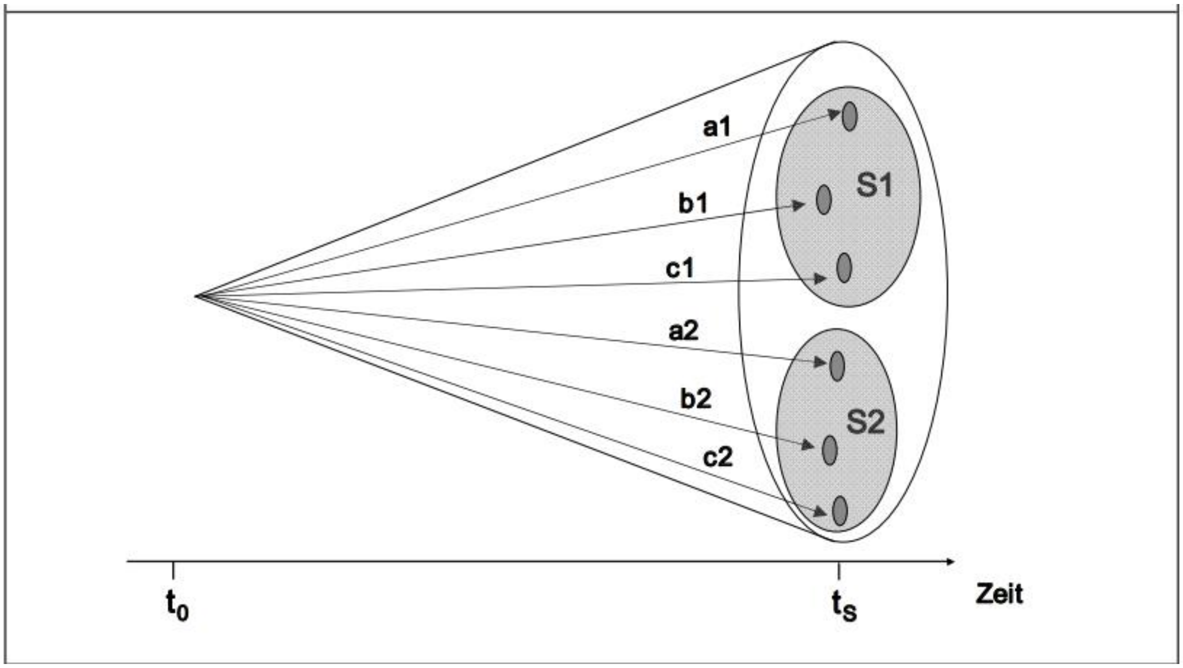
> *a description of a possible future situation including paths of development which may lead to that future situation*

Thus a scenario is not only a description of a future potential situation but also takes into account what aspects lead to that situation. In general, the real word is complex or even chaotic and scenario analysis main purpose is to address this uncertainty by providing possible and useful estimations to the future developments of events, according to Forge et al (2006).

Scenario analysis can, according to Van Notten, Rotmans, van Asselt and Rothman (2003), be divided into normative scenarios and descriptive scenarios. Normative scenarios describe future scenarios that seem preferable or probable while descriptive scenarios simply explore possible future situations that might arise.

The purpose of a scenario analysis is not to describe a future situation in all its detail; rather the aim is to put attention to a few important factors and events. According to Kosow and Gaßner (ibid), the researcher deliberately include and exclude different sets of relevant factors and events based on his or her knowledge and assumptions about what seems most relevant. The different scenarios at a given time, t_s are then given by analyzing how these factors will develop given certain events. Kosow and Gaßner depicts this process with the scenario funnel seen in Figure 2, where different directions of the factors a, b and c result in different future scenarios (S1 and S2). According to Forge et al (ibid) two to six different scenarios are normally suitable to establish and these scenarios should be as convincing, yet as startling as possible with the argument that the future seldom turn out as expected in any case.

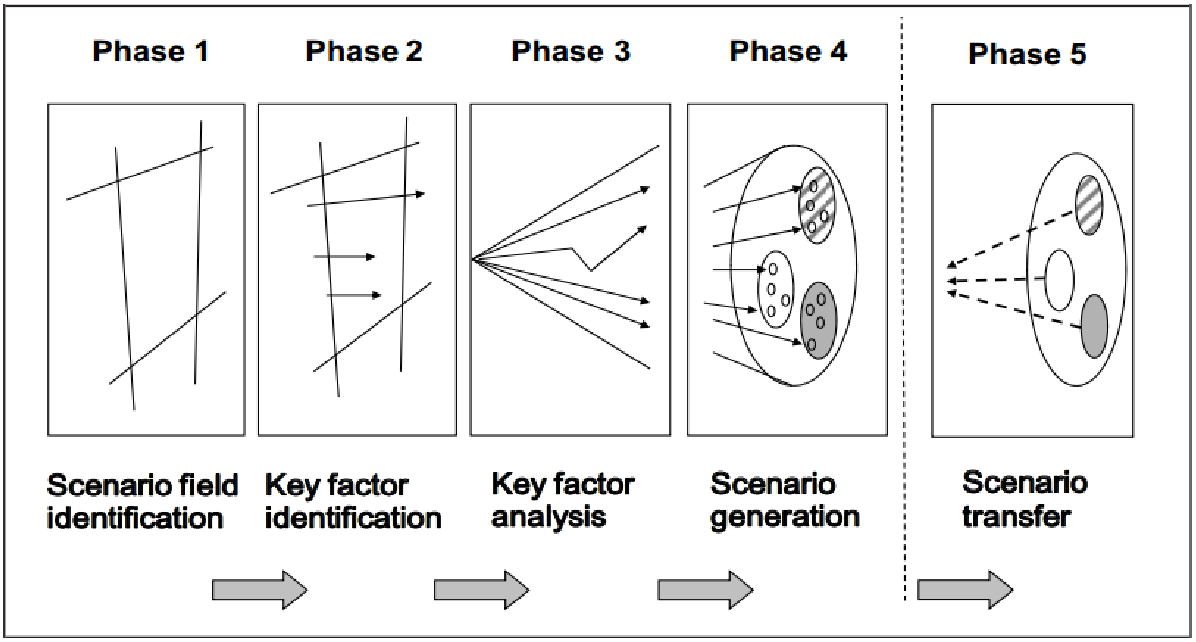
Figure 2. Scenario Funnel



Source: Kosow and Gaßner (2008)

Based on several other researchers' description of the process of scenario analysis, Kosow and Gaßner (ibid) have suggested the five phases in Figure 3 as a depiction of the major stages a scenario analysis should go through. The first phase identifies the scenario field as a baseline for the rest of the analysis. The purpose with the scenario analysis and the scenario field's borders in terms of what is integrated and what is left out are established in this phase. In the second phase, the key factors that will have an impact on the scenario field are established. These descriptors are also the major factors to describe the scenario field by. The establishment of these parameters, events, developments and trends requires an initial knowledge of the scenario field. How the factors are generated differ among different studies ranging from empirical and theoretical research to workshops and surveys. The third phase of analyzing the factors is the core of scenario techniques as this phase involves the creative and intuitive characterization of different factors' potential developments. In the fourth phase, the possible developments of each factor are bundled into consistent groups to generate a few scenarios. The way these factors are narrowed down can differ from mathematical models to less quantitative methods such as grouping different factors which progression are intertwined. The fifth phase of scenario transfer is optional and concerns how the identified scenarios can be further processed.

Figure 3. The scenario process in five phases



Source: Kosow and Gaßner (2008)

3 Methodology

Due to the complexity in forecasting future technology, the result of this study is based on a scenario analysis. This approach enables some necessary variation in the answers to the research questions while still providing valuable information.

Further theories regarding technology forecasting and how new technologies are adopted on a market have been used in order to elaborate on each scenario.

3.1 Scenario analysis

This study follows the path indicated in chapter 2.3 according to the scenario analysis process indicated in Figure 3.

3.1.1 Step 1 – Scenario field identification

The scenario field provides the major part of the data in this study since there is an extensive amount of aspects and actors affecting the development of autonomous cars. The scenario field is divided into two main parts.

The first part elaborates on several different and generally broad aspects that are important for the development of autonomous cars. These comprise chapter 4-10 and include:

- A classification of autonomous cars
- A brief summary of the history of autonomous cars
- An overview of the current state of autonomous cars
- An overview of the current global passenger car market and its current trends
- Perceived user segments for autonomous driving
- An overview of currently available advanced driver assistance systems (i.e. semi-autonomous systems)
- A description of the benefits and potential impact of autonomous cars
- An examination of the technologies involved in autonomous cars
- An analysis of the major barriers to emergence and adoption of autonomous cars

The second part of the scenario field was established based on an extensive review on the current actors most active in the field of autonomous technology for automobiles. This information can be found in chapters 11-12 and includes:

- Automobile manufacturers
- Technology companies
- First tier suppliers
- Specific regions (countries)

Automobile manufacturers were evaluated based on the following aspects:

- Overview of the company and its products
- Currently available semi-autonomous systems in their cars
- Their attitude and approach to autonomous cars
- Their current and planned development of autonomous technology

- Their relative position among actors in the development of autonomous cars

The major **tech companies** that are trying to develop autonomous cars were evaluated based on the same aspects as the automakers except for the “currently available semi-autonomous systems in their cars” as they have no such cars available. Several additional tech companies with high interest in autonomous technology for cars were given brief reviews as well.

The most active **first tier suppliers** were given an overall review with focus on their approach to autonomous technology, what they have developed so far as well as their plans for the future. Both traditional first tier suppliers of the automotive industry and new entrants that have emerged because of the demand for new technologies (sensors, computing power etc.) were evaluated.

Due to the sheer amount of companies and other institutions that is currently pursuing development of autonomous technology the empirical data has some limitations. For automakers, only the top 20 brands were considered. Of these 20, Volkswagen and Daimler have been emitted in their status as umbrella brands. Focus is instead on their luxury brands (BMW and Mercedes-Benz) since these are the parts of the respective companies that pursue autonomous cars. It should also be noted that some of the top 20 brands are owned by other brands on the list and have thus not received a chapter on its own (e.g. Daihatsu and Kia). Furthermore, the automakers in the top 20 list that have not showed much interest in autonomous cars have only briefly been mentioned.

Some **specific regions** that have showed a particularly high interest in the development of autonomous cars were reviewed. With one exception (the EU) these regions constitute nations. The regions were evaluated based on the governments overall attitudes to autonomous cars and their policies and regulations. Some countries have particular interest in autonomous cars for specific reasons which have also been included in this data collection.

3.1.2 Step 2 – Key factor identification

Three factors of particular importance for the emergence of autonomous cars were identified together with four factors for the global adoption of these cars. These factors were chosen by the researcher based on the findings presented in the empirical study as well as interviews with people active in the industry. These factors are presented in chapter 13.1 and 13.2.

3.1.3 Step 3 – Key factor analysis and scenario generation

According to Kosow and Gaßner (2008) the third step should focus on possible developments for the key factors. However, for this study and with respect to the factors chosen, it was more reasonable to describe the potential development along with the scenarios generated.

Three different scenarios were generated. The first scenario takes a pessimistic approach and estimates time for emergence and rate of adoption based on slow advancement of the key factors. The second scenario is based on the researcher’s estimation of how the development is most likely to be, the base line scenario. The third scenario (the optimistic scenario) assumes a quick development of the key factors resulting in a fast emergence and adoption of autonomous cars.

3.2 Setting classifications of autonomy

To provide a common frame of reference for what autonomy actually means in the context of this study, different industry standards were evaluated. A specific classification were then picked and established as a foundation for the rest of the study.

The classification of various degrees of autonomy is important as both emergence and adoption of the technology is dependent on its level of sophistication. This classification was used in the analysis so that each scenario describes the development of different levels of autonomy. Note that the classification of autonomy is thus both a frame of reference for the study but also a part of the scenario field setting.

3.3 Gathering of empirical data

The core of this study is devoted to empirical data collected over several months and from various sources including:

- Scientific articles
- News articles
- Press releases
- Annual reports
- Company web pages
- Interviews
- Berg Insight reports

Of the list above, most company related information such as sales figures were collected from annual reports or the company's web page. For specific statements regarding a company's approach to autonomous cars, press releases and news articles proved to be useful sources of information. The scientific articles were mainly used to get insight into various experts' views on autonomous cars in general. This was particularly useful to understand the impact autonomous cars can have on an economical and societal level.

As this report was created in cooperation with and for Berg Insight, some parts of this study have been copied from another Berg Insight report. The entire chapter 5 has been copied from the Berg Insight report *The Global Automotive OEM Telematics Market* but updated with new numbers and other changes where applicable. The overall information (i.e. the first paragraph) dedicated to the specific automotive manufacturers in chapter 11 as well as most of the sub-chapters describing their car offerings were also copied from *The Global Automotive OEM Telematics Market.* As in chapter 5, the information has been updated with more recent data where suitable. Each paragraph or chapter that has been copied in this manner is also highlighted at the start of that section and the text indented to make it easily distinguishable for the reader.

3.3.1 Interviews

Interviews were held with representatives from companies or other institutes involved in the fields of self-driving technology and they provided both information regarding their activities as well as estimates to when autonomous cars will emerge.

The interviews followed a semi-structured approach where the researcher had specific questions written down beforehand but overall kept an open dialogue in the interviews. The interviews where typically structured in three parts. The first part focused on an overall introduction to the company and its products or services. The second part focused on the company's projects in autonomous technology. The third part included broader questions about autonomous cars in general and the company's belief of the future development of this area.

3.4 Estimating each scenario

As mentioned above, the scenario analysis was based on some main factors for emergence and adoption and divided into three scenarios (base line, pessimistic and optimistic). However, a vital part of the analysis was the estimation about the progress of these key factors in each scenario. What does actually a pessimistic scenario mean, what result would an extrapolation of the current development be and how fast can the development be under optimistic conditions? To answer these questions, the researcher relied on the techniques for forecasting future technology and its adoption described in chapter 2.1 and 2.2. The estimate for the base line scenario was based on these techniques and the pessimistic and optimistic scenarios were then extrapolated from that.

To estimate emergence, the Delphi method could have been suitable to use. However, due to this method's complications in assembling a panel of experts the researcher decided to go for a more simplistic approach. Several interview subjects were asked to give their best indication of when an autonomous car will emerge. This was then combined with statements from different companies and other actors to give an indication of time of emergence. Moreover, this information was assessed together with other important aspects (listed in the setting of the scenario field above) and thereby provided the researcher with a position to estimate the time of emergence and rate of adoption. The method of environmental monitoring played a significant role in this study due to the complexity of the subject.

The method of forecasting by analogy was considered but due to the lack of a reasonable analogy, it was not used. Chapter 13.3 elaborates further on this topic.

The forecasting technique of extrapolating trends was only partly possible to use with regard to various levels of autonomy. There are currently some car models available in the market with some degree of autonomous capabilities. For this level of automation, the future adoption was possible to estimate based on initial data. However, there are no publicly available cars of higher autonomy. Thus the adoption rate for these cars could not be based on trend extrapolation. However, in all cases the researcher has assumed the rate of adoption will follow typical s-curves (as described by Martino, Meredith and Mantel, and Rogers in the literature review above). Another important aspect accounted for in the analysis is the fact that the market size for autonomous cars is finite. This means that the adoption of different levels of autonomy will affect each other if they occur with an overlap rather than in succession. Because of this dependency, the sizes of both the global as well as regional markets for passenger cars were evaluated (chapter 5). Additionally, a forecast of global future car sales was made and used as a frame in the analysis. However, this part has been omitted in the analysis as it is not the main focus of the study.

The theory of measures of technology was reviewed to aid the analysis of the technologies behind autonomous cars (chapter 9). Moreover, this chapter also elaborates on technologies correlating with autonomous cars and describes how some specific technologies are likely to be developed before autonomous cars emerge.

Although most of the analysis in this study is based on an exploratory approach (i.e. estimating the future based on the current state), a considerable part is also dedicated to more normative methods. The base data for the normative approach can be found in chapter 8 which deals with perceived benefits and potential impact of autonomous cars. The aim with this chapter is to show why autonomous cars might emerge rather than extrapolating a time of emergence based on the current situations. This chapter thereby also provides the causal model to the development of autonomous cars. It states why different actors are or should be pursuing the development of autonomous cars.

This study has not used relevance trees, morphological models or mission flow diagrams as indicated by Martino in the literature review for normative methods. However, the entire chapter 9 dealing with the technology aspects of autonomous cars summarizes the necessary development of technology in a similar way as the models described by Martino. Moreover, the different possibilities of technology development generate various end results. These end results are further impacted by different actors' approaches to autonomous cars. These aspects have been elaborated in an overall analysis for the future of autonomous cars in chapter 13.3.

To evaluate the possible impact of autonomous cars on both incumbent actors as well as on society, a review of the literature regarding disruptive innovations was necessary. This study does not explicitly deal with the question whether autonomous cars will be a disruptive innovation or not. However, it takes into account how different actors perceive the technology and the effect it might have if it indeed is a disruptive innovation.

To summarize, several of the techniques listed in the literature review were used to further elaborate each of the scenarios analyzed and to give reasonable estimates to the time of emergence and rate of adoption of autonomous cars. In particular, environmental monitoring, explorative as well as normative methods, trend extrapolation where applicable and growth curves have been used in the more detailed analysis of each scenario.

4 Overview of autonomous cars

4.1 Definitions and classifications of autonomous cars

A fully autonomous car can formally be defined as a car completely able to drive from an arbitrary point A to another arbitrary point B in the same environmental conditions as manageable by a human driver. However, this is the very last step on a continuum of more or less autonomous cars. There are cars with automatic capabilities that enable them to apply emergency braking when they detect an obstacle in front. There are also cars that automatically can stay in their lanes and even overtake other vehicles at a simple push of the turn signal. These systems enable partially autonomous driving but they are not truly autonomous. To better categorize self-driving cars it therefore makes sense to define different levels of autonomy.

Today, there are two major classifications for the scale of autonomy made by two independent organizations with the aim of providing common terminology. The National Highway Traffic Safety Administration, NHTSA, of the United States has developed a five stage scale for different levels of driving autonomy while the global standards developing organization Society of Automotive Engineers (SAE) has developed a six level standard. This report will use the SAE definitions as it has gained the most traction on an international level and since it provides a more detailed classification. The following picture illustrates the SAE classification.

Figure 4. SAE classification of levels of autonomy

SAE level	Name	Narrative Definition	Execution of Steering and Acceleration/ Deceleration	*Monitoring* of Driving Environment	Fallback Performance of *Dynamic Driving Task*	System Capability *(Driving Modes)*
***Human driver* monitors the driving environment**						
0	No Automation	the full-time performance by the *human driver* of all aspects of the *dynamic driving task*, even when enhanced by warning or intervention systems	Human driver	Human driver	Human driver	n/a
1	Driver Assistance	the *driving mode*-specific execution by a driver assistance system of either steering or acceleration/deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	Human driver and system	Human driver	Human driver	Some driving modes
2	Partial Automation	the *driving mode*-specific execution by one or more driver assistance systems of both steering and acceleration/ deceleration using information about the driving environment and with the expectation that the *human driver* perform all remaining aspects of the *dynamic driving task*	**System**	Human driver	Human driver	Some driving modes
***Automated driving system* ("system") monitors the driving environment**						
3	Conditional Automation	the *driving mode*-specific performance by an *automated driving system* of all aspects of the dynamic driving task with the expectation that the *human driver* will respond appropriately to a *request to intervene*	System	**System**	Human driver	Some driving modes
4	High Automation	the *driving mode*-specific performance by an automated driving system of all aspects of the *dynamic driving task*, even if a *human driver* does not respond appropriately to a *request to intervene*	System	System	**System**	Some driving modes
5	Full Automation	the full-time performance by an *automated driving system* of all aspects of the *dynamic driving task* under all roadway and environmental conditions that can be managed by a *human driver*	System	System	System	**All driving modes**

Source: SAE International J3016

At Level 0 there is no autonomy at all. Instead the driver controls all aspects of driving the car although some automatic functions like anti-lock braking system can be present. At Level 1, certain assistive features like adaptive cruise control, autonomous emergency braking or lane keeping assist help the driver with some parts of the driving in some situations. There is some concern whether a basic cruise control could be classified as a Level 1 feature since it does not respond to external output but simply maintains a set speed. However this function does let the car drive on its own to some extent and is therefore classified as a Level 1 feature in this report. At Level 2 the car is able to control both steering and speed on its own (for instance by coupling adaptive cruise control with lane keeping assist) but the driver must still remain attentive at all times to respond to unexpected situations and system failures. The third level is the first to provide some actual autonomy in the sense that the driver can divert attention from the road although he or she must be able to regain control of the vehicle with some seconds of prior warning. The fourth level provides full autonomy in specific use cases, for instance motorway driving or parking. The final stage, Level 5, features full autonomy as defined above, i.e. being capable of driving to any specific place as long as the environmental conditions allow it.

An important aspect to note is that although the different levels progress from a phase of no automation to full automation it does not necessarily imply that market introduction will occur in the same order. Different projects target different levels and it is yet not clear which project will be introduced first, especially since various use cases in each level can have different complexity.

Furthermore, the SAE categorization is a largely simplified generalization of the reality. The automotive industry is large and complex and the same goes for the development of autonomous cars. Often, it makes more sense to talk about the specific parameters affecting an individual autonomous vehicle project since it might meet the prerequisites of a certain level but only under some specific circumstances. This is especially the case when considering other vehicles than cars, such as transportation pods in pedestrian areas that only can be autonomous below, say 15 km/h. Despite these short-comings of the SAE classification it is still a useful tool for indicating different levels of autonomy and will be used throughout this report.

4.2 Brief history of autonomous cars

Autonomous cars have been envisioned for a long time. One of the first examples is General Motors' and RCA Labs joint concept in the 1950s which idea was to bury detector circuits in the pavement along roads. Radio receivers in the cars would then receive guiding impulses from the circuits to make them drive without the need of human control. However, these cars would only work on specific road stretches and would therefore not really be autonomous.

An early initiative was made by Carnegie Mellon University which in 1984 started to develop its first of the so called Navlab vehicles with semi-autonomous functionality based on a Chevrolet panel van. The university has since then expanded the Navlab series with ten additional research vehicles for various purposes. In 1987, the Eureka PROMETHEUS project was initiated in Europe. The project received € 749 million in funding from the member states of Eureka and kept going until 1995 with several automakers and universities participating. In 1995 a re-engineered Mercedes-Benz S-Class was able to drive from Munich in Germany to Copenhagen in Denmark and back with an average distance of 9 km between each human intervention. The project's main contribution was establishing which state of the art systems would be needed to enable autonomous driving in the future and thus to some extent provided the foundation for the research that is performed today.

The initiation of the DARPA Grand Challenges in 2004 marked the next milestone in autonomous driving. The 2004 Grand Challenge was a competition held in the Mojave Desert in western USA where robot cars competed along a 150 mile off-road route completely without human controls. The Defense Advanced Research Projects Agency (DARPA) commenced the challenge and sponsored the competition with a prize of $ 1 million to the winner. However, the best performing team which came from Carnegie Mellon University only managed to make 7 miles of the route and thus no participant was rewarded with the prize money.

The follow up event of the 2005 Grand Challenge was much more of a success as five vehicles finished the course with Stanford University having the winning team. In 2007, DARPA initiated its Urban Challenge which took place at an air-base and featured a mock urban area where the participating vehicles had to cover a 60 mile course. The vehicles had to obey traffic rules and adapt to traffic from human drivers as well as other competing autonomous cars. A team from Carnegie Mellon University won the competition with a modified Chevrolet Tahoe model. The DARPA Challenges showed that the concept of autonomous cars is viable and that they are perfectly possible to build, although it is tremendously difficult.

4.3 Current state of autonomous cars and key stakeholders

Semi-autonomous systems have been an important aspect in cars for many years now and passenger cars have evolved to be a prominent market segment for robotic functions. Cars have always been refined with ingenious engineering and craftsman skills that have focused on making the car easier to handle for the driver. Today's cars already have lots of automatic functions which in some sense make them partially autonomous. Especially when multiple systems are bundled together it is possible to achieve relatively advanced automatic driving. This study estimates that 194,000 cars were sold in 2015 with autonomous functions of Level 2 capability as defined according to SAE above.

Automatic transmission, anti-lock braking system (ABS) and electronic stability control are some examples of functions that are handled automatically by the car. However, these systems are not intelligent. They work in a relatively simple manner by identifying easily obtained data. An ABS for instance works by measuring the speed of each wheel to identify if an individual wheel rotates significantly slower than the rest, which indicates that it is skidding, and reduces that wheels' brake block pressure. Such a system is certainly clever but nevertheless very far from the intelligent software that is required to actually drive a car autonomously.

Semi-autonomous technology or what is often termed advanced driver assistance system (ADAS) is becoming increasingly sophisticated. The most cutting-edge ADAS of today allow the driver to release the pedals and refrain from turning the steering wheel while driving on highways or arterial roads, although it would be ill-advised for the driver to remove attention to the road. These systems are close to autonomous in the sense that the cars actually handle the driving without input from the drivers. However they are not really autonomous since they are not self-governing, meaning the driver still has to remain attentive. Nevertheless, these automatic functions are by many actors seen as small building blocks on the path to a fully autonomous car.

There are two different approaches to developing autonomous vehicles – the evolutionary and the revolutionary. The evolutionary approach sees a step-by-step increase of automation in the vehicles while the driver remains in control until the systems are sufficiently developed to enable autonomy. The revolutionary approach instead targets immediate development of highly autonomous vehicles, i.e. vehicles with Level 4 capability or higher.

4.3.1 Automotive manufacturers

Nearly all of the top 20 global car manufacturers are involved in the development of autonomous cars. Most of these actors target the evolutionary approach. The luxury carmakers have the most sophisticated systems that provide some level of autonomy today. With Tesla pioneering the roll-out of semi-autonomous autopilot features in the fall of 2015, some additional brands including Mercedes-Benz, BMW, Infiniti and Volvo Cars have started to offer similar features. All these semi-autonomous modes are at Level 2 autonomy according to the SAE classification.

4.3.2 Tier-1 automotive suppliers

The first tier suppliers also have an important position in the autonomous car trend. The first tier suppliers are the major developers and providers of advanced driver assistance systems (ADAS) to the automakers. The enhancement of ADAS is well in line with the evolutionary approach to develop autonomous features and first tier suppliers are thus key stakeholders in this market.

4.3.3 Technology companies

The automotive industry has in recent years seen the entrance of numerous new players following the trend of autonomous cars. This includes IT companies like Google, Baidu and Apple but also software developers, sensor providers, and providers of computer components. The entry of this type of companies is expected to play a significant role for the future development of self-driving cars. Both automakers and the traditional suppliers of the automotive industry are starting to see competition from these companies. The automakers view Google's self-driving car project as a particular threat. The first tier suppliers' problem is instead a more fragmented market where automakers have started to directly approach technology companies for deliveries of autonomous technologies.

4.3.4 Connectivity service providers

Increased connectivity is a parallel trend in the automotive industry and the entrance of mapping companies as well as telematics providers is starting to have an impact on the industry. This trend is also expected to have an impact on mobile network providers as well as operators.

Telematics systems as well as various forms of car-to-car and car-to-infrastructure communication are integral parts of ADAS and future autonomous driving technologies. The cars’ built-in sensors can be complemented with crowd-sourced information from other vehicles on the road to get non-line of sight awareness of the environment. Telematics systems already enable connected navigation services where vehicles not only get access to the latest traffic flow information, but also contribute with its own speed data. Future navigation systems will also be able to contribute information about the weather and current road conditions. Volvo Cars has for instance launched a pilot project together with the Swedish Transport Administration and the Norwegian Public Roads Administration in which road friction information from individual cars is shared within a cloud-based system. The real-time data about slippery patches on the road are used to warn vehicles nearby, at the same time as it contributes to making winter road maintenance more efficient.

5 The global passenger car market

As this report was created in cooperation with Berg Insight, some parts of this study have been copied from another Berg Insight report. The entire chapter 5 has been copied from the Berg Insight report *The Global Automotive OEM Telematics Market* but updated with new numbers and other changes where applicable. For more details see chapter 3.3.

The automotive industry is a major contributor to the global economy. The total annual turnover of manufacturing of passenger cars, light trucks, light commercial vehicles, trucks and coaches is about € 1,900 billion worldwide. In 2015, total automotive production grew 1.1 per cent to 91.5 million vehicles worldwide, including more than 77.5 million passenger cars and light trucks. China is now by far the leading nation in terms of automotive production with over 24.5 million vehicles manufactured in 2015, followed by the US with over 12.1 million, Japan with nearly 9.3 million and Germany with more than 6.0 million vehicles produced. In 2015, automotive production in the Asia-Pacific region grew 0.8 per cent to nearly 47.8 million vehicles while production in North America increased 2.3 per cent to 14.4 million. In the EU, where the market is gradually recovering from the financial crisis and economic downturn, automotive production grew 7.2 per cent to over 18.4 million vehicles in 2015. Direct and indirect employment in manufacturing of vehicles and automotive parts is about 9 million worldwide, the equivalent of five per cent of total global employment in manufacturing. Roughly six times more are employed in automotive related activities ranging from raw materials production to various forms of services supporting the production and use of vehicles. In the EU, the € 840 billion turnover generated by the automotive sector in 2011 represented about 6.5 per cent of the GDP in the region. In addition, motor vehicles account for over € 400 billion in tax contribution in the EU15 area.

Various stakeholders including government bodies and industry organisations in different countries and regions have established several definitions for classifying car segments based on type of vehicle and size. Although vehicle segments in Europe do not have formal characterisation or regulations, the European Commission and the automotive industry often segment the market into nine groups.

A-segment mini cars, often referred to as city cars or micro cars in the US and the UK, are between 2.7 and 3.7 meters in length and include three- and five-door hatchbacks. B-segment, small cars, known as subcompact cars in the US, range in length from 3.7 meters to 4.4 meters and include three- and five-door hatchbacks and sedans. C-segment compact cars, often called small family cars in the UK, range in length from 4.3 meters to 4.7 meters, typically have a sedan body or three- and five-door hatchback bodies. D-segment large cars that are usually called mid-size cars in the US and large family cars or compact executive cars in the UK, range between 4.7 meters to 4.9 meters, having sedan or estate/station wagon bodies. E-segment executive cars, known as full-size cars or mid-size luxury cars in the US, range in length from 4.9 meters to 5.1 meters and usually have sedan or estate/station wagon bodies. F-segment luxury cars in Europe are known as full-size luxury cars in the US and normally have sedan bodies. S-segment sport coupés include a wide range of car types with different body styles and sizes, including cabriolets/convertibles, roadsters, grand tourers and supercars. M-segment multi-purpose cars, often called minivans or multi-purpose vehicles (MPVs) in the US, are usually taller than sedans and estate/station wagons, designed for seating four to eight passengers. J-segment sport utility cars comprise many different vehicle types including sport utility vehicles (SUVs) with four wheel drive and full off-road capabilities, as well as cross utility vehicles (CUVs) optimised for on-road handling and comfort.

In Europe, vans and pick-up trucks are often categorised as light commercial vehicles. In the US, light trucks are usually divided between vans that are used for transport of goods and pick-up trucks that are vehicles with an open-top rear cargo area. Most pick-up trucks in Europe have a length of 4.8 to 5.2 metres, while pick-up trucks in North America can have lengths of up to 6 metres.

5.1 Passenger cars in use by region

At the end of 2014, there were an estimated 1024.65 million passenger cars and light trucks registered worldwide. This corresponds to a car parc density of 141 per 1,000 inhabitants. The number of registered passenger cars and light trucks has increased nearly 24 per cent globally since 2008. In Asia-Pacific, the passenger car parc has increased nearly 68 per cent, mainly driven by China where the number of passenger cars in use has grown from about 38 million in 2008 to almost 116 million at the end of 2014. China now has the second largest passenger car parc in the world behind the US, which had an estimated 239 million registered passenger cars and light trucks at the end of 2014. Japan, Germany and Russia are the remaining top five nations with 60.7 million, 44.4 million and 43.4 million registered passenger cars respectively at the end of 2014.

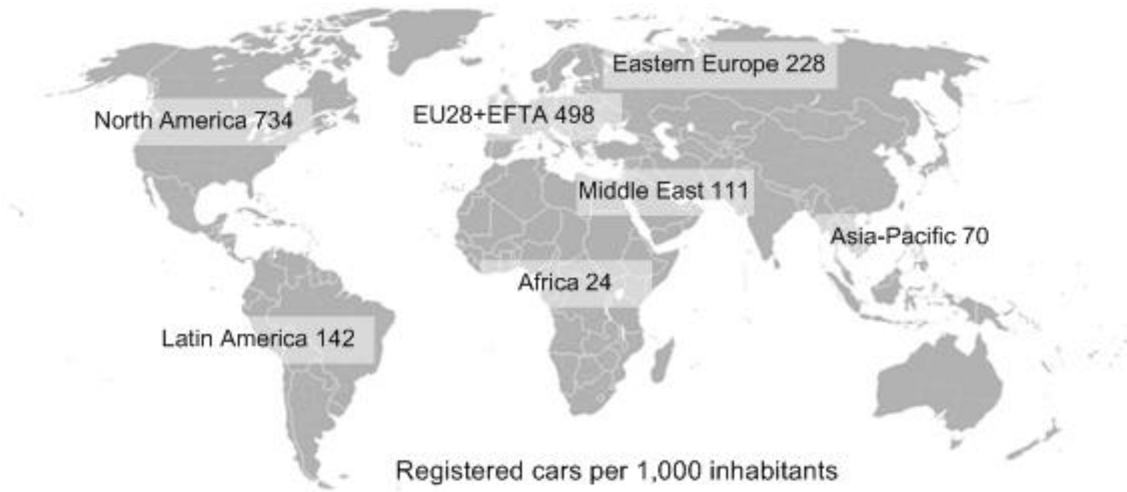
Figure 5. Car parc by region (World 2008–2014)

Million units	2008	2009	2010	2011	2012	2013	2014
EU28 + EFTA	243.67	245.53	248.57	251.65	254.02	256.62	259.83
Eastern Europe	51.07	52.97	55.20	58.35	61.32	65.13	68.19
North America	256.26	254.91	253.86	251.84	252.79	255.46	260.31
Latin America	63.61	67.23	71.29	76.17	80.86	85.04	88.77
Middle East	23.16	25.07	27.37	29.87	31.99	33.86	36.12
Asia-Pacific	170.48	184.62	203.39	222.54	242.08	263.01	286.13
Africa	19.27	19.97	20.99	21.93	23.14	24.15	25.30
Total	*827.53*	*850.29*	*880.68*	*912.35*	*946.19*	*983.27*	*1024.65*

Source: ACEA/OICA/US DOT/Berg Insight

However, the car parc density in China and the Asia-Pacific region remains low. At the end of 2014, there were only 70 registered passenger cars per 1,000 inhabitants in the Asia-Pacific region. The corresponding figure for China was 85 passenger cars per 1,000 inhabitants. Only Africa has a lower car parc density with 24 registered passenger cars per 1,000 inhabitants at the end of 2014. The top ten countries in terms of car parc density include the US, Luxembourg, Iceland, New Zealand, Canada, Lithuania, Italy, Malta, Finland and Australia, ranging from 748 to 556 registered passenger cars and light trucks per 1,000 inhabitants. At the end of 2014 about 259.8 million passenger cars were registered in the EU28+EFTA area. This corresponds to a car parc density of 498 per 1,000 inhabitants. In North America, there were 260.3 million registered passenger cars and light trucks at the end of 2014, corresponding to a car parc density of 734 per 1,000 inhabitants.

Figure 6. Passenger car parc density by region (World 2014)



Source: Berg Insight

5.2 New passenger car registration trends

New passenger car and light truck registrations grew 2.8 per cent to 77.4 million worldwide in 2015. However, performance was mixed on both a regional and country level. Vehicle sales grew 5.2 per cent in Asia-Pacific, 5.4 per cent in North America and 9.5 per cent in the EU28+EFTA area. New registrations of passenger cars fell 13 per cent in Latin America and declined 31 per cent in Eastern Europe. Estimated sales of new cars in the Middle East fell about 1.7 per cent in 2015, while sales in Africa declined about 9.4 per cent.

Overall, passenger car sales in emerging markets have increased steadily in the past few years while many developed markets, especially in Europe, have not yet fully recovered from the sharp declines that followed the last economic crisis. Over the past few years, different countries have seen fluctuating sales as governments have introduced various forms of market incentives such as scrapping schemes and car loan subsidies, but the weaker consumer confidence and tighter credit conditions continue to affect sales on new cars negatively in many countries. In the EU28+EFTA area, new passenger car registrations grew to 14.3 million vehicles in 2015, which is still 19 per cent below the peak of over 16.1 million new registrations recorded in 2007. New registrations in Eastern Europe fell to nearly 2.12 million vehicles in 2015, which is 46 per cent lower than the peak of 3.9 million new registrations in 2008. The Russian market has declined 56 per cent since the peak in 2008, while the Ukrainian market is down over 92 per cent. However, new registrations in North America increased for the fifth year in a row to almost 19.4 million vehicles in 2015, which corresponds to a 4.7 per cent increase from the previous peak of 18.5 million new registrations in 2005.

Figure 7. New car registration data (World 2008–2015)

Million units	2008	2009	2010	2011	2012	2013	2014	2015
EU28 + EFTA	14.91	14.53	13.83	13.64	12.57	12.34	13.06	14.30
Eastern Europe	3.91	2.08	2.67	3.52	3.62	3.60	3.09	2.12
North America	14.78	11.80	13.14	14.36	16.17	17.33	18.38	19.37
Latin America	4.25	4.16	4.81	5.19	5.41	5.49	5.03	4.38
Middle East	2.41	2.30	2.87	2.98	2.60	2.45	3.01	2.95
Asia-Pacific	15.99	19.61	24.37	24.66	27.52	29.88	31.76	33.40
Africa	0.70	0.69	0.73	0.86	0.96	1.00	0.96	0.87
Total	56.96	55.16	62.43	65.22	68.85	72.09	75.29	77.39

Source: ACEA/OICA/Berg Insight

China has been the largest market for new passenger car sales since 2010. New passenger car registrations in China grew 7.3 per cent in 2015 to 21.1 million vehicles. In the US, new registrations of passenger cars and light trucks grew 5.7 per cent to 17.4 million vehicles, 2.9 per cent above the previous all-time high of 16.9 million vehicles in 2005, driven by the economic recovery and easier access to car loans for consumers. In terms of new passenger car registrations, Japan remains the third largest country ahead of Germany. The Japanese market declined 10.3 per cent to 4.2 million new vehicles registered in 2015. The German market increased to 3.2 million vehicles, up 5.6 per cent compared to 2014. In India, sales of new passenger cars have increased over 300 per cent since 2001 and the country is now the fifth largest market. However, car sales declined for the first time in 11 years in 2013 and the market grew only 0.7 per cent to about 2.6 million vehicles in 2014. In 2015, new registrations in India recovered and grew 7.9 per cent to 2.8 million vehicles, a level similar to the peak in 2012. In 2015, passenger car registrations in the UK grew for the fourth consecutive year to an all-time high. More than 2.6 million new vehicle registrations were recorded in 2015, up 6.3 per cent year-on-year, reflecting the gradual economic recovery in the country. The Brazilian market fell for the third year in a row to only 2.1 million new registrations, down 24 per cent compared to 2014, due to lower consumer confidence as the economic downturn in the country worsened. In Canada, passenger car and light truck registrations grew 2.7 per cent to a new record of 1.93 million and thus maintained its slight lead over France as the ninth largest vehicle market in the world in terms of new annual registrations. However, the French market is recovering. The modest increase of new passenger car registrations in 2014 marked the first full year growth recorded in the country since 2009 and in 2015 passenger car sales grew an additional 6.8 per cent to nearly 1.92 million vehicles. After experiencing declining sales since 2008, the Italian market started to recover in 2014 with a slight growth of 4.3 per cent. In 2015, new passenger car registrations in Italy grew 15.8 per cent to almost 1.6 million vehicles. Car manufactures have also continued to stimulate demand with attractive financing deals. In Russia, the worsening economic crisis has led to an accelerated contraction of the passenger car market. Despite some government incentives, new vehicle sales fell 12 per cent to nearly 2.3 million cars in 2014 and registrations declined a further staggering 45 per cent in 2015 to 1.3 million cars and thus did not make the top ten list. Other countries with annual sales in the region of 0.8–2.0 million vehicles in the past few years include South Korea, Spain, Iran, Mexico and Indonesia.

Figure 8. Top 10 countries by new passenger car and light truck registrations (2015)

Country	New registrations			Change
	2013	2014	2015	2015 vs. 2014
China	17,928,000	19,708,000	21,146,000	7.3%
USA	15,532,000	16,497,000	17,434,000	5.7%
Japan	4,562,000	4,700,000	4,216,000	-10.3%
Germany	2,952,000	3,037,000	3,206,000	5.6%
India	2,554,000	2,571,000	2,773,000	7.9%
UK	2,265,000	2,476,000	2,634,000	6.3%
Brazil	3,041,000	2,795,000	2,123,000	-24.0%
Canada	1,798,000	1,883,000	1,934,000	2.7%
France	1,790,000	1,796,000	1,917,000	6.8%
Italy	1,305,000	1,361,000	1,576,000	15.8%

Source: ACEA/OICA/Berg Insight

5.3 Market trends

There are a number of developments in technology, regulations and customer demands that are shaping the future for the automotive industry. Increased connectivity is an important such trend that is believed to be part of the technology enabling autonomous cars and extending their capacity. Furthermore environmental regulations are driving adoption of hybrid and electric vehicles while safety regulations stimulate the development of increasingly capable advanced driver assistance systems (ADAS). At the same time, more customers are seeking new ways to solve their mobility problems, for instance by becoming members of car sharing programmes instead of buying a car or using traditional car rental services.

5.3.1 Hybrid electric, plug-in hybrid electric and all-electric vehicles

There are different kinds of environmental car segments – mainly hybrid cars, plug-in hybrid cars, all-electric cars and ethanol cars. In many parts of the world, governments have introduced permanent or temporary incentives for stimulating sales of environmentally friendly cars. Examples include direct purchase subsidies, exemption from registration fees and road taxes, free parking spaces, as well as free battery charging. Most car manufacturers are hedging their bets on alternative powertrains by developing multiple technologies. The current environmental friendly trend that is boosting the development of hybrid and electric vehicles will affect the autonomous car industry positively in the medium to long term since autonomous cars and electric cars goes hand in hand.

5.3.2 Hybrid electric vehicles

One of the most promising technologies for reducing emissions in conventional cars is known as hybrid technology, since it combines the benefits of two types of power sources instead of relying on just one. A hybrid electric vehicle uses both an electric motor and an internal combustion engine to propel the vehicle. A hybrid is designed to capture energy that is normally lost through braking to recharge the batteries, which in turn powers the electric motor. A parallel hybrid electric vehicle uses the electric motor or the internal combustion engine to propel the vehicle. A series hybrid electric vehicle uses the electric motor to provide added power to the internal combustion engine when it needs it most, for example in stop-and-go driving and acceleration. All hybrid electric vehicles have the potential to achieve greater fuel economy than conventional internal combustion engine vehicles. A new category of hybrid vehicles is the Plug-in Hybrid Electric Vehicle (PHEV) that can restore the internal battery to full charge by connecting the vehicle to an external power source, such as a normal electric wall socket. PHEVs usually have larger batteries and longer all-electric range than conventional hybrid cars (20–70 km). PHEVs effectively eliminate the issue of range anxiety associated with all-electric vehicles, as the combustion engine is used as a range extender.

5.3.3 Electric vehicles

There are many terms for electric cars without internal combustion engines, including all-electric vehicles (EVs), Plug-in Electric Vehicles (PEVs) or Battery Electric Vehicles (BEVs). Highway-capable electric vehicles began shipping in 2010. Consumer interest in electric vehicles – initially driven by concern over climate change and now also fuelled by a desire for energy independence – continues to grow. However, electric cars are most likely to account for only a small share of new car sales in the next few years due to high costs. These vehicles will also require the rollout of a new infrastructure for charging access at home, at work, around town and along major freeways. The main usage for electric vehicles today is as a city car with typical travel ranges of 40–200 km. The foremost limitation in electric cars today and the near future is battery technology. Batteries have limited range, are heavy, wear out quickly with repeated recharging and are expensive to manufacture.

As of July 2015, the number of highway-capable all-electric cars and light commercial vehicles available had grown to about 30 models worldwide. The best-selling all-electric passenger cars in 2015 include the Tesla Model S, Nissan LEAF, BMW i3, Geely-Kandi Panda, Renault Zoe, BAIC E Series, Zotye Cloud and Volkswagen e-Golf.

The Nissan LEAF – introduced in December 2010 and now available in 46 countries – remains the best-selling highway-capable electric car to date. Cumulative sales of the LEAF surpassed 202,800 units globally at the end of 2015. The considerably more expensive Tesla Model S luxury sedan is however catching up rapidly as sales are expanded to more markets. The Model S was launched in North America in 2012, followed by Europe in the second half of 2013. Availability has been extended to 30 countries by June 2015. Cumulative worldwide sales of the Tesla Model S surpassed 107,100 units at the end of 2015. The BMW i3 became the third best-selling electric car in terms of cumulative sales at the end of 2015, ahead of Renault ZOE. The following top brands on the list are emerging models from Chinese car manufacturers. Cumulative sales of the Mitsubishi i-MiEV, including the rebadged Peugeot iOn and Citroën C-Zero versions, surpassed 36,000 units worldwide at the end of 2015.

The top 5 models in terms of unit sales worldwide during H1-2015 were the Tesla Model S, Nissan LEAF, BMW i3, Renault Zoe and Chery QQ3 EV. Total sales of all-electric vehicles worldwide reached an estimated 283,000 units in 2015, compared to 180,000 units in 2014 and 120,000 units in 2013.

Figure 9. Top selling highway capable all-electric cars (World 2015)

Model	Sales				Launch
	Total[1]	2015	2014	2013	
Nissan LEAF	202 802	43 870	61 027	47 716	Dec. 2010
Tesla Model S	107 116	50 366	31 623	22 477	June 2012
BMW i3	41 295	24 083	16 052	1 160	Nov. 2013
Renault Zoe	39 094	18 846	11 323	8 857	Dec. 2012
Chery QQ3 EV	24 263	6 885	7 866	5 007	Mar. 2010
BAIC E Series	22 432	16 488	5 234	710	2013
Geely-Kandi Panda	21 675	20 390	1 285	-	2014
Renault Kangoo ZE	21 192	4 426	4 257	5 874	Oct. 2011
Mitsubishi i-MiEV	20 800	1 580	2 609	4 000	July 2009
Volkswagen e-Golf	19 041	15 356	3 685	-	June 2014
JAC J3 EV / i EV	17 938	10 420	950	2 500	2010
Smart ForTwo ED	15 830	3 706	5 824	4 130	2009
Peugeot iOn / Citroën C-Zero	15 787	2 935	1 327	805	Dec. 2010
Zotye Cloud	15 620	15 467	-	-	Nov. 2014
BYD e6	14 308	7 029	3 611	1 544	May 2010
Zotye E20	13 726	6 385	7 341	-	2014
Volkswagen e-Up!	9 682	2 769	5 448	1 465	Oct. 2013

Fiat 500e	9 591	5 498	1 793	2 300	July 2013
Kia Soul EV	8 819	7 510	1 159	-	May 2014
Chery eQ	7 804	7 262	542	-	Nov. 2014
Mitsubishi Minicab MiEV	6 615	501	865	2 063	Dec. 2011
Ford Focus Electric	6 475	1 600	2 210	1 980	Dec. 2011
Nissan e-NV200/Evalia	5 949	3 649	2 300	-	2014
Mercedes B-Class ED	5 624	4 700	924	-	July 2014
Bolloré Bluecar	4 932	1 166	1 170	654	Dec. 2011
[1]Cumulative sales worldwide at the end of 2015					

Source: Berg Insight

Figure 10. Registered highway capable BEVs and PHEVs (World 2015)

	BEVs	PHEVs	Total
Registered BEVs and PHEVs[1]			
USA	206,000	194,000	400,000
Canada	9,000	7,500	16,500
Japan	79,000	52,000	131,000
China	187,000	86,000	273,000
EU28+EFTA	242,000	157,000	399,000
Others	17,000	5,500	22,500
Total worldwide	*740,000*	*502,000*	*1 242,000*
New registrations (2015)			
USA	71,300	44,000	115,300
Canada	4,500	2,400	6,900
Japan	99,000	91,000	190,000

China	125,000	63,000	188,000
EU28+EFTA	12,700	12,600	25,300
Others	12,500	2,000	14,500
Total worldwide	*325,000*	*215,000*	*540,000*
[1]Registered cars at end of 2015			

Source: Berg Insight

Berg Insight estimates that there were about 1 242,000 highway-capable plug-in vehicles registered worldwide at the end of 2015, including 740,000 BEVs and 502,000 PHEVs. One year earlier, there were roughly 420,000 BEVs and 290,000 PHEVs registered worldwide. Although the US still has the highest number of plug-in vehicles in use, both China and Japan have surpassed the US in terms of total annual new registrations.

Even though the number of PHEV models available worldwide is growing, BEVs continue to outsell PHEVs worldwide. BEVs accounted for 60 per cent of total plug-in vehicle sales worldwide both in 2015 and in 2014 but has increased from the 56 per cent in 2013 and 50 per cent in 2012. Major markets including the US, Japan and China now have a sales split close to the world average, whereas several other markets see a distinct preference for either BEVs or PHEVs. In major plug-in electric car markets such as France and Norway, BEVs have previously been outselling PHEVs by a factor of at least 10 to 1. However, following a spree of new PHEVs introduced in 2015 the number has gone down to around 4 to 1. In the Netherlands, on the other hand, PHEVs outsell BEVs by a factor of at least 10 to 1.

Norway and the Netherlands are the leading countries in terms of adoption of electric vehicles. The BEV market share of total new car registrations in Norway is the highest in the world, its market share increased from 3.1 per cent in 2012, to 5.7 per cent in 2013, 12.5 per cent in 2014 and 17.1 per cent in 2015. New registrations of BEVs together with PHEVs accounted for 22.4 per cent of total passenger car registrations in Norway in 2015, up from 13.5 per cent in 2014. Only the Netherlands comes close to this, with 8.5 per cent plug-in vehicle market share. The Netherlands saw a dramatic increase of sales of new cars in general and especially PHEVs in the three last months of 2015 as a result of vehicle taxation changes that went into effect on the first of January in 2016. In the Netherlands, PHEVs accounted for 8.0 per cent of total new car registrations in 2015, up from 3.2 per cent in 2014. Norway and the Netherlands are also the leading countries in terms of relative size of the electric vehicle car parc with 3.9 per cent and 1.1 per cent of the total passenger car parc respectively. Both numbers are far ahead of the global figure of 0.1 per cent by the end of 2015.

5.3.4 Car sharing and personal transportation as a service

Carmakers are gradually exploring new business models and service propositions that aim to better meet the needs of people that use cars occasionally. There are already numerous car-based mobility services available for people that do not own a car or need to access a car temporarily when travelling. Traditional car rental services still dominate the market, offered by commercial service providers like Enterprise Rent-A-Car, Hertz, Avis, Europcar and SIXT. These companies rent out cars for a specific period of time ranging from a few hours to a few weeks. The total car fleet operated by car rental companies now exceeds an estimated 4 million cars worldwide. Although total revenues for car rental services is growing worldwide, the traditional car rental industry is now facing increasing competition from car sharing and ride sharing services.

Car sharing is a car rental model that enables users to rent cars for short periods of time, usually by the hour or minute. Besides peer-to-peer services, there are a growing number of commercial services available, including station-based services and free floating services that allow pick-up and drop off anywhere within a defined zone. These services are becoming increasingly popular in larger cities due to lack of parking spaces, increasing congestion and higher cost of car ownership due to regulations. Car sharing is especially popular among younger people that do not consider the car to be a status object. At the end of 2015, car sharing services were available in more than a thousand cities across at least 30 countries worldwide. Berg Insight estimates that there were roughly 7.7 million members of car sharing services excluding peer-to-peer services worldwide at the end of 2015. North America and Europe accounted for more than 60 per cent of the global market.

Examples of specialist car sharing companies active in Europe include Flinkster (a subsidiary of the German railway company Deutsche Bahn) and Stadtmobil in Germany, Bolloré Bluecarsharing in France, Greenwheels in the Netherlands, Sunfleet in Sweden and Mobility Carsharing in Switzerland. Examples of specialist car sharing outside Europe include ORIX Carshare in Japan and South Korea's largest car sharing company, Socar.

The car rental company Avis Budget Group acquired Zipcar, the market leader in North America, in 2013. Zipcar has grown significantly in the last couple of years by extending its presence in Europe to include Austria, France, Spain, the UK and Turkey. There are also plans to enter the Australian market and Latin America in the future. Several traditional car rental companies have also introduced car sharing services. Examples include Enterprise CarShare and Enterprise Car Club by Enterprise Rent-A-Car, Hertz 24/7 by Hertz and UhaulCarShare by U-Haul. Some carmakers have likewise launched car sharing programmes in select countries and cities, primarily in Europe and North America. Examples include Daimler, BMW, Volvo Cars, Groupe PSA, Volkswagen, Fiat, Ford and Opel.

Car2go, launched in October 2008, offers car sharing services in 29 cities in Germany, Austria, Denmark, Italy, Netherlands, Sweden, Canada and the US. The company has about 14,500 Smart ForTwo petrol and Smart ForTwo ED electric cars available for rental by the minute, hour or day. The Car2go service does not rely on fixed rental locations, instead customers can rent any vehicle they find distributed at their location or book online 30 minutes before they want to drive. Car2go had about 1.2 million members at the end of 2015.

DriveNow is a joint venture between BMW and the car rental company Sixt that began operations in Munich in 2011. The premium car sharing service gives members access to several of the latest Mini and BMW models. DriveNow has over 4,000 cars in 10 cities in Germany, Austria, the UK, Denmark and Belgium. The company plans to expand availability to more cities in Europe and the US in the future. DriveNow increased its customer base with 49 per cent during 2015 to 580,000. Like Car2Go, DriveNow does not have any stationary pick-up or return locations.

Figure 11. Car sharing and mobility service companies (World Q4-2015)

Company	Main markets	Fleet size	Members
Automotive OEM carsharing services			
Car2go (Daimler)	Europe, USA, Canada	14,500	1,200,000
DriveNow (BMW)	Germany, USA	4,000	580,000
Sunfleet (Volvo Cars)	Sweden	>1,100	40,000
Citroën Multicity	Germany (Berlin)	350	NA
Quicar (Volkswagen)	Germany (Hannover)	200	12,500
Car rental companies and specialist carsharing operators			
Zipcar (Avis Budget)	North America, UK, Austria	13,000	970,000
ORIX CarShare	Japan	2,200	145,000
Enterprise CarShare	North America, UK	NA	NA
Enterprise Car Club[2]	UK	950	35,000
Hertz 24/7 (Hertz)	France, Germany, UK	NA	NA
UhaulCarShare (U-Haul)	USA	NA	NA
Flinkster (DB Rent)	Germany	800	287,500
Socar	South Korea	4,800	1,500,000
Times Car Plus	Japan	13,500	571,000
Enjoy (Eni)	Italy	1,700	350,000
Bolloré Bluecarsharing[1]	France (Paris, Lyon, Bordeaux)	4,300	200,000
Mobility Carsharing	Switzerland	2,900	127,300
Greenwheels	Netherlands, Germany	2,000	80,000
Cambio	Germany, Belgium	2,100	74,000
Zoomcar	India	1,600	150,000
Stadtmobil	Germany	2,300	50,000

GoGet	Australia	2,000	70,000
Commonauto	Canada, France (Paris)	1,900	50,000
Citiz	France	1,000	20,000
[1] Operates the Autolib', BlueLy and BlueCub services [2]Owned by Enterprise Holdings			

Source: Berg Insight

Enjoy is a car sharing service created by the Italian energy company Eni in partnership with Fiat, the Italian train operator Trenitalia and Vodafone. The free floating car sharing service provides access to 1,700 Fiat 500 and Fiat 500 L cars in Milan, Rome, Florence and Turin. Vehicles can be booked via the company website or the smartphone app. The per-minute rental fee covers all costs including insurance, maintenance, fuel and parking. Enjoy had about 350,000 members at the end of 2015.

Ford has launched several projects and experiments as part of its Ford Smart Mobility plan to use technology and innovation to take the company to the next level in connectivity, mobility, autonomous vehicles, customer experience and big data. GoDrive is a car sharing service project for drivers in London that launched in mid-2015, offering 50 cars across 20 locations. GoDrive offers one-way trips with guaranteed parking, based on a pay-as-you-go model with pay-per-minute pricing covering all fees. Drivers book and access cars via a smartphone app. Ford is also exploring car sharing in Germany and India.

In the beginning of 2016, Ford unveiled a new app called FordPass which includes several mobility features. FordGuide helps app owners solve their mobility concerns through live chats or calls, free of charge. The app also includes a collaboration with FlightCar to at first enable car rental but in the future to offer ride sharing, car sharing and multi-modal transportation.

Opel has taken a slightly different approach with its next step of becoming a mobility service provider. The company launched the CarUnity car sharing concept in Germany in mid-2015. CarUnity enables owners of any car brand, not only Opel, to share their car using the CarUnity smartphone app. Owners can decide who may rent their car, for instance only to their Facebook friends, or people in their personal CarUnity network. Insurance is provided by Opel Bank in cooperation with R+V Allgemeine Versicherung. Moreover, GM Ventures, the investment division of General Motors, has invested in the German ridesharing platform Flinc in order to extend Opel's mobility service offer throughout Europe.

PSA Peugeot Citroën introduced the car rental service Mu by Peugeot in 2010. It enables customers to rent a Peugeot vehicle for any duration. The service is available in France, Germany, Spain and the UK. Citroën launched its mobility services portal Citroën Multicity in France in 2011 and in Germany in 2012. The portal provides users with an itinerary search engine that identifies and compares all possible modes of transport, providing estimated cost, time and CO_2 emissions for each option. Customers can also reserve a rental car, including passenger cars, light commercial vehicles and electric cars. With the exclusive Call Car service, Citroën delivers rental cars directly to the doorstep in France's largest cities. In Berlin, Citroën Multicity also offers a free floating car sharing service featuring 350 Citroën C-Zero electric cars. Other mobility solutions include peer-to-peer rental and car-pooling services from partner companies BlaBlaCar and OuiCar.

Volkswagen is also exploring new mobility concepts. The company launched the car sharing pilot project called Quicar in Hannover, Germany in 2011. Moreover, Volkswagen Financial Services acquired 60 per cent of Collect Car in April 2013, which operates the Greenwheels car sharing service in the Netherlands and Germany.

Audi launched the new Audi Unite micro car sharing concept in Stockholm, Sweden at the end of 2014. Audi Unite is a leasing programme that makes it easy for a circle of up to five friends, colleagues, family-members or neighbours to have an Audi together. The circle can choose any model from the whole Audi product range, with contract lengths of 12 or 24 months. The Audi Unite app helps each member with reservations, locating the car and checking the fuel level. The Audi Unite flex plan automatically calculates each portion of the monthly bill for each circle member proportionately to the time the car is used. The consumed fuel, car liquids, additional cleaning and congestion taxes are shared based on the individual mileage driven by each circle member.

6 User segments for autonomous driving

It can be argued that self-driving cars is an innovation for the mass market and some even advocate that in a utopian future, human driving will be banned for safety reasons. However, even an optimistic forecast would acknowledge that it will be a long time before autonomous cars become a commodity and available on all markets. Therefore this chapter's focus is to identify the most important segments and their benefits of autonomous driving in a foreseeable future. However some segments, or rather use cases, that can be reached in the future will also be discussed briefly. In addition this chapter ends with a description of the main possible ownership models in the future.

The diffusion on various markets is dependent on the definition of autonomous cars - such as if the car has to be completely self-driving to be considered autonomous. However, the diffusion of the technology to specific consumer segments seems to be independent of whether the car is fully autonomous or only feature semi-autonomous capabilities with one notable exception - the segment of people unable to drive by themselves. Moreover, some user segments require truly driverless vehicles to be relevant. This chapter is therefore structured in a way that first focuses on the early adopters, before turning attention to the more reluctant adopters and lastly to the segments that will require full autonomy to be viable. It should also be mentioned that the various segments are heavily intertwined and that this chapter does not aim to recommend what markets to specifically target at any given time. It only serves to identify what segments of the market are important for autonomous technology.

Lastly it is important to notice that the roll-out of autonomous technology is not something that happens overnight. The diffusion of autonomous systems happens incrementally and is already starting to emerge in the high-end market. As this market attains increasingly sophisticated semi-autonomous systems, technology in the older models are instead deployed in more price sensitive segments and thus become available to a broader public a few years after the high-end market.

6.1 Luxury segment

This segment is highly probable to be the first to be introduced to autonomous cars. In fact, semi-autonomous technology is already available in luxury brand vehicles. Luxury and comfort goes hand in hand and autonomous cars certainly offer increased comfort since people can relax instead of being required to control the car. The fact that the luxury segment is made up of expensive cars with higher performance is also a reason why these cars are outfitted with increasingly autonomous technology. The technologies enabling semi-autonomous driving is still very expensive and therefore it is difficult for the automotive manufacturers to integrate them on inexpensive models. Fully or near-fully autonomous cars will require even more advanced technology both in terms of hardware and software and this will result in even higher costs.

Although there is no unified definition of what represents the luxury market for cars, roughly 11 percent of total global unit sales is made up of the luxury car market while it constitutes about 20 percent of global turnover. The luxury segment is thus of great importance for the automotive manufacturers. In general, the luxury car segment also accounts for larger profits compared to other car segments due to the possibility to inflict a higher margin as a result of brand awareness among customers.

6.2 Commuters

In the US, people spend on average 26 minutes commuting to work, in UK the number is around 45 minutes. These numbers indicate that commuters make up an important segment for autonomous cars. The promise of autonomous cars is to open up the commuting time slot for other activities than driving the car. Especially commuters with long stretches of congested highways could heavily benefit from autonomous driving. These people could do work in the car, read e-mail or a newspaper or even sleep. Cars with semi-autonomous traffic jam assist features are already available on some high-end models and although the driver is not allowed to let go of the control of the car, these systems still make the driving less tedious. Furthermore, several automakers are currently working on delivering traffic jam assist systems with full autonomy within five years and possibly as little as two years. When those system arrive it will further improve commuters' ride to and from work even though the cars will not be able to drive the passenger all the way completely autonomously. This highlights an important aspect of autonomous cars - they do not necessarily have to be autonomous in all situations to induce significant benefits.

The commuter segment somewhat intersects with the luxury segment since people that commute long distances tend to prioritize safe and comfortable cars. Moreover, there is a significant group of affluent people who drive luxury cars and commute to a work located relatively far from their homes. However, there is an even larger group of middle-class commuters who would benefit from autonomous cars but for this market to be relevant, the cost of autonomous systems must decrease and the large impact is therefore likely to occur some years after the roll-out of autonomous cars.

6.3 Young drivers

Young drivers have been identified as an important segment for autonomous cars since these drivers have less experience, in general take more risks and are more prone to distraction (partly due to less willingness to refrain from smartphone usage) and is therefore over-represented in incident statistics. Autonomous vehicles could diminish the accident rates in general but could potentially have greatest impact on this segment.

The problem is that young drivers tend to have a smaller budget when buying a car compared to more mature drivers. A large impact on this segment will therefore probably take a while after the first autonomous cars are available. However, cars are becoming increasingly safe and some semi-autonomous systems should start to drizzle down to less expensive vehicles in a relatively short time frame and these systems will also have an impact on the segment of young drivers.

6.4 Paratransit

An interesting aspect of fully autonomous cars is that they enable transportation for people who are not capable of driving themselves. Autonomous cars could provide elderly and impaired people with significantly more freedom in everyday life. Even if it is possible for a disabled person to get Para transit or to ask a friend of help, these options are not without troubles, especially over a longer time. Taxi is expensive and to ask friends or family can easily be tiresome or frustrating in the long run. Long-distance journeys make for even more inconvenience. Autonomous cars will give more independence to impaired or old people.

6.5 Delivery fleets

The typical consumers do not constitute the only potential segments for autonomous cars. All companies working with some kind of deliveries can benefit from fully autonomous cars. The most important segment is arguably made up of logistics companies transporting goods over long distances. These companies are currently investigating platooning as a potential way of cutting costs and fully autonomous commercial vehicles could lead to even larger cost savings.

However, for fully autonomous cars, also last-mile deliveries or other local transports of goods could be performed without a driver. This could have an impact in such various businesses as deliveries of mail to pizza- or flower deliveries. However, just as is the case with people who lack the ability to drive, this use case of autonomous cars is still quite distant in the future since it requires full autonomy.

6.6 Transportation on demand

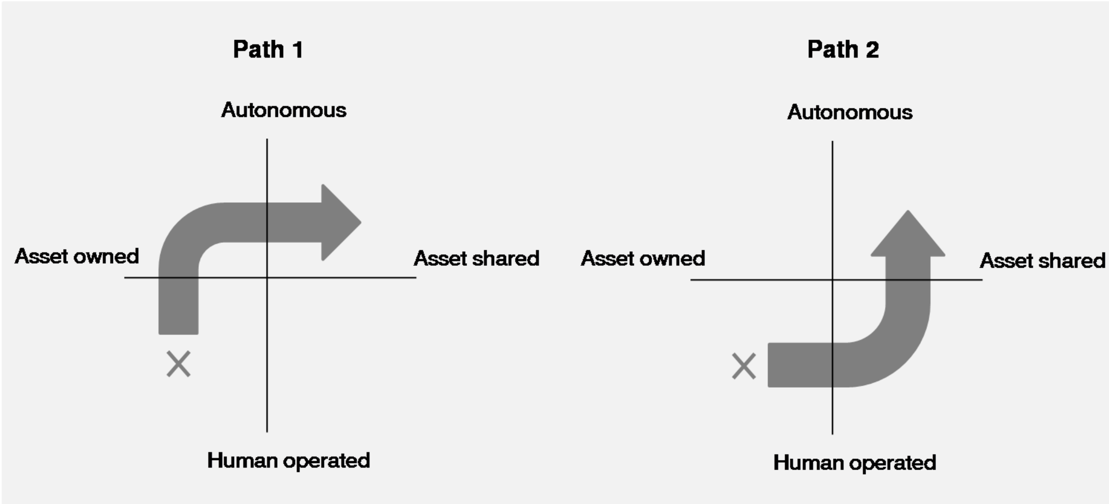
A car has traditionally been something private and often seen as a symbol of status. As cars have turned into commodities in most regions around the world today, the status symbol has also changed in many markets. Especially in cities, cars have started to become much more of a means for mobility rather than something to possess. Many people in cities want the flexibility of a car but do not have the need for it most of the time and also do not want to own it due to the high costs associated with insurances and parking spaces. Along with this new attitude have car sharing and new business models for ride-hailing emerged as important alternatives to the traditional services of taxi and public transportation.

A potential business model for a developer of autonomous cars could be to offer mobility in an on-demand basis through a city-based fleet of driverless cars. This business model could potentially apply to all citizens and thus target a mass market. Such an application of autonomous cars could have a large impact on urban mobility and infrastructure which is further discussed in chapter 8.

6.7 Ownership models for fully autonomous cars

The automotive industry will benefit from realizing that autonomous cars will have an impact on ownership models. It has already been mentioned that self-driving cars will increase the trend of mobility as a service rather than as a product. However, the transformation from cars as an owned asset into a shared asset is also a separate trend from autonomous cars. Both the transformation into autonomous technology and the transition to cars as a shared asset come gradually and it is not certain which will happen first. If autonomous cars evolve quickly, these will initially be rolled-out as products to private consumers before the market transitions to a majority of shared assets. In such case, the development will take the direction indicated in the leftmost graph below. Another possibility is that the automotive market transforms into a shared asset structure before the emergence of autonomous cars as in the rightmost graph. The first path seems more likely as autonomous cars enable better capitalization on cars as a shared asset while current incentives to transition from regular car ownership to shared ownership is still rather low.

Figure 12 Potential paths to shared ownership of autonomous cars



Source: Berg Insight

If we look far into the future where fully autonomous cars have become standard there are five main possible models for ownership of the self-driving cars.

6.7.1 Full ownership

Individuals have full ownership of the car just like how current vehicle ownership looks like. This will undoubtedly be an important ownership model also in the future, especially with top-end or sports cars. The autonomous car can be a private retreat not unlike the Luxury in Motion concept by Mercedes-Benz. However, for the mass market, the portion of this model of ownership is expected to decrease as new models emerge

6.7.2 Fractional ownership

A fractional ownership means that the customer through a monthly fee is able to rent different models from a specific car brand. The cars would deliver themselves to the customer and the pricing would be dependent on the use case of the vehicles. Consumers thus buy equity in the brand rather than a single vehicle similar to current leasing models.

6.7.3 Own and share

The customer assumes full ownership of the autonomous vehicle but is in turn able to rent it to others when the car is idle. The model is comparable to private wind power or solar power stations that can transfer any extra power obtained to the common grid for a monetary reward. In a similar way to this example, the ability to let the car autonomously transport other people would make the investment in a self-driving car less expensive over time. This model of car ownership is especially interesting at the beginning of the roll-out of autonomous cars since they are not unlikely to be expensive and not attainable to the mass market other than on a rental base.

6.7.4 Mobility services

This ownership model is based on a subscription to a mobility service company that solves the customers' mobility needs through multi-modal transportation leveraging on a combination of means such as car sharing or public shuttle services and including autonomous vehicles as well.

6.7.5 Pay per ride

Pay per ride is the traditional model for private transportation service with actors like taxi companies but also other ride-hailing services like Uber and Lyft. The business model will essentially be the same in the future where customers call for or use an app to receive a transport but the cars will not have any drivers and be owned by the ride-hailing companies.

7 Advanced driver assistance systems

An advanced driver assistance system (ADAS) is a term used to describe an ingenious system in a vehicle that help the driver control it. An agreed-upon industry standard for what classifies as ADAS does not exist. In this report, ADAS is defined as *any automotive system that is in place in excess of the basic functions of the vehicle with the purpose to aid the driver controlling the vehicle either by increasing the driver's awareness or by automatically influencing the speed or the steering of the vehicle.*

Before describing the various advanced driver assistance systems that are available on the market, it is important to highlight a potential pitfall here. ADAS all have in common that they operate automatically in the purpose of helping the driver and provide safety. These systems are thus, technically speaking, autonomous in the way they operate. However, none of these systems enable the driver to divert attention from driving and for that reason ADAS do not provide autonomous driving in the sense the term is used in this report. ADAS and autonomy are separated by the differences of Level 2 and Level 3 according to SAE's definitions. The distinction between the terms can thus essentially be found in the level of intelligence associated with each term. An autonomous car must have some level of intelligence to make decisions on its own while ADAS are only in place to assist the driver (as the name implies).

However, there exists a strong connection between ADAS and autonomous technology since the development of ADAS follows a direction towards more and more self-governance. Furthermore the automotive manufacturers that lead in terms of ADAS development also seem to lead the race for a ready solution of an autonomous car (not accounting for progress of non-automotive manufacturers). The automakers' development of ADAS will therefore be integrated in this report as a way to compare these actors’ positions in the closely related field of autonomous technology. This chapter will first give a brief overview of the different ADAS available today before it goes on to describe some of the more sophisticated Level 2 use cases enabled by ADAS that are starting to emerge on the market.

7.1 List of prominent ADAS

In general, ADAS are factory installed and hard to retrofit to the vehicle. The following subchapters describe the most prominent ADAS available on the market. Some ADAS that are virtually standard on all new models such as GPS navigation, cruise control, anti-lock braking system (ABS) and electronic stability control (ESC) have been omitted here since they do not provide any significant differentiation on the market or relevance to the development of autonomous cars.

7.1.1 Adaptive cruise control (ACC)

ACC is essentially a regular cruise control where the driver sets a fixed speed with the addition that the vehicle can also be set to keep a specific distance to the vehicle in front. The distance can be measured by a forward looking radar or lidar. The system can also be coupled with the measure of the car's speed to provide a constant time interval to the vehicle in front instead of a certain number of meters. An advantage with ACC is that it can reduce phantom traffic jams that are induced when drivers alter their speeds significantly in dense traffic. In such circumstances a driver's braking or acceleration behavior tends to propagate backwards while simultaneously increase in magnitude due to people's slow reactions and inexact application of the pedals. The ACC lets the vehicle maintain a more stable speed behind the preceding vehicle than it would if a human operated the pedals and thus reduces the risk for these phantom traffic jams.

7.1.2 Cooperative adaptive cruise control (CAAC)

A CAAC is an extension to a regular ACC where a preceding vehicle wirelessly transmits its acceleration or deceleration to the following vehicle which then can adapt its own speed accordingly. This might seem unnecessary since the ACC's radar or lidar performs the same feature but the advantage is that a CAAC can react quicker since the information is more precise and does not require the same amount of processing. An advantage with CACC over ACC is thus that it can have a more significant effect on the reduction of phantom traffic jams. CAAC is not yet available in production vehicles.

7.1.3 Lane departure warning

This system relies on either a camera typically mounted in the rear-view mirror, infrared sensors that can be placed under the car or behind the windshield, or laser sensors in the front of the vehicle. The system detects when the vehicle comes close to the lane markings and makes the driver aware of the danger with either a visual or an acoustic warning or both. If the turn signal is on in the same direction the car is moving, the system does not react to the lane departure.

7.1.4 Lane keeping assist

This system has the same functionality as a lane departure warning but with the addition that it can actually keep the vehicle in its lane. Either the system takes control over the steering wheel or it brakes the wheels on the opposite side of the lateral movement to in a more subtle way return it to the middle of the lane. This feature can also be used to proactively keep a vehicle center in the lane rather than reacting when the car is leaving the lane, a function that is often called lane centering assist. If a lane centering assist system is coupled with an ACC it results in a system that is able to automatically drive the vehicle although it is unable to negotiate more tricky situations and is prone to errors.

7.1.5 Autonomous emergency braking (AEB)

An AEB system is designed to detect when the preceding vehicle suddenly brakes and immediately follow with appropriate braking power. The system uses forward looking radar, lidar or cameras or a combination of them. These systems also respond to other objects suddenly emerging in front of the vehicle. A challenge for an AEB system is that panic braking is not always the best action, especially not in cases with small animals jumping out in front of the car. Therefore, many systems rely on the driver to initiate braking and instead prepare the brakes to quickly respond to the driver's action. However, studies have shown that people tend to refrain from applying full pressure on the brakes even in situations where it is appropriate. Many AEB systems are therefore designed to detect when insufficient braking is applied after the driver has initiated panic braking and help the driver by applying full braking power.

7.1.6 Collision avoidance system

A collision avoidance system (sometimes referred to as forward collision warning by automakers) is intended to detect potential collisions and mitigate them either by warning the driver or taking own action such as braking or steering. Braking is appropriate in low speeds, below 50 km/h, while swerving often is better at higher speeds. The system uses forward looking radar, lidar or cameras or a combination of them. Some systems also have pedestrian and cyclist detection in addition to detecting other vehicles. The pedestrian detection is usually limited to situations where the entire person is visible and prone to declining performance at dusk and dawn.

7.1.7 Blind spot monitor

This system monitors the vehicle's blind spots to the side and rear of the car. The sensors used are typically a camera or radar in each external rearview mirror or by the rear bumper. The system can warn the driver for vehicles positioned in the blind spot, for instance with a visual warning light in the driver's peripheral sight. However, the system is most beneficial for issuing warnings when a driver starts shifting lanes at the same time as the sensors detect another vehicle in the blind spot (this is also termed lane change assist). The warning omitted is often a light signal close to the corresponding external rearview mirror or a sound but can also be a vibration in the seat or in the wheel. Some systems also take over the steering to avoid an imminent collision with the approaching vehicle.

7.1.8 Rear cross traffic alert

This is essentially an extension to the blind spot monitor since it uses the same sensors but is instead intended to warn the driver of crossing vehicles when reversing from a parking spot. Some systems also automatically brake when they detect crossing traffic. The sensors need to be placed close to the rear bumper to provide sufficient sight.

7.1.9 Forward cross traffic alert

Systems for forward cross traffic alert work in a similar way as the rear cross traffic alert but instead monitors crossing traffic in front of the vehicle, in particular at intersections. The system typically detects potential hazards such as approaching vehicles and warns the driver before it automatically applies emergency braking. These systems normally rely on camera sensors in the front and to the side of the vehicles.

7.1.10 Turning assist

Turning assist is one of the more recently developed ADAS. Its purpose is to monitor oncoming traffic when the driver is about to make a left turn at low speed and if necessary stop the vehicle to avoid a collision. Left turns on busy roads is one of the most frequent causes of traffic incidents. These accidents are also particularly dangerous as the oncoming vehicle hits the turning vehicle to the side where it lacks strong crumple zones. A turning assistant typically relies on forward looking radars and cameras.

7.1.11 Road sign detection

System for road sign detection is based on a forward looking camera that recognizes information on road signs. This information can then be indicated on a display to allow the driver to always stay informed and can also send out warnings when the driver exceeds the speed limit. Currently available systems are only capable of recognizing specific signs with simple information, like speed signs or signs indicating that overtaking is prohibited. For autonomous cars, the recognition of traffic information from signs will be important and this is therefore a field that is undergoing a lot of research. A road sign detection system can also be extended with a system for intelligent speed adaptation which automatically keeps the vehicle at the right side of the legally enforced speed. Such a system can also rely on information obtained in digital maps or potentially from communication with infrastructure (V2I communication).

7.1.12 Other ADAS

The following is a list of some additional advanced driver assistance systems less important for the purpose of this report:

- Hill Assist
- Driver Monitoring Systems
- Driver Drowsiness Detection
- Advanced Front-lighting System
- Crosswind Stabilization
- Night Vision Camera
- Swiveling Curve Lights
- Adaptive High Beam Control
- Heads-up display (HUD)

7.2 Specific semi-autonomous use cases

Virtually all automotive manufacturers are pursuing a step-by-step path towards fully autonomous driving. Therefore it also follows that some use cases will be implemented before others letting autonomous functions diffuse one at a time. Three important initial steps that are starting to emerge are the features called parking assist, traffic jam assist and highway autopilot.

7.2.1 Parking assist

Parking is a maneuver that often requires high precision and by some drivers can be perceived as a stressful experience. Since parking takes place in low speed and in a relatively confined environment, many automakers have started to develop systems that can perform this automatically or with only partial help from the driver. These systems usually rely on a combination of ultrasonic sensors, radars and cameras to interpret the surrounding environment. Ultrasonic sensors are used in particular since they are very reliable in short range applications.

A typical parking assist is capable of identifying parking spaces of appropriate size when driving slowly. Normally, the system requires the driver to fully pass the space and put the car in reverse before the actual automatic function can be activated. Some systems are able to completely without aid drive the car into both perpendicular and parallel spaces while others require the driver to handle the pedals and the changing of gears. Some systems simply indicate the necessary movements on a rearview display. So far, regardless of brand or system, the driver has full responsibility of any incident that might occur and can always regain control of the car, for instance by braking or steering aggressively.

7.2.2 Traffic jam assist and highway autopilot

A traffic jam assist leverages on the combination of an adaptive cruise control with a lane keeping assist to control both speed and steering automatically in congested and slow traffic. Most automakers' systems require the driver to maintain at least one hand on the wheel while the system is engaged and some brands have incorporated driver monitoring systems that for instance can detect if the driver's eyes have been closed for a too long time. These systems are usually only possible to activate in congested traffic and in speeds approximately below 60 km/h, though this number vary between different automakers. The reason why many automakers are reluctant to enable the systems at normal uncongested driving in higher speeds is because such a situation provides less predictability and more room for unusual events. When driving in a congested environment it is easier for the ACC to simply track the vehicle in front and if it changes lanes the lane keeping assist will prevent the car from following the preceding vehicle. The consequences of an error are also likely to be much more serious in high speeds.

However, some carmakers have started to offer what can be denoted highway autopilot systems that are able to drive semi-autonomously in the same lane on deserted as well as congested roads. Tesla was notably the first automaker to offer this in the fall of 2015. However, BMW, Infiniti and Mercedes-Benz and even Volvo Cars to some extent have since then made similar systems available on selected models.

In addition to ACC and lane keeping assist, a traffic jam assist system and especially a highway autopilot needs additional safety features such as an emergency braking system or a more sophisticated collision avoidance system. When these systems are added to the package, the car starts to approach real autonomy and should be able to drive relatively safely even without the driver paying attention. The problem is that these systems are still prone to errors. All lane keeping assist systems available on the market today encounter problems when lane markings are unclear and occasionally even fail to stay in the lane for no obvious reason. The insufficient reliability is the main reason why autonomous highway autopilots yet have not emerged, with regulations as an additional problem on top of that.

A next step for a highway autopilot could be to add features such as automatic lane changing and overtaking and to adopt redundant systems to increase reliability. However, it is worth noting that the cars are not autonomous in the sense that they can make proactive decisions on their own. A highway autopilot is more of a reactive system that reacts in a pre-defined manner to certain input. The step from a highway autopilot to a fully autonomous car is significant since, in addition to the advanced driver assistance systems, a certain level of intelligence is needed to control the decision making.

7.2.3 Platooning

The idea behind platooning is that road capacity as well as fuel efficiency can be increased by reducing the distance between vehicles. This can be achieved by wireless coupling of the vehicles, essentially turning them into a road-based train (hence the name platooning) where the leading vehicle provides the driving controls for the entire convoy. When the leading vehicle slows down, the following vehicles brake simultaneously. This diminishes safety space needed between vehicles of today and generates fuel savings due to the aerodynamic benefits. Platooning is mainly suggested for use on highways where vehicles drive long distances in a somewhat closed environment. Potential additional benefits with platooning are increased safety and driver comfort since drivers will not have to control the vehicle for long periods of time.

One of the major problems with platooning is how to safely integrate the convoys among other road users. In particular, how the convoy should prevent other drivers from trying to enter the spaces between the platooning vehicles is a sizeable problem.

An alternative solution to rely on a leading vehicle and still provide the lateral guidance could be to install some kind of tracks in the roads that the vehicles could follow independently. Magnetic bars have been suggested as a possible solution since the magnets polarization can be encoded to indicate direction.

Platooning is an interesting aspect to consider in the passenger cars market. Autonomous cars could be able to connect to each other to create convoys to increase road capacity. More efficient usage could provide the additional benefit of less need for big multi-lane roads. Another potential benefit could be increased safety since the convoys are not prone to human errors in the same extent as the traffic of today. Nevertheless, the actors with greatest interest in platooning can be found in the commercial transportations industry. Platooning could potentially decrease labor cost if a single driver in the leading vehicle could control the entire fleet. In a shorter perspective, convoys that require a driver in each vehicle could still drive closer together if coupled and thus decrease fuel consumption due to aerodynamics and increase road capacity.

Even if the system would be safer than manual driving, it can be questioned how stressful it is for each driver to stay in such a tight position to the preceding vehicle. If the drivers are removed it results in another problem stemming from the fact that trucks seldom are going to the exact same place. Even if they are heading for the same destination, the unloading becomes less efficient if it has to be done with several trucks at the same time. Another problem is that the infrastructure of today is impractical for platooning with trucks - roads are not adapted to handle long chains of trucks.

A lot more can be said about platooning of trucks but since this report is limited to the passenger car market it suffices to conclude that there are specific use cases where platooning of commercial trucks seems to be beneficial. However, there are also several problems with flexibility that seems to make it unfeasible in most everyday situations in a near time frame. A probable development is that the technique will diffuse incrementally with merely two trucks being coupled for simultaneous braking and acceleration as a first step.

8 Benefits and potential impact of autonomous cars

Similar to many other aspects of autonomous cars, the benefits they carry and the impact they could have on society at large depends on how far the autonomy is developed. The major areas that are believed to be impacted of autonomous technology include safety, convenience, traffic efficiency, mobility, sustainability and city infrastructure. Self-driving technology is generally believed to have a positive impact on all of these aspects.

Overall, the arrival of autonomous cars will generate economic benefits which are an integral part of all areas mentioned above. Today, there are large societal costs (or externalities) associated with automobiles. Externalities are costs that are imposed on the society as a whole rather than on an individual driver. The three most significant externalities are traffic accidents, traffic congestion and the infliction of regional and global pollution. An additional externality that is often mentioned is oil dependency. Autonomous vehicles have the potential to have a positive impact on all four of these major externalities.

8.1 Safety

According to the World Health Organization (WHO) around 50 million people incur non-fatal injuries related to traffic accidents globally each year. The number of fatalities seems to have stabilized at around 1.25 million worldwide each year (accounting for about 2 percent of all human deaths annually). The stagnation is positive since the sales of vehicles are still increasing each year as a result of emerging economies with a growing middle-class. However, the death toll in these emerging economies is increasing along with the increased car use. The reason for the stagnation of the global fatalities can be found in changing road usage behavior in developed countries and these countries' focus on safety in cars and road infrastructure. Semi-autonomous ADAS like electronic stability control have, in fact, already had an impact on vehicle safety. Nevertheless, 1.25 million fatalities per year is a large number and it indicates that much more could be done.

In addition to the significant loss of human lives and individual costs of non-fatal incidents, traffic accidents also inflict large externalities on society. These externalities are mainly a result of emergency service and medical care but also include more indirect consequences such as people being traumatized and decreased road efficiency. According to WHO an estimated 3 percent of the world's GDP is lost to road traffic injuries and fatalities.

Due to the staggering loss of human lives as well as monetary costs indicated above, the safety aspect is the most heavily advocated benefit of semi- or fully autonomous vehicles. These vehicles have the potential to significantly reduce the number of traffic accidents of both fatal and non-fatal outcomes. The underlying reason for this is the fact that humans are prone to errors when driving. The idea to have a passive system that takes over control when the driver misses something is therefore advantageous and the logic behind safety features such as seatbelts and airbags or autonomous emergency braking. To have active systems that take control of the actual driving tasks requires much more development than passive systems but also has greater safety advantages. For instance, a computer does not reduce attention or get distracted and it has the ability to react immediately (or at least significantly quicker than a human) to information.

A major reason behind people's mistakes when driving is lack of attention due to distraction such as texting, conversing with a passenger or simply a result of fatigue after driving for a long time. Another much too significant reason is driving under influence of alcohol or other drugs. A fully self-driving car would solve both these problems. Furthermore, a computer can be programmed to not engage in aggressive driving behavior - something that is much harder to realize among people.

However, full autonomy is not necessary to reap large safety benefits. Estimates have shown that current accidents could be reduced with a third if all vehicles where equipped with forward collision warning, lane departure warning, blind spot monitor and adaptive headlights. These systems do not even correspond to SAE Level 2 of autonomy. In addition to this, connectivity among cars, to infrastructure and to the internet also has the capability of significantly increasing safety. For instance, a car that encounters a hazardous situation can warn following vehicles of the danger.

8.2 Convenience

Another benefit that receives a lot of attention is the increased convenience associated with autonomous cars. This benefit is similar to the safety aspect in that it has an impact even with semi-autonomous systems. Many of the current high-end passenger cars are equipped with ADAS that make the driver's task less tedious. However fully autonomous cars would result in a larger impact since drivers then are completely allowed to remove attention from driving and instead can read a book or sleep or engage in another activity.

A traffic jam assist system that features full autonomy as long as the car is in congested traffic and on motorways is significantly easier to develop than a fully autonomous car. Such a system would also enhance the driver's experience of the most tedious condition to be driving in and thereby increase convenience. A parking assist is another relatively simple feature compared to full autonomy which also could have an impact on convenience.

To ride in a car can be a different experience in the future compared to today's driving. Microsoft, for instance, has envisioned self-driving cars as mobile offices while other actors talk about using autonomous cars to explore the world through long distance journeys. Several carmakers have showcased concepts for interior design in autonomous cars with large touch-screens along the side panels of the car or with chairs that can be spun around to facilitate conversation among the car's passengers.

8.3 Traffic efficiency

In addition to make congested driving more convenient, self-driving vehicles might also have a positive impact on congestion itself. Fully autonomous cars could potentially be wirelessly connected to each other and drive closer together to increase the road throughput efficiency. A decreased rate of accidents would also result in reduced congestion in addition to the safety benefits discussed above. Furthermore, connected or autonomous vehicles could eliminate phantom traffic jams which occur for no external reason but simply from small changes in speed escalating backwards in the congested traffic.

A benefit that emerges already with semi-autonomous car is these vehicles capability of keeping a continuous speed. A human constantly applies slightly different pressure to the gas pedal and often brakes harder than necessary while an adaptive cruise control keeps a much more consistent vehicle speed. Connected vehicles that can plan their speeds as well as routes taken in collaboration results in even higher efficiency - platooning is an initial example of this. In a more distant scenario, connected and self-driving cars can collaborate to plan speed and route in a better way to further increase traffic efficiency.

The great advantage with increased traffic efficiency is the economic benefits that follow from it in terms of saved fuel and time.

On the other hand might vehicle miles travelled (VMT) increase since autonomous vehicles could stimulate additional vehicle usage. More vehicles on the roads could lead to more congestion if the self-driving vehicles are not able to increase efficiency to a sufficient extent. Furthermore, if cars should not be allowed to park in cities the exit and entry routes into the city will be more heavily trafficked and thus require enhancement of the infrastructure. However, most studies estimate this effect to be small.

8.4 Mobility

Human mobility could be enhanced by autonomous vehicles in a number of ways. Not only would it be convenient but people could also drive longer distances much more efficiently if they could sleep in the car while it continues to drive. However, the most dramatic influence autonomous vehicles could have on mobility is for people who are unable to drive.

Another important aspect of fully autonomous vehicles is the new mobility patterns that are starting to emerge with car sharing and similar use cases. The advent of fully autonomous vehicles could transform the way people travel in cities from a car-ownership model to one based on a public fleet of driverless cars.

8.4.1 Benefits for people unable to drive

There are a lot of people who, for various reasons, are unable to drive. As mentioned in chapter 1.9.4, people with disabilities and elderly people could benefit from cars that drive by themselves but transportation of these people is not the only circumstance in which people are unable to drive. There are several specific situations when people could use an autonomous vehicle such as after having sprained an ankle or been in another accident. Furthermore, people without a driver's license could obviously benefit from driverless vehicles. Another use case is for parents to send their kids with a self-driving car to soccer practice or to school. A perhaps less obvious use case stems from the fact that people should not drive under influence - with a fully self-driving vehicle it could be possible to avoid the expensive taxi fare after a night out and also reduce the number of drunk drivers.

These benefits are not without problems. How reliable must a self-driving vehicle become before a drunk person or someone without a driver's license can be allowed to operate it; will parents be fine with sending their kids off all by themselves in an autonomous vehicle; will old people trust or understand the autonomous technology enough to benefit from it - those are some question marks regarding the benefits of autonomous vehicles. Furthermore, it is important to remember that the advantages for people who lack the ability to drive, generally or in a specific situation, are realized first at full autonomy corresponding to an advanced Level 4 or even a Level 5. However, the areas mentioned are likely to be affected once these cars emerge.

8.4.2 Public driverless fleet of cars

Perhaps the most advocated benefit on mobility is related to the emerging trends of car sharing, carpooling and ride hailing which can be greatly influenced by the advent of autonomous vehicles. Due to large costs for fuel, insurance, congestion, parking and other fees, people in cities are becoming less interested in owning vehicles and instead want to use alternative methods for transportation. Public transportation is limited to transport between specific stations and often takes more time compared to taking the car. Private transportation, on the other hand, is too expensive for most people.

Ride hailing services like Uber and Lyft have found a way to leverage on the fact that there are people who have extra time in which they can transport other people for a reasonable price. In general, a sharing economy, such as Uber's and Lyft's business model, utilizes a platform to have supply meet demand in the most efficient way. In the case of Uber and Lyft this means that owners of cars can get an extra profit on their spare time from driving people who for various reasons do not want to or are unable to drive by themselves. The advantage of such a service is that it has the flexibility of private transportation but a significantly lower price which makes it more accessible than regular taxi business.

Companies like Uber and Lyft have thus already changed the market for ride hailing significantly but the full potential of ride hailing will not be realized until the service can leverage on driverless vehicles. Another interesting aspect is that the cars in a driverless fleet will not have any incentives to outperform each other by keeping to the most popular locations. Coordination in general can be greatly enhanced with a centrally organized fleet of autonomous cars.

A fleet of driverless vehicles could provide the same mobility as privately owned vehicles while simultaneously being a cheaper alternative and provide the added benefits of not requiring an attentive driver as well as diminish the need for parking infrastructure in cities. The economic benefits with such a fleet could be substantial since each vehicle could be utilized much more than privately owned cars which spend most of their time standing still. A simulation study made by Columbia University estimated that the city of Ann Arbor in Michigan with a population of about 285,000 and 200,000 cars could completely satisfy its local mobility demand with a fleet of only 18,000 fully autonomous cars. A similar study made by MIT has showed that by combining ride hailing and ride sharing, the vehicle fleet in a city such as New York can diminish by 80 percent. Diminishing number of vehicles in a city results in additional benefits like less noise, less pollution and less potential accidents.

The new mobility patterns could, combined with autonomous cars, thus have a significant impact on efficiency. This could result in substantial economic benefits since it would increase the time an individual vehicle is deployed as opposed to the current situation where cars spend most of their time parked and non-utilized. Moreover, should a driverless fleet consist of electric vehicles it would also eliminate the costs of petrol and reduce emissions. However, it should be noted that the technology for cars to drive completely autonomously in cities still needs a lot of development before it can be launched.

8.5 Sustainability

Autonomous cars in general will have an impact on all three dimensions of sustainability (i.e. environmental, economic and societal sustainability). The economic and societal sustainability is affected mainly due to the benefits of increased traffic efficiency and safety. However, this section will focus on the environmental aspects of sustainability since the economic and societal impact is covered by other sections.

Although environmental benefits seldom are the primary goal with different actors' development of autonomous cars, they are believed to have an impact on sustainability for two main reasons. The first is that autonomous vehicles go hand in hand with electric vehicles. The second reason is that autonomous vehicles have the potential to increase efficiency in a number of ways as described above. Electric vehicles and to some extent better fuel efficiency also diminish oil dependency.

8.5.1 Electric autonomous vehicles

Most projects in autonomous vehicles today use electric cars and sometimes hybrids to test their systems for self-driving technology. The automakers seem interested in aligning one technology for the future with another. To combine autonomous vehicles with electric cars also has some engineering benefits with less complex drive trains and longer lasting motors. It is also not trivial to adapt an existing model to the drive-by wire operation required by autonomous vehicles but it is easier with an electric car than with a combustion driven.

The most prominent argument against electric vehicles is their short range. Autonomous vehicles, however, might transform this into a non-problem due to the new mobility benefits they bring. If mobility in cities is provided with fleets of public driverless cars, range will be a much lesser concern since these cars can drive autonomously to a charging station when battery power has declined below a threshold level. Current electric vehicles have sufficient range to cover several city-bond journeys on a single charge as these trips normally do not extend beyond 10 km. Autonomous electric vehicles could thus remove most of the vehicle-emitted green-house gases and pollutions in cities.

This niche-type usage with fleets of autonomous cars is also easier to realize than a Level 5 autonomous car capable of driving by itself everywhere. In fact, there are projects that already have launched electric and autonomous vehicles to the public in special confined areas. For instance, there are electric and autonomous four-seated pods at Heathrow airport that transport people back and forth from Terminal 5 to a parking lot. A similar project has taken place in Wageningen in the Netherlands with transportation of people in autonomous electric buses and in Milton Keynes in the UK will self-driving and electric pods soon shuttle people between the train station and the city center. This type of autonomous public transportation is likely to emerge in more places and be an early specific use case for autonomous vehicles. Needless to say, cars with fully autonomous capabilities in cities require far more development than the specific use cases at Heathrow, in Wageningen and in Milton Keynes. Nevertheless, these initiatives indicate that it makes sense to let autonomous vehicles run on batteries.

8.5.2 Increased efficiency

Assuming carmakers eschew from making autonomous vehicles electrical but instead rely on combustion engines, the self-driving vehicles can still have a significant impact on emissions since autonomous cars offer extensive enhancement of fuel efficiency due to the reasons discussed above regarding traffic throughput. The fuel efficiency benefit starts already with semi-autonomous systems like adaptive cruise control which maintains the same speed much better than a human. Platooning and connected cars can increase fuel efficiency even more. Furthermore, the transition to on-demand fleets of autonomous cars, mentioned above, would significantly reduce amount of vehicles necessary and thus have a positive impact on sustainability even if they are driven by conventional combustion engines.

Another way to improve fuel efficiency is by making cars lighter, something that might be viable if cars virtually never crash. Today, it is necessary to reinforce cars with heavy body structures and crumple zones to increase passenger safety. If all cars are autonomous and never crashes, vehicles' weight could be significantly reduced.

8.6 Impact on city infrastructure

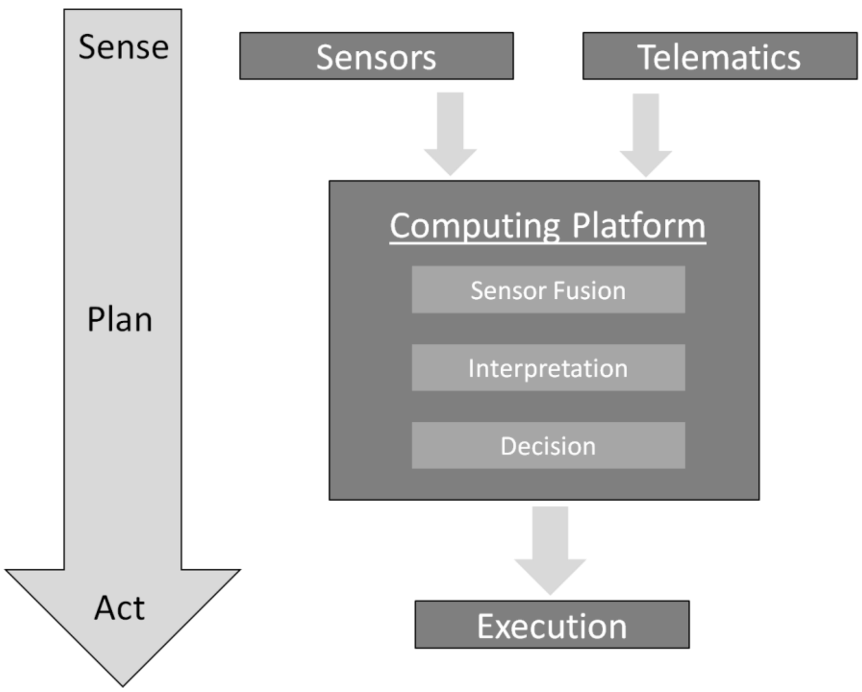
One of the largest benefit envisioned with autonomous cars is the impact such vehicles could have on city infrastructure. Most heavily advocated is the idea that we will need less parking spaces when cars are fully autonomous and can drop off passengers before parking outside of the city. Parking areas make up a large amount of the space in cities and the freed up space can be used for other buildings or parks. Driverless cars can also reduce the need for parking by the side of the streets which then can be made more narrow and thereby free up space for people and cyclists or for buildings to stand closer to the streets. Parking can also be more efficient when vehicles are communicating with each other and infrastructure, further reducing the need for parking spaces. As cars get increasingly autonomous they also need less traffic signs and similar infrastructure.

The increase of on-demand mobility services might come with the downside that it requires more drop-off or pick-up places which could reduce space for cyclists and pedestrians. However, this effect is likely to be small compared to the removal of entire parking areas.

9 Autonomous cars technologies

One of the main challenges associated with autonomous vehicles is the advanced level of several technologies that is required for the vehicles to function in a reliable and safe way. The technologies necessary and especially the level of their sophistication are of course dependent on the level of autonomy for the individual vehicle. In general, though, for a car to be able to drive with only partly or none influence of a human driver it needs to follow a sense-plan-act process. In other words it must be able to perceive its surroundings, translate the information into different options, make decisions and finally execute these decisions. It follows that autonomous cars need both additional hardware and software compared to regular cars.

Figure 13. Sense-Plan-Act process



The decisions making in an autonomous car can be based on parallel loops of a sense-plan-act logic that runs at different frequencies. An emergency loop for instance might have to be updated very frequently and be more of a sense-act type to quickly detect and respond to emergency situations while other less important loops can be updated more slowly.

This chapter describes the major technologies necessary for enabling a car to drive partly or completely without a human driver. These technologies can broadly be divided into the following subchapters: Sensors, Telematics, Computing Platform and Execution.

9.1 Sensors

Although a mix of technologies is necessary, sensor devices are arguably the single most important technology to enable autonomous cars. The sensors scan the car's immediate environment and the embedded software process this into actions to steer and control the car's speed. To attain the best result, different types of sensors are necessary since they vary in range and in what they are able to detect.

In general, the market for sensors is increasing since they are becoming more integrated with semi-autonomous systems across the automotive industry. The price of the sensors relative to their capacity is decreasing due to continuous technical enhancements as well as economies of scale. This chapter will introduce the most important sensors for building autonomous cars. These sensors are currently being used in research vehicles aiming for full autonomy. Except from the roof-mounted spinning lidar, the production cars of today that feature semi-autonomous technology leverage on the same kind of sensors as used in the research projects.

9.1.1 Cameras

A camera functions in a similar way as the human eye, it registers light reflected from objects in the environment and creates a picture of it. However, when it comes to the next step, to interpret the picture, humans outperform technology. Our brain can quickly make out a 3D representation of a 2D picture and perceive details such as a person during various light conditions and we can even notice in what direction the person is going. The current image recognition capacity in computers does not perform at this level which is one reason why cameras are being supplemented with other types of sensors in autonomous cars. Another reason is that cameras do not work very well in dark conditions and additional sensors enable the creation of redundant systems with multiple sources of input.

The fact that cameras resemble our own way of perceiving the environment (by the use of eyes) leads to some obvious advantages compared to other sensor technologies. For instance cameras are the only sensor technology that can make up a high resolution representation of the environment with all its colors and thus are able to identify for example road signs, brake lights and the color of a traffic signal. On the other hand, since cameras identify reflected light, they are dependent on headlights or other light sources during the night. Cameras used in cars are not very different from cameras used in everyday life which makes them inexpensive and feasible to use in multitude. A technique used to improve the performance of cameras is to mount them to the car with slightly overlapping field of sight. Just like with the human eyes this enhances their ability to see peripheral movements as well as depth of field and thus the dimensionality of objects.

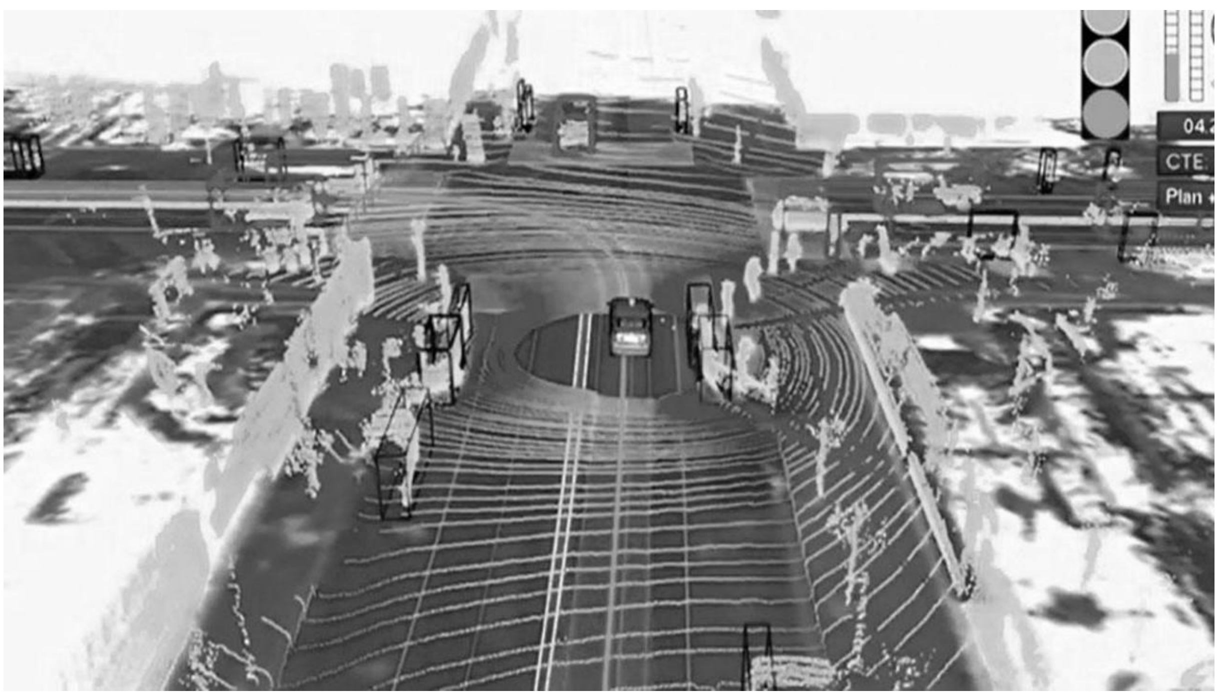
One can argue that cameras are best a detecting road signs, traffic lights and lane markings simply because we have built these information systems with our own seeing capability in mind. A possible alternative could be to equip the road signs, traffic lights, lane markings and other roadside information systems with beacons that emit information to the vehicles about their current state (e.g. "the light is red", "speed limit is 50 mph" or "this is an exit lane"). Such systems could make the use of a camera redundant in some use cases but then again a camera is likely to be needed to detect hazards such as objects blocking the path of the car.

9.1.2 Lidar

Lidar is a type of detection system that works by detecting the rebound pattern of an emitted laser that is allowed to bounce against solid objects. The time it takes for the laser to return precisely measures how far away the objects are and makes it possible for the lidar to interpret the surrounding environment in a 3D model. A lidar is thus much better than a camera at perceiving depth. The technique has been used for various purposes including measuring clouds and mapping the surface of the moon. A lidar mounted to the front of a vehicle can be used to achieve adaptive cruise control. Many experts believe that lidar will be necessary to have reliable and safe autonomous cars. In today's' prototypes, the lidar is mounted on top of the car on an axis that is constantly rotating when the car is in motion. This position and spinning system allows the lidar to map the environment in a 360 degree without being blocked by the car it is attached to. Since lidar uses emitted laser it is independent on the ambient light meaning it works just as good during the night or in cloudy weather as during the day. The resolution from a lidar is high in a horizontal dimension but low in the vertical dimension. This is because a lidar needs an additional laser beam to measure an additional vertical point while the horizontal dimension is taken care of by sending multiple beams from the same origin while the device is spinning. Compared to typical radar, though, the resolution is much better and the signal is also less prone to interference.

There are, however, some disadvantages with lidar. The range is limited - a lidar typically functions well to about 70 meters and can discern larger objects up to 100 meters. The signal can encounter trouble during heavy rain, snow or very foggy conditions, not because of the lack of light but because the signal is rebounded on the particles in the air instead of the objects behind them. The signal from materials with low reflectivity (such as asphalt) can also be low. Furthermore, unlike radar, the lidar is not good at determine the movements of other objects; it simply renders snapshots of the environment. The lidar does not perceive different colors, rather it sees a gray scale of infrared light and is therefore inferior to cameras in that aspect. Also, lidars are still very expensive although cheaper alternatives have started to emerge. The Velodyne HDL 64E, which is the most used lidar in prototype driverless cars today, comes with a price tag of around $ 75 000. However, in the long run the technology is probable to become significantly cheaper as a result of Moore's law and larger production volumes.

Figure 14. Typical lidar 3D depiction integrated with a digital map



Source: Alphabet Inc.

A lidar's main advantage is that it is highly reliable. If the laser hits something of decent size, like a pedestrian or a bicycle, it is going to show in the 3D model. Even if the lidar is unable to tell precisely what the object is it does not necessarily have to. If something is blocking the road, the car must come to a halt regardless of it being a person or a vehicle, or even a toppled tree for that matter. On the other hand, today's lidars can occasionally return false positives such as interpreting the smoke from the exhaust pipe of the vehicle in front or a paper blowing in the wind as a solid object which could cause unnecessary and dangerous emergency braking.

9.1.3 Radar

The radar technology predates lidar and works in a similar way but uses radio waves instead of light. A radar emits radio waves which reflect from surrounding objects and is detected by a receiver which translates the signal into information about where the objects are positioned as well as what speed and direction they have. Individual objects' velocity can be measured thanks to the fact that waves from an object in motion relative to an observer change in frequency, a phenomenon called the Doppler effect. Since radar, unlike lidar and cameras, is not based on optics it has no problem seeing through clouds and it can even detect a vehicle obscured from visual sight by another vehicle immediate in front of you since the waves can bounce on the road beneath the obscuring car.

The main problem with radars is that they have very low resolution. Radar simply is not very accurate in mapping where objects are positioned or making out their shape. For instance, when a radar detects another car it is not certain whether it maintains its position in the adjacent lane or if it is creeping into yours. Another major problem with radar is that although it typically has no trouble detecting metallic objects such as vehicles, it is much harder for it to detect nonmetallic objects making pedestrians virtually invisible to them.

9.1.4 Ultrasonic and Infrared sensors

Ultrasonic sensors are relatively inexpensive and have the ability to provide accurate short-range data (below 10 meters). Today they are being used in most premium vehicles as warning sensors when parking. Some major OEMs have developed partially automatic parking assist systems that are based on ultrasonic sensors and there are also some ongoing projects aimed at developing fully automatic parking systems that will rely on these sensors to a large extent. Another potential benefit with the ultrasonic sensors is to use them in an emergency backup system that can apply pressure to the brakes if it detects an obstacle just in front of the vehicle.

Infrared sensors have the advantage to standard cameras that they work equally well in darkness as in daylight. This means that it can detect, for instance, lane markings even in darkness which is also the major application for these sensors in cars. However, the range of the sensors is very short and they are therefore more suitable for detecting when the vehicle is crossing a lane rather than to help it track lanes. A long-wave infrared (also known as thermal) camera can perceive differences in temperatures which can be very useful at night to detect animals. However, these type of cameras are rather expensive. Infrared sensors are not believed to be of equal importance for an autonomous car as the other sensors mentioned above but they have the potential to increase the redundancy and safety of these cars.

9.1.5 Inertial navigation system

An inertial navigation system (INS) is deployed in a vehicle as a complement to satellite navigation systems. INS uses a type of dead reckoning method to calculate its position, i.e. it bases the calculations on information about its previous location and velocity. The INS is equipped with a computer connected to gyroscopes and accelerometers that communicate changes in direction and speed. The technique is a suitable complement to positioning via satellites since it is not reliant on a transmitted signal that can be blocked in a tunnel for instance. However, INS is not suitable for use without satellite navigation since it is prone to integration drift which is an error that occurs as a result of the accumulation of many small errors in the mechanical measurements. These inaccuracies must be offset, for instance by the use of a GPS device.

9.2 Telematics

In this report, telematics is defined as an automatic system designed for passenger cars that incorporate some form of cellular communication. Telematics is a somewhat separate technology from autonomous vehicles with its own applications and benefits but it is also likely to be an integral part of future autonomous cars. The bottom-line is that vehicles with integrated telematics are a probable development simply because of the increased service it brings.

Most of the leading carmakers today include telematics in their offerings. These offers consist of infotainment systems with the ability to stream music, movies and other applications and also the possibility to call the service provider for roadside assistance if a vehicle malfunction occurs. An embedded system for navigation and positioning (such as GPS) is also a popular service. Further examples include stolen vehicle tracking, vehicle diagnostics and applications for convenience such as preconditioning through heating or cooling of the passenger compartment prior to a trip.

The drivers behind adoption of telematics are not only commercial - regulatory decisions are also affecting the development. For example, starting in April 2018, all new cars manufactured inside EU is required to be equipped with eCall, an emergency system that automatically dials 112 (Europe's single emergency number) in the event of a serious accident. This system transmits data about the accident even if the passengers are unable to speak because of injuries. Aftermarket service providers are also probable to benefit from an increase of telematics in cars. Insurance firms can offer usage-based insurance, where an individual's driving performance is logged and reflected in the level of premium charged by the insurer. Leasing and rental fleet management as well as electronic toll collection are other possible applications of telematics in the future.

The number of telematics subscribers using embedded systems is according to Berg Insight forecasted to grow at a compound annual growth rate of 39.9 percent from 20.5 million in 2014 to 153.4 million in 2020. However, not all these subscribers will have the extensive access to all applications but rather only to safety services such as eCall. Berg Insight forecasts that the number of active subscribers using at least one additional premium telematics service will grow to 110 million worldwide users at the end of 2020.

Telematics is an important part of driverless technology for multiple reasons. First of all, to enable smooth updates to vehicles' software, a constant connection to the manufacturer or the service provider is necessary. Otherwise, updates have to be downloaded manually through connecting the vehicle to a network while parked at home. Tesla, for instance, is currently using patches to upgrade its customers' cars and has through this method been able to make already distributed cars semi-autonomous in certain driving situations. Manufacturers of driverless cars could also receive information from its cars' behavior on different roads and in various situations and make updates to the self-driving performance based on this information. For example, a vehicle might take a specific turn at too high speed, causing the driver to regain control and slightly push the brake pedal. If the manufacturer receives information that many drivers do this in this specific turn, it could transmit an update that makes the cars approaching the turn at a slower speed in the future.

It should be mentioned that telematics alone are not enough to enable automated driving mainly since the current global navigation satellite systems (GNSS) are not sufficiently reliable or precise in its measurements. Moreover, the next generation of GNSS, despite significant improvements resulting in an estimated maximum error of less than 1 meter in normal situations, will still not be precise enough to be a reliable guiding technique for autonomous cars unless coupled with other on-board sensors. Telematics in general is not a substitute to other sensors in an autonomous car, rather it is a complement.

9.2.1 Mobile networks

Internet connectivity is becoming an increasingly important service in today's car market. The internet connection is made available by the use of mobile networks such as 2G, 3G or 4G. Automotive manufacturers can choose between several connectivity options when creating connected car services, which are not mutually exclusive. The main options are embedded telematics devices, tethered devices and integrated smartphones. With embedded systems the connectivity and intelligence is built into the car. In the case of tethered devices, the connectivity is provided by an external modem or handset while the intelligence is built into the car. Solutions relying on integrated smartphones leverage the connectivity and intelligence built into the smartphone. Carmakers often use a combination of these options to address different customer requirements and keep pace with the rapid development of mobile technology.

The fact that the use of telematics are likely to increase in vehicles implies that networks with higher capabilities in terms of coverage and speed will be of need. Thus there is a big potential market both for companies providing infrastructure for communication technology as well as mobile network operators. Furthermore, the use of in-vehicle Wi-Fi hotspots are probable to increase along with increased autonomy. Some manufacturers offer in-vehicle Wi-Fi hotspots that use the car's embedded cellular module for connectivity. Other possibilities include aftermarket provided USB modems placed in the glove box or another area in the passenger compartment. With today's offers, passengers are able to use the Wi-Fi to surf but the driver still has no benefit from it. One of the most common uses of cars is as a means of transport to and from work, a journey that is often undertaken without additional passengers. To give these commuters the ability to do work in the car would be a much more efficient and valuable use of their time.

9.2.2 Location tracking

There are two alternative methods for remote tracking of vehicles. One option is to equip the vehicle with at radio transmitter that starts emitting a VHF signal when activated. The VHF technology is mainly used in stolen vehicle tracking applications since the signal omitted is hard to jam. The other, more common, option is to use a global navigation satellite system (GNSS). There are currently two GNSS operational on a global scale - the United States' GPS and the Russian GLONASS. In addition, two other GNSS are under development, the Galileo system and the BeiDou 2 system being developed by EU and China respectively. Preferably, multiple GNSS are used in conjunction since this provides superior coverage and reliability compared to only using one system. To provide navigation and positioning through the integration between GNSS and digital maps are nowadays standard in premium cars.

A problem with the use of GNSS devices is that it is not perfectly reliable since vehicles at times are not visible to enough satellites. This is particularly apparent in urban areas where high skyscrapers create what is often termed as street canyons that obscure the signals. It should be noted though that GNSS are getting increasingly reliable and is soon down to an error margin of less than 1 meter. Still this precision is not sufficient to control a driverless vehicle.

9.2.3 Digital maps

Digital maps represent real world objects such as roads, cities and land use, with digital data. The data can be stored in two generic formats, vector format and raster format. The vector format uses mathematical expressions to describe geometric primitives such as lines, curves, polygons or points. Vector maps depict real world objects using combinations of several geometric primitives. The raster format represents objects as pixels and a raster map is thus simply a picture representing real world objects. There are several advantages to model real world objects using a vector format. Firstly, the content of a vector map is searchable. Secondly, much less data is generally needed for storing the map. Thirdly, the user can zoom in and out without affecting the visual quality of the graphics. Finally, line widths, color and other display features can easily be modified.

Three general types of information are normally included in digital maps: geographic information, attributes, and display information. The geographic information contains the position and shapes of each feature in the map, for example roads, railways, rivers and land use. The position of each feature is expressed in the coordinate system defined in the map system. Usually three fundamental geometric objects are supported: points, lines and polygons. Attributes are additional information associated with certain features in the map, such as street names and addresses. An important group of attributes for navigation purposes is routing information, including road type and class, road number, traffic flow (e.g. one-way, two-way, highway with separate lanes), turn restrictions, toll roads and speed limits. Increasingly rich data is gathered by map providers, including for instance road sign information as well as 3D information and images to offer lifelike views of roads, complex intersections and buildings. Finally, the display information contains data about how the map is to be displayed, for instance in terms of line widths and types, colors and text.

Built-in navigation systems are becoming standard in new cars, especially in the high-end segment. There are alternatives, such as providers of external GPS devices like TomTom or, perhaps even more significant, free smartphone based apps. Nevertheless, many customers prefer to have an integrated navigation system.

Digital maps will probably play a major role in the transition to increasingly autonomous vehicles. At the most fundamental level, an autonomously driven car must know where it is positioned and where it is supposed to go and for that, digital maps are a necessity. What is less obvious is the fact that digital maps can be very rich in detail, including information about road conditions, if there is a road work going on, what the traffic is like and how the weather is. For this information to be relevant, the vehicles will need a connection to a cloud service where current road data is obtained from other vehicles.

As an example, Google Maps has today a feature that shows color-coded traffic conditions (green to red scale for fast to slow traffic). The function is available thanks to a database that collects real-time GPS information about mobile-phone users' locations. The relative changes in the users' position are then calculated and the result can be compared to the speed limits along specific routes to determine the levels of congestion. This extended use of digital maps with crowd sourcing of real-time information is of importance for an autonomous car to make efficient route decision possible.

Autonomous cars might also provide information to a cloud-based digital maps service by the use of their sensors. For instance, an autonomous car's camera can notice debris on the road and automatically transfer this information to the cloud which in turn distributes it to other vehicles. Certainly, vehicles that constantly generate updated maps require a lot of computer power, a strong connection to the cloud and also sophisticated algorithms for deciding what information to transmit. Developments in the field of big data might therefore be important for these type of systems to work. However, the required technology in itself is perhaps not the biggest challenge. To determine what standards should apply and what actor should be responsible for operating the cloud service could provide an even large obstacle. In addition, there is security as well as ethical issues related to these types of systems that have to be dealt with.

9.2.4 V2V and V2I communication

The development of vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communication is likely to play a significant part in the development of autonomous driving. V2V and V2I are often referred to with the broader term V2X where the "X" indicates an arbitrary vehicle or infrastructure node that the vehicle is communicating with.

When representatives from General Motors presented their anticipation of automatic driving during the New York World's Fair in 1964, they guessed that it would be made possible through the use of sensors alongside super-highways that would communicate with the vehicles and guide them in the right direction. Due to the enormous complexity of the world's road network, that type of a system seems to be unfeasible to implement everywhere. However, such a system could be implemented today on specific and highly utilized paths such as major highways much like GM forecasted. The problem is that such a road would require every user to have an autonomous car since it would be unsafe to mix self-driving and human operated vehicles. Furthermore, highway automated driving is starting to become a reality only by relying on a cars' on-board sensors, even though drivers still have to maintain attention. Therefore it is more likely that V2I communication will be used as an aid to autonomy rather than enabling it in itself.

Development of infrastructure that communicates with vehicles has a significant potential to aid autonomous driving in many situations. A traffic light, for instance, could inform an approaching car to stop or keep going which makes the autonomous driving less dependent on the camera sensor's interpretation of the traffic light color. Another use case could be parking space dedicated sensors that omit signals with information whether they are available or not to decrease the time for a car to find a parking spot.

V2V communication can provide cars that are blocked by other vehicles with awareness of the environment to aid the autonomous driving. Connected vehicles can for example communicate traffic flow information and send warnings for congestion or slippery road conditions. The US army has recently experimented with heavy truck convoys (platooning). A single driver operates the leading truck while the rest automatically follow close behind by the use of coupling between the trucks. Each truck is also fitted with sensors that enable the vehicle to detect dangers and slow down if necessary. The US army is also planning to test platooning with V2I capabilities where infrastructure along a test road will communicate various information such as speed limits and lane closures to the vehicles.

One way to achieve V2V and V2I is by using DSRC (dedicated short-range communications), a wireless technology specifically designed for automotive use. DSRC utilize a designated bandwidth and works at high speed and in severe weather conditions. If DSRC is equipped on a large scale it has the potential to reduce so called phantom jams that often follows from a minor disturbance (for instance a vehicle braking too hard) because of the accumulation of differences in responding time and amount of braking. Even ACC is prone to reaction times to changes in speed, although this lag is less than the average of a human driver. DSRC can thus be a valuable technology even for cars that use cameras and other sensor devices to autonomously drive it.

Much like the case with digital maps, one of the main problems with V2X communication is the lack of industry spanning standards for the sensors and their communication specifications. The bandwidth allocated in EU is different from the one in the USA, meaning that the connectivity devices must be specifically manufactured for each market which is inefficient. Moreover, incumbent firms have not showed a very keen interest on collaborating in V2V communication. Some of the foremost players such as Mercedes have already the technology necessary but so far a Mercedes vehicle is only able to talk to another Mercedes which is sub optimal to vehicles communicating across brands.

Privacy is another issue in the sense that the connectivity might pose threats of being hacked. Malicious people could also put up devices that transmit false information to the car. Such devious behavior can of course occur in today's road traffic as well but the difference is that drivers can more easily identify suspicious circumstances whereas a computer is not programmed to identify information as false.

9.3 Computing platform

Vehicle systems that gather data about the environment (such as lidar, radar, cameras and GPS) are to no use if their data is not interpreted by software that can understand what it sees and use this information as a basis for decision making. An autonomous car will need a computing platform that allocates the information from the sensors and communication technologies to a main computing unit which combines this input with information from digital maps to create a model of where the car is located, where it is going and what its surrounding environment looks like. To put all this information together is certainly not a trivial task but the next step, to interpret the data that is being merged, is even harder. This interpretation provides the foundation for the decision making and therefore has to be reliable.

Although computers completely outperform humans when it comes to making calculations, they are still inferior to humans in terms of understanding a complex situation, making predictions and come up with a well-informed decision. However, this is starting to change and the key for that change seems to be for a computer to truly understand camera input. If a computer is able to understand images at a level similar to humans, its advantages in computational speed, scenario analysis and precise driving control would make an autonomous driving system safer than any human driver.

This chapter first highlights some important aspects in fusion of all the sensor data before discussing the conceptual challenges associated with creating a decision making program for an autonomous car. The focus is then shifted to the actual software that is required to create the decision making algorithms. This latter part will focus on computer vision and how machine learning techniques are starting to revolutionize this field.

9.3.1 Sensor fusion

Autonomous cars will leverage on multiple input of data from different sensors. It is possible that one single technology, such as a very sophisticated lidar or camera, in some distant future will be able to create an ultra-reliable model of the environment and thus need no extra input. However, such an advanced technology is far from available today and therefore prototypes and test efforts rely on a central computing platform that merges all the data from the different sensors.

Since different sensors have different strengths and limitations, a way to create an integrated model is to rely on a certain type of sensor for a specific type of data. However, it is probably unwise to program one kind of sensors to always overrule others in specific situations as every sensor is prone to errors. Rather, an integrated system's strength lies in its diversity and the resulting possibility to analyze each situation from multiple perspectives to make a well-informed decision.

For autonomous vehicles, sensor fusion has two tasks, localize where the car is and perceive the surroundings. Solutions to the first task are already available in virtually all new cars where data from GNSS and INS are used together with digital maps to give the driver information about the position. To integrate the different inputs from gyroscopes, accelerometers and GNSS with digital maps demands some computing power but is a relatively straight-forward process. However, the precise location of the car on the road or in a lane needs additional input from sensors which make the positioning problem more difficult.

Furthermore, when it comes to performing the second task of perceiving the surroundings, the process of integrating the data gets even harder for a number of reasons. First of all, the amount of data from cameras and other sensors is much larger than from INS and GPS. A lidar for, instance can scan the environment at a rate of about 10 Hz (i.e. ten revolutions and 3D images per second). The implication is that software will have to understand one image and relate this to data from other sensors ten times per second which demands a lot of computer power. The result is an ever-changing model of the environment that can be used to make decisions.

The actual hardware where the sensor fusion takes place is still an area of advancement. So far, the massive amount of processing power needed has been resolved by putting several computers in the trunk of a test vehicle. However, developments in big data capabilities are constantly made and there are alternative methods to handle the rich image data captured. A graphics processing unit (GPU) for instance is significantly faster at image processing than a standard CPU because of its capability of parallel processing. GPUs can therefore be of importance for tackling computer vision and the difficult process of object recognition. However, a GPU is less suitable for more general operations where the amount of data is smaller but requires more operations.

9.3.2 Interpretation and decision making

When we enter driving school we are told that most of the driving experience after a while will become intrinsic - we will not think about changing gears but rather do it in a sort of automatic way. The reason for this is that we will eventually have changed gears so many times that we know exactly how the action is performed making it a part of our muscle memory. Most driving situations are indeed repetitive which might indicate that it could be handled by a sequential logic that controls the action of the car in accordance with a certain predetermined set of rules. For example, when a car should enter a highway, it must know the speed limit either from information in digital maps or from cameras detecting road sign information, its sensors should notice whether there are other vehicles obstructing the adjacent lane and the driving platform should turn on an indication signal. Such things could basically be checked off from a list one after another as the car makes its way onto the highway. However, even such a typical and relatively simple maneuver has a level of complexity to it. Imagine that another vehicle is approaching at a similar speed slightly behind in the lane adjacent to the entry lane, the autonomous car then has to know whether it should slow down and pull up behind the neighboring vehicle or if it should accelerate to enter in front of it. Furthermore, a human would probably alter this choice based on the looks of the approaching vehicle, if it is a sports car or a heavy truck for instance. This simple discussion regarding a specific situation reveals the very core problem in the decision making for autonomous cars - the complexity. Even though most parts of driving is repetitive and fairly easy, there must be some kind of intelligence to deal with the situations that are unusual and difficult which moreover tend to be situations correlated to human injuries or fatalities.

Since the complexity in input data makes a traditional approach with conditional statements unfeasible, software developers have become forced to find other solutions to handle the decision making. A way that has become increasingly popular for dealing with the complexity of situations is the use of deep learning algorithms. In particular, a convolutional neural network (CNN) seems to be the most promising solution for this problem. Both deep learning and CNN will be discussed in further detail below.

The complexity in programming the rules that actually perform the driving of the vehicle should not be underestimated although it does not seem to be an unsolvable issue. In fact, current test drives with autonomous cars have proven that the logic behind the decision making in the driving platforms is able to deal with most typical driving situations with sufficient reliability. However, no car is yet able to deal with any (or close to any) situation and the overall reliability is therefore not good enough. A typical approach that initiatives of driverless cars have taken to reduce the complexity has been to program the car to always make the safest decision in ambiguous situations. Generally this results in less aggressive driving compared to a regular human driver. That is also a probable development for autonomous cars in general since increased safety is one of the key factors that an autonomous car must provide its passengers with. On the other hand, this indicates that people must be okay with increased travelling time compared to when driving on their own.

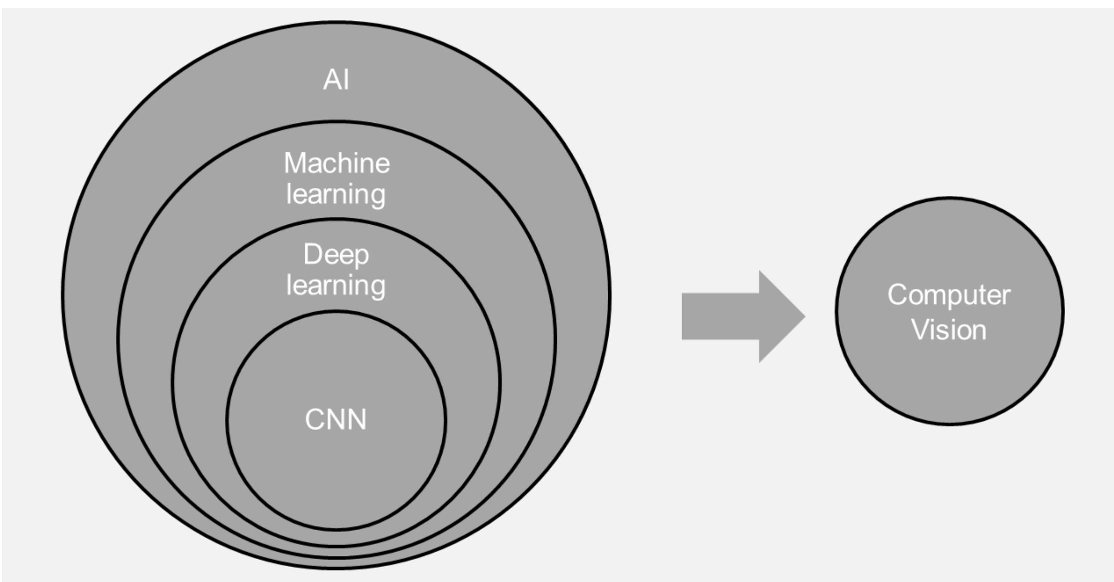
The fact that sensors might occasionally get some things wrong can lead to difficult situations for the decision making logic. For instance, the lidar might erroneously depict the exhaust gas from the vehicle ahead as a solid motionless object contradicting the camera and the radar saying it is nothing there. How the computer is supposed to react in such a situation is an interesting question. It can be argued that it is generally safer to always brake in ambiguous situations but if it happens too often people will lose confidence in the autonomous driving and what is worse, emergency braking can easily result in a rear end collision.

Another problem that may arise as a result of the complexity of driving is if the sensors simply do not understand what they see and thus are unable to make an informed decision. An automatic response in such a situation could be to slow down and drive to the side of the road. For partially autonomous cars of Level 3 capability, a way to circumvent the issue would be to notify the driver when the car does not understand what it sees and let the driver take over the control. Obviously this is an approach with intrinsic risks because it is difficult for a human driver to regain control within a moment's notice. Another way to deal with this is to make the cars self-driving in some situations that are relatively confined and manageable, such as motorway driving, and simply notify the driver to take over control of the vehicle well in advance of exiting the motorway.

Even if we assume that the driving platform gets perfect information from the sensors and understands it correctly in virtually all situations, another type of dilemma occurs. How should the car respond if it finds itself in a situation where it has to choose between only bad choices. Of course, it can be argued that it should pick the least bad choice but the problem is that what is the least bad choice is far from always indisputable. If an old man walks out in the path of the car, should the car brake although it is far too late or should it swerve and risk hitting the ten year old child that is standing on the sidewalk? Perhaps even more relevant is a situation where the car has to choose between hurting the passengers or a pedestrian. Although these situations seem unusual they can occur and if the sensor systems together with software programs actually are able to make a highly detailed model of the environment surrounding the car it also follows that the people programming the decision making rules must take these rather uneasy questions into consideration. Some carmakers say they will solve this issue by making sure they will never end up in such a situation by keeping safe margins at all times - a promise that might be hard to live up to.

The following figure illustrates the hierarchical relationship between artificial intelligence, machine learning, deep learning and convolutional neural networks. These areas are important for the interpretation in an autonomous car since they enable enhanced computer vision. Moreover, these fields of research also lie at the foundation for decision making algorithms that enable autonomous driving.

Figure 15. Relationship between fields in computer science



9.3.3 Computer vision

Computer vision is a field of study that focuses on retrieving, processing and understanding real-world data of multiple dimensions with the goal to make decisions based on this understanding. A typical example of this is to use various processing techniques and algorithms to interpret an image and automatically take action accordingly. Computer vision is thus the field of study that can enhance an autonomous vehicle's understanding of its camera input. As of now, the capabilities of computer vision are limited due to the enormous complexity of images. However, a lot of research effort is made in this field and progress is constantly achieved. The achievements are not only a result of investments from the automotive industry but can be found in a range of other business fields and scientific research since the benefits of advanced computer vision have lots of other applications than driverless vehicles. Some examples are surveillance of people, controlling a robot's movements and medical applications such as extracting information from an X-ray image.

Object recognition is a subfield of computer vision that focuses on recognizing specific objects in an image. The division has obvious benefits to autonomous vehicles in that it can be used to recognize for example pedestrians, cars, trucks, bikes and other objects that are relatively usual in a driving environment. Pedestrian detection is arguably one of the most researched fields due to its many use cases including surveillance and safety systems in vehicles. However, for a computer to quickly detect a person in an image becomes much more challenging than one might anticipate. Although humans seem to have an easily discernible shape, a number of factors make the detection difficult. For instance, parts of the body might be obstructed (such as when only the upper body is visible above another car's hood). Furthermore, people wear clothing of different shapes that alters the appearances, others might miss a limb or use crutches or be in a wheelchair. Moreover, different lighting conditions provide further problems.

Another problem in autonomous driving is that the car and objects in its surrounding environment have different velocities. Object recognition can be used to estimate the position of these objects, although it is not an easy task which is part of the reason why autonomous technology in addition relies on radar, ultrasonic sensors and, depending on level of autonomy, also lidar. Even though movement sometimes can be advantageous, since it makes an object more discernible from its background, it also poses challenges when it comes to calculating relative velocities and even more so when there are a lot of objects involved - as often is the case when driving and especially in cities. Moving objects, such as pedestrians and vehicles are arguably most important for an autonomous car to keep track of, making it an unfortunate fact that few moving objects are of a simple shape. Yet another problem is the fact that people often move in groups and places such as zebra crossings easily get filled up with numerous people which makes it hard for a computer to make out each individual. A counter argument is that a decision making unit does not necessarily have to keep track of each person since the group of people is probable to move in a predictable way. Still, all these small problems definitely pose challenges for developers of software algorithms to autonomous technology.

A third use case with computer vision in addition to object recognition and position estimation is the possibility to generate 3D reconstructions from images. A camera is essentially turning 3D scenes into 2D images. With computer vision techniques, a reversed process to create 3D models from the 2D images can be achieved. The process requires triangulation from images taken from multiple angles and gets further complicated when objects are moving relative to each other. The technique is very similar to stereopsis which is the way our pair of eyes works where each eye detects slightly different images of the object in focus (also known as parallax). The amount of disparity between each eyes' vision is translated by the brain into a sense of depth and thus gives us the ability to perceive a 3D world. Cameras though, unlike eyes, lack the ability to quickly and automatically switch focus between objects and this result in a substantial increase in complexity for the calculations. The human brain knows how much the eyes contracts to make the images fit together and can thereby tell the distance to the object in focus while a camera has to do this with every point in the entire field of spectrum simultaneously. Despite the challenges, to generate a real time 3D model of the environment is a necessity for any autonomous vehicle to work in a safe way. A Lidar can be used to achieve this but a camera-based model can be used for redundancy and to generate a more precise depiction when combined with the lidar model.

9.3.4 Artificial intelligence

Artificial intelligence (AI) is a concept and a field of research that has gained increased attention over the last years. In fact, the concept of intelligent machines has been present in human history for a long time and can for instance be found in several religious or superstitious beliefs in myths and magic. The term artificial intelligence was coined in 1955 by John McCarthy when he organized a conference at Dartmouth University with the aim to study how machines can simulate intelligence. McCarthy subsequently became a Stanford professor emeritus of computer science and was a key person in developing the foundation for today's research in artificial intelligence.

Artificial intelligence can be defined as the ability of a machine to creatively interpret a complex situation and make a well-informed decision based on the interpretation. AI mimics intelligent human behavior. An ideal intelligent machine understands its environment and makes rational decisions to reach a pre-defined goal. For something to be termed as artificial intelligence thus requires more than just an automatic function. An interesting observation to make is that the definitions of the terms "artificial intelligence" and "autonomous" are not very different from each other. Autonomous essentially means self-governing which undoubtedly requires some level of intelligence in excess of being automatic. This indicates the strong relationship between artificial intelligence and autonomous vehicles.

AI has for a long time been envisioned as the area that soon will emerge as the solution to most everyday problems and render human work unnecessary. However, people who have advocated this belief have failed to recognize some of the significant challenges associated with AI. One of those challenges has to do with the vast amount of data any advanced AI system has to process. The evolution of AI has thus been taken in gradual steps that partly can be derived from Moore's law and has still a long way to go before human work becomes redundant.

In the 1990s AI started to become increasingly used in technology and industry with use cases such as data mining and medical diagnosis. In 1997 a chess-playing computer program was for the first time able to beat the current reigning chess champion, Garry Kasparov. The most recent and one of the largest breakthroughs related to AI research happened in the programming technique known as deep learning. In 2011, IBM showcased a computer system termed Watson that by the use of deep learning algorithms could understand questions asked in natural language, quickly search a database (without using the internet) for a suitable answer and vocally retrieve the answer to the questioner. Watson was showcased on the quiz show *Jeopardy* where it easily won against two previous winners of the show.

9.3.5 Machine learning

Machine learning is a subfield of computer science that is closely related to AI. Machine learning aims at developing software that is able to learn from input data to develop its own model which in turn generates predictions or decisions based on the input. Machine learning provides the basis for AI since it enables a system to learn without being explicitly programmed. One of the most common use cases is Bayesian spam filtering which works by comparing the content in new mails to the content of old mails already classified as either "good" or "spam" mails or to other categories to determine where the new mail belongs. The algorithm constantly learns and improves its performance the more mail the respondent receives. The technique is essentially based on the probabilistic occurrence of different words in different contexts. Another common use case is search engines that are based on cross-referenced ranking of the material searched for, such as websites or documents, to retrieve the most relevant source. Google's search engine is based on machine learning techniques which should give an indication of the field's importance.

As for autonomous driving, object recognition provides the key for enabling a vehicle to make its own decisions and machine learning is the main field of software techniques that is being used to solve the complex issue of recognizing objects in an image as well as performing the decision making. Programming based on simple conditional statements such as "if-then" are not feasible due to the complexity of the situations that might occur. The content of images captured by the cameras must be interpreted and it would require an enormous amount of conditional statements for a computer to classify specific objects, such as pedestrians or vehicles.

Machine learning takes a different approach than conditional programming and is similar to how our brains function (thus its relationship to AI). When we see an object, let's say a cat for instance, we do not run a number of if-statements in our head to understand that it is a cat. Instead we have learned what a cat is supposed to look like based on a number of key features and therefore when we observe it we quickly associate it with our stored rendition of a cat. Machine learning aims to do a similar thing by not writing a specific program to recognize cats but instead show the machine a large number of images of cats to train the software to write its own model of how to determine whether an image contains a cat or not. This technique can of course be scaled up to include a number of objects other than cats but still operate under the same method. By feeding the algorithms with pictures where objects already have been classified, the software learns for instance what a person, a car or a bike is supposed to look like and is able to discern objects in new images from this information. The algorithm is able to enhance its knowledge as it encounters more objects and thus develops its ability to classify objects more precisely.

Although the learning ability undoubtedly is the technique's key strength it is also important to remember that the systems perform very poorly in the initial phase before learning has taken place. The implication of this is that, for the algorithms to be reliable, they must be tested extensively. Current projects try to achieve this by combining simulations with real-world testing. The advantage with simulations is that it enables vast amount of testing, while testing on actual roads incorporates the complexity dimension needed.

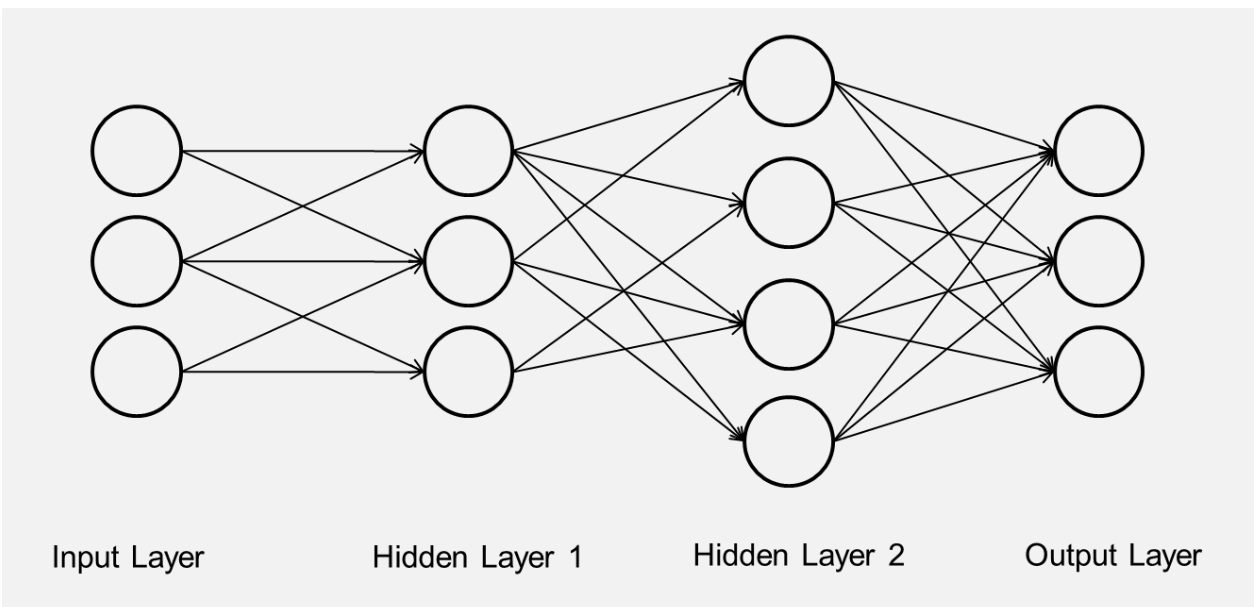
Still the main challenge is not to be found in the amount of testing to be done but rather in making the models smart enough. It is, by definition, impossible to simulate all situations that might occur since there are an unlimited number of them. The key is that since the software is not based on conditional statements but rather on association with previously encountered situations it is possible to cover the most important situations through a limited amount of testing and on the off-chance that something remarkably strange happens the software might understand enough of it to make a decent decision. Another possibility is that the software alerts and hands over control to the driver if a certain threshold of comprehension fails to be reached. In fact, today's available highway autopilot systems offered by some car manufacturers warn the driver to regain control when the systems do not understand what they see.

9.3.6 Deep learning

The division of machine learning that has gained most grounds in the recent past is deep learning. As was mentioned in the above chapter of AI, deep learning was an integral part of IBM's quiz show robot, Watson. Another very well-known example is the recent Go playing software based on convolutional neural networks (CNN) that beat the world champion in the game that allegedly is supposed to be more complex than chess. Deep learning is not only used for playing games, though. In fact, deep learning is used to tackle all kinds of complex problems where a traditional programming approach is futile. In the creation of autonomous cars, deep learning could provide both the solution for object recognition in images as well as the understanding of the images that enables decision making.

Deep learning has taken inspiration from biology and more specifically from the structure of neural networks in our brains that enable us to construct thoughts and retrieve memories. Deep learning is based on artificial neurons in multiple layers where each neuron assigns weights to different sources of input and through some function transforms it to a specific output. The output from an individual neuron is then used as input in others. A sigmoidal neuron for instance sums the weighted inputs and inserts the value into the logistic function to compute a final output. The key is not so much the function in itself (although it is beneficial to use functions with simple derivatives) but rather to find the right weights to use. The goal is to find weights for each individual neuron so that the final output of the network will have an error as small as possible. This is done by training the network. Training is essentially a process of feeding the network with data which output has values that are known in advance. Based on functions that arise with the sole purpose to minimize errors, the true value can be used to back-propagate to find the most suitable values of the weights. These weights can then be used to calculate output from new data.

Figure 15. Conceptual structure of a simple neural network

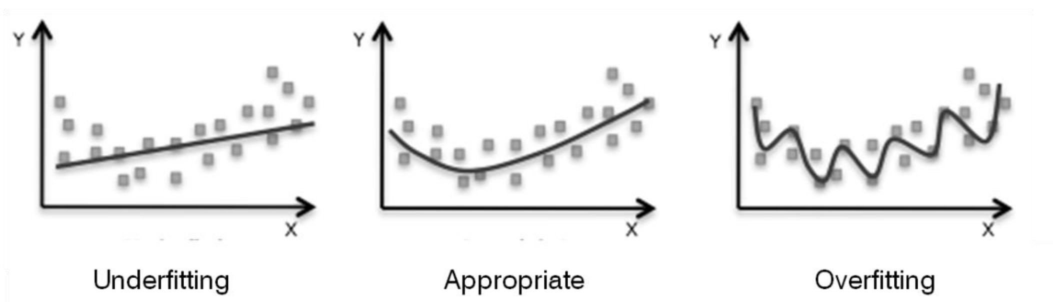


One of the most important benefits with deep learning is that it circumvents the need for manual feature extraction which is a necessary and tedious process in traditional machine learning. Feature extraction is the process of telling the software which specific features it should target to base its output on. A neural network, on the other hand, has the ability to learn to focus on the right features on its own.

Object recognition in an autonomous driving context can leverage on neural networks that are trained with images where objects often seen in traffic (such as cars and pedestrians but also buildings and trees) are categorized. When the camera then provides novel input to the software it is able to detect a specific object since it shares some features with a similar object in the training data set. Trees for instance have some characteristics that the neural network can learn by being trained on multiple images of trees.

A problem with deep learning is the risk for over fitting which can happen if too many layers of neurons or too many connections between neurons are used in relation to the amount of training data. Although the calculated weights might generate very small errors for the training set, the network is probably useless at correctly classifying objects in novel data. The underlying reason is that an extensive amount of parameters combined with limited training data results in too detailed descriptive features that are not sufficiently generic to classify new data correctly. On the other hand, it is also important to avoid under fitting which can happen if the complexity of the function that classifies the data is instead underestimated.

Figure 16. Graphical representations of under fitting and over fitting



An interesting aspect with deep learning is that when it works it is not trivial to understand why it does so. Likewise, since there are no specific algorithms that control the network's classifications or decisions it is virtually impossible to go and check what went wrong if the software makes a mistake. The only thing a programmer can do is either to change the networks structure or feed the network with more training data and test it on the same specific situation to see if the problem is gone. However, even if the change eliminates the error, the change might generate new errors in situations that the network previously was able to handle. The implication is that the system must be tested on all historical situations after each adjustment to ensure reliability.

A specific type of deep learning is convolutional neural networks (CNN). This type of networks is further inspired by the brain's visual cortex in terms of how the neurons are connected in an overlapping structure. It would be far too technical to go into details as to how these networks function. For the purpose of this report it suffices to say that CNN is arguably the most researched field of deep learning to enable highly capable object recognition and in the extension autonomous cars. It seems very likely that breakthroughs in CNN will be the factor that finally allows for a computer to control a car.

It should be noted that deep learning in general and CNN in particular is not only useful for object recognition but also to control the decision making. The examples above in the sections dealing with machine learning and deep learning have focused on object recognition particularly since such examples are easy to conceive and is the first necessary step in the development. However, as mentioned before, it is not enough to know what objects are in an image to make decisions. The software of an autonomous car must understand the entire scene of all the identified objects and realize what decision is best according to that understanding. Humans for instance are able to make predictions of what is about to happen based on what the objects are and how they move. A self-driving car would need a similar capability to actually be able to drive safely. Put simply, it is not enough for a car to know that a human is approaching a zebra crossing, it also has to know that is supposed to stop in such circumstances. Thus, a true understanding of images provides an additional challenge for programmers to the already difficult task of object recognition. However, the fact that deep learning can be used also for this problem should speed up the process of development.

9.4 Execution and related technologies

In addition to the sensors and the logic that decides over the car's movement, systems for executing the decisions must be installed. The execution relies on electronic control units that operate individual tasks in the vehicle. However, not all autonomous cars will have full autonomy at all times. Most actors are trying to first develop cars that can drive autonomously in certain situations (typically motorway driving) and the control of the vehicle thus alternates between the driver and the vehicle. Many of the semi-autonomous systems, like an automatic emergency braking system, will still be running even if a person is in control of the vehicle. However, in this case it is the driver that does the decision making as well as the execution of the vehicle's controls. To create a suitable interface for this part-human part-machine environment is an additional challenge for automakers.

9.4.1 Electronic control unit

An electronic control unit (ECU) is a type of device that controls some kind of electrical system in a vehicle. The systems can for instance control the transmission, powertrain, engine, suspension as well as cruise control and telematics. Modern cars typically have multiple ECUs, some have as many as about 80 different units. ECUs provide the foundation for the transition to more electrical systems in cars such as parking brake at the push of a button instead of the manually pulled wire extending to the brakes on the rear wheels. ECUs are important for autonomous vehicles since they enable the decision making unit to actually control the vehicle's movement. These systems do not constitute any large technical challenge for the development of autonomous cars but are nevertheless an important part of them. There are some engineering synergies that render electrical vehicles more suitable for autonomy than regular combustion driven vehicles.

It is beneficial to develop more sophisticated ECUs that are able to integrate information from multiple sensors rather than a single one. For example, an adaptive cruise control ECU is typically only connected to a forward looking radar although it could also benefit from input from a backward looking radar that know if another vehicle is overtaking and can tell the ACC to be prepared for it.

9.4.2 Human machine interface

Human machine interface (HMI) and driver monitoring systems are fields that are gaining increased attention. A major reason for this is the automotive industry's recognition that a transition to autonomous vehicles will not occur overnight. There is still a long way to go before cars drive themselves but semi-autonomous systems are nevertheless becoming increasingly ubiquitous. These systems, however, require the attention of a driver which explains the necessity of a well-developed interface between human and machine. An advanced system with semi-autonomous capabilities can still be used to aid the driver with various information as well as with reactive emergency systems. However, the system relies on the driver to handle decision making and execution.

The automakers today that offer highly developed driver assistance systems which feature semi-autonomous driving on highways leverage on display interfaces. These displays show the car's position amidst the lanes on the road and give alerts of approaching traffic by blinking symbols or other similar graphical indicators. However, this is just the beginning of the development of HMI. The interface towards the driver must be even more developed when autonomous cars reach the next level of autonomy - a level where the driver can be allowed to divert the attention from driving in specific situations (i.e. Level 3 according to the SAE definition). This is because the driver must be made aware of when he or she is to regain responsibility of the driving. Light signals, acoustic warnings, vocal messages as well as seat vibrations are potential ways to achieve this and are already implemented in other use cases.

9.4.3 Driver monitoring systems

The field of driver monitoring systems (DMS) is related to HMI but also different in that it takes the opposite perspective starting from the machine rather than the driver. HMI is about how humans percept information from machines and control them while DMS on the other hand are used to monitor a driver's actions and react to undesirable behavior. The typical use case for a DMS is to analyze if the driver starts to show signs of being inattentive. A driver for instance often drifts more to the sides when tired or not paying attention to the road. A DMS can log how a driver behaves in the beginning of journeys and compare subsequent performance to this baseline. If a threshold of deviant behavior is identified the driver can be warned that her or she is tired or otherwise inattentive and should take a break. A more simple system can count the hours of active driving and tell the driver when it is advisable to rest. A third method is to have a camera watching the driver's face to detect signs of diminishing attention. Examples of such signs are dropping eyelids indicating weariness or increases in pupil dilation indicating increased mental workload.

Driver monitoring systems can be seen as a part of the human machine interface. Increased DMS features is thus a probable development along with autonomous cars especially since partly autonomous vehicles will need to hand forth and back control to the driver and the car.

9.5 Summary of the state of autonomous cars technologies

To summarize what have been discussed above, an autonomous car needs to follow a sense-plan-act process. This process is dependent upon a range of technologies which can be categorized into four groups: sensors, telematics, computing platform and execution.

Even though the technologies necessary and the basic design for the creation of an autonomous vehicle are well-known, it is not that simple to actually build one. The overarching problem is that the requirements for cars are very high. They must be able to withstand some 15 years of wear from the elements and, most importantly, they may not do mistakes.

The technology for executing the driving does not provide any major challenge for creating an autonomous car; the necessary ECUs are already developed and can be found in modern cars. A more important area for improvements is how the interface between a semi-autonomous car and the driver should look and function.

Sensor technologies do, generally speaking, have a sufficient level of capacity although some enhancements would be beneficial. The sensors encounter problems in unusual circumstances, for instance when driving in bad weather or snowy conditions where a camera is unable to identify lane markings. Lidars are widely believed to increase the reliability of the perceived surroundings but lidar technology is still rather expensive. There are, though, good reasons to believe that the cost of this technology will decrease significantly due to technical advancements and future economies of scale. However, the price of a lidar today is of such a magnitude that it would affect most customers' interest in buying an autonomous car. Overall, the cost of the sensors is the major set-back with them. It does not make it impossible to develop an autonomous car but it might affect the diffusion of them on the market. On the other hand the cost of sensors is dropping at a rate of about 15 percent each year.

Telematics is also starting to become relatively mature technology. The main challenge in this field is not the technology in itself but rather for different policy makers to agree on what standards to apply. There are great benefits to reap from a cloud-based system through which cars can communicate with each other and with infrastructure but to agree on the development of such a cloud is much harder. In addition, the cellular network capacity also needs improvements.

The main technological challenge in the development of an autonomous car is the creation of a computing platform. There are two main parts of this problem. First of all, the computing platform must understand its input which essentially comes down to understand images since lidar, radar and ultrasonic sensors tell very little in addition to the position of an object and roughly its shape. For a computer to understand images has proven to be a very difficult problem. Secondly, when the computer has reached an understanding of what is around the car, it has to make decisions based on this information. It is easy to fall in the pitfall of believing that this second problem should not provide much of a challenge. If the computer has realized that a pedestrian is about to cross the road in front of the car it seems obvious that the car should apply the brakes. However, that response is not at all obvious to a computer. The solution to both these problems lies in the realms of artificial intelligence. It is impossible to write all the conditional coding that would be required to address all situations a vehicle might encounter. That is why the vehicle's computer must learn to make decisions on its own.

Today, some very skilled computer scientists have managed to make a program based on deep learning algorithms beat the world champion in Go. It is a large step from that achievement to make a car drive on its own. There are several actors testing systems that simultaneously train the cars to drive by themselves but so far the reliability of the deep learning programs is not sufficient. This is the main piece to get in place to finish the technological puzzle of an autonomous car.

10 Barriers

There are a number of challenges in order to roll-out this technology successfully on the market. The barriers can be divided into two categories – performance barriers and adoption barriers. The main performance barriers are technology reliability, the necessary development of standards along with the importance of further collaborations, the mixed environments of autonomous and regular cars and the specific HMI challenges to accomplish Level 3 autonomy. Adoption barriers are obstacles that have high probability to slow the uptake of autonomous cars. These barriers are made up of regulations and liabilities, public acceptance of the technology as well as car longevity.

Figure 17. Performance and Diffusion barriers

Performance barriers
Technology reliability
Mixed vehicle environment
HMI problems in Level 3
Standards and collaborations
Diffusion barriers
Regulations and liabilities
Public acceptance
Car longevity

In addition to the factors listed and further described below, the vast amount of jobs that would be lost as a result of emerging autonomous cars (e.g. taxi drivers, tow service providers and car insurers) is often mentioned as a negative aspect. However these factors are not included in this report since such effects always follows in the wake of new technology that fundamentally changes society. Autonomous cars have the potential to both disrupt jobs and create new ones just like the transition from horse carriages to automobiles once did and can therefore not be seen as negative aspect from a macro perspective. In fact, most experts advocate that autonomous cars would be beneficial for society.

10.1 Technology reliability

Perhaps the biggest hurdle to introduce self-driving cars is to achieve a sufficient reliability of the technology. Technology still has some way to go before a fully autonomous car is possible. Moreover, it is not a trivial task to prove that an autonomous car is sufficiently reliable. It would demand hundreds of millions of miles in real-life traffic to prove that autonomous cars are perfectly safe. This indicates that alternative ways of testing autonomous cars – such as simulations, scenario testing and mathematical modeling – will be necessary. Some of the challenging areas associated with the very development of the technology are driving logic, infrastructure, security, sensor capacity, big data capacity, HMI and cost.

Sensor and big data capacity are the only factors on the list above that could be seen as having sufficient reliability to use in Level 3 or higher autonomous car. However, these factors too would benefit from enhancements which is also an ongoing process. Currently available sensors are for instance not good enough to enable fully autonomous driving in rough weather conditions such as on snowy roads or in rainy or dusty weather.

The most significant challenge is to program the car to be sufficiently smart to perform the actual driving decisions. There are several sub-problems to this category such as necessary breakthroughs in computer vision, object recognition and deep learning. In fact, a self-driving car would need an unprecedented level of artificial intelligence which undoubtedly is far from trivial to accomplish.

What makes the overarching problem of reliability so difficult is the vast amount of unusual situations that might occur. Google's self-driving prototype vehicle once encountered a lady in an electric wheelchair driving around in the middle of the road, chasing a duck with a broom. The prototype is programmed to realize when something strange is going on and respond by simply coming to a halt and let whatever is going on play out before it continues. That is one way to solve the problem but it is not adequate in all situations and can potentially result in long delays when the car has to stand still. Another more frequent problem than ladies chasing ducks is the occasional occurrence of a large vehicle parked in the middle of the road while there at the same time is a double yellow line demonstrating that overtaking is prohibited. Most people would agree that it is okay to make an exception in such circumstances and pass the truck in the opposite lane despite the prohibiting lines. The question is how to make an autonomous car able to make such decisions and how to deal with the liability implications in the event of an accident.

Another often mentioned problem is the scenario of a left turn in heavy traffic. A human can choose to take more of a risk and apply extra throttle to cross the road when a small space is apparent, something that an autonomous car's safety system surely prevents. A human could also slowly inch closer to the side of the road to indicate the intention of turning. Furthermore, a human could notice a waving hand from an oncoming driver indicating that it is okay to pass. Both these subtle signs are something that would be difficult and potentially risky for an autonomous car to perform or interpret. The fact that self-driving cars are expected to avoid risks also implies that it will be hard for them to drive in a way similar to humans which will be particularly problematic in regions where traffic is heavy and aggressive. To get through an intersection in Ho Chi Minh City, for instance, requires aggressive driving.

Figure 18. Traffic in Ho Chi Minh City

Source: Istockphoto

Infrastructure is another challenge. Roadside infrastructure like traffic signs need to be adapted with devices for V2X communication. Furthermore, most autonomous cars are expected to be electrical which will require a major extension of the currently available charging stations.

Car connectivity also enables security risks. A connected self-driving vehicle could potentially be hacked by someone that could then take over the vehicle's controls. The goal with IT security is to make an attack more costly than the harm it can inflict. Since the potential harm in the automotive industry is very high it follows that very secure systems are necessary.

HMI is an important field that needs development to allow Level 3 and higher autonomy in cars. Level 3 obviously needs solutions for smooth transition of control between the driver and the car but Level 4 or Level 5 vehicles also relies on communication with the passengers to enable changes in the route for instance.

10.2 Mixed vehicle environment

A high autonomy would most likely be easier to achieve if indeed all cars one day reached an equal level of self-driving capability. Since this is not the case, the first driverless vehicles will have to be adapted to blend with regular vehicles. This provides all sorts of problems especially in terms of the subtle signs that drivers use to communicate their intentions. Although self-driving cars likely can learn to interact with regular vehicles, human drivers are unlikely to have the same proficiency in dealing with self-driving cars. It could result in confusion and more accidents rather than less.

People might take advantage of self-driving cars built-in safety features. For instance, people could cross the street right in front of an autonomous car since they know it will apply emergency braking to avoid an accident. On a similar note, aggressive drivers could potentially drive even more aggressive because they know the autonomous cars will always prefer the safe choice.

10.3 HMI challenges to accomplish Level 3

Currently available semi-autonomous cars have reached Level 2 and now it seems like Level 3 autonomous car will be next to reach the market. Level 3 vehicles are able to drive without driver supervision in specific situations and with the assumption that the driver is able to regain control of the vehicle within some seconds of prior warning. It is worth to point out some particular problems with Level 3 which all stem from the fact that the system relies on the interaction between human and machine.

The main problem is that it is difficult for a person to be told that he or she can relax and let go of the control of the vehicle and then in a relatively short time frame, say five seconds, must regain control and attention to the driving task. It is not always easy to switch on and off just like that. Moreover, the situations in which the driver is supposed to take over control are almost by definition bound to be unusual which makes the driver's task even harder. Especially inexperienced drivers might encounter problems if they suddenly have to respond to a request from the car to intervene. Considering that people will have to do less and less of the driving, that effect might also increase with time.

Some say that even Level 2 vehicles with highway autopilot makes driving so convenient that it is difficult to maintain attention to what is going on. The recent fatal accident with the Tesla is an indication of that being the case. A Level 3 vehicle would actually allow for drivers to let go of the attention and could thus be argued to be safer than current Level 2 autonomous modes.

A well-functioning and easy to use HMI will be especially important in Level 3 vehicles since it is vital for the driver to know who is in control of the vehicle. A parallel can be drawn to the aircraft industry and an accident that occurred in 2013 at San Francisco international airport mainly because the pilots mistakenly assumed an autopilot was controlling the throttles during the decent – a misassumption that resulted in the plane crashing into a seawall short of the runway. The accident could have been avoided if the controls had better indicated to the pilots that the autopilot was not engaged. This is a crucial aspect also for Level 3 autonomous cars in order for them to work safely.

10.4 Standards and collaborations

To reap the full benefits of self-driving cars they will need to work regardless of location (i.e. across national borders). They will also need constant Internet access to leverage real-time map data and be able to adapt to different countries' traffic signs and regulations. All these aspects call for some type of standardization on many levels. Network providers and mobile operators might find collaborations necessary to enable the development. It is also unclear what institutional organization shall decide on standards for different issues. Governments and international organizations are likely to play a part in this but it is still very uncertain exactly what each party's role will look like.

The making of autonomous cars will also require collaborations since it involves a tremendous amount of different technologies that must work together. Cars of today are already very complicated machines which no actor is able to build single-handedly. Cars are joint efforts by numerous suppliers and car manufacturers as well as other institutions.

10.5 Regulations and liabilities

Although many governments and other authorities for policy making have a positive view on autonomous cars, regulation is believed to be one of the major barriers to a fast adoption of autonomous vehicles. However, restrictive regulations for testing of the vehicles are probably a minor issue. In fact, most countries that have actors working on autonomous cars have also made it possible for them to test the vehicles in real-life settings – Japan, South Korea, Germany, Sweden, UK, France and China are some examples. The US is a bit special since regulations differ from state to state and only a few states have enacted specific legislation for testing of autonomous vehicles. So far, all testing in everyday traffic has required the use of a test driver who is ready to cease control of the vehicle in the event of unexpected situations or system failures.

Legislative frameworks are derived from the presumption that a human drives the vehicle as this is what traditionally has been the case. From this follows rules about what components a vehicle must have – such as a steering wheel and a brake pedal for instance. Moreover, which actor is liable in which type of situation is also adapted to the notion of human drivers. It follows that regulatory and liability issues can have a significant delaying effect on the roll-out of autonomous cars to the consumer market.

10.5.1 International conventions on road traffic

There are two major international treaties with the purpose to coordinate traffic across national borders. The first one was agreed upon by 96 states in 1949 in Geneva and the second by 73 states (including nearly all European countries) in 1968 in Vienna.

The Geneva convention on road traffic states that every vehicle must have a driver who is constantly able to control. However, it has been argued that the rule can be satisfied in an autonomous vehicle as long as a human has the capability to intervene when necessary. To allow for fully self-driving cars probably requires alterations of the treaty.

The Vienna convention even more explicitly than its predecessor states that every driver must at all times be able to control the vehicle. Article 8 states that “Every moving vehicle or combination of vehicles shall have a driver” and “Every driver shall at all times be able to control his or her vehicle”. A UN amendment to the treaty, that was agreed upon in 2014 and comes into action in 2016, allows “systems which influence the way vehicles are driven” as long as these systems can be overridden by an attentive driver. This enables the driver to remove hands from the steering wheel but not to divert attention from the road and it certainly does not allow driverless vehicles. The implication is that after Level 2 autonomy, the treaty needs to be renegotiated further.

To summarize, both international treaties must be changed to allow for cars with autonomy of Level 3 or higher. In addition to the international treaties, many countries have laws which state that any moving vehicle must have a responsible driver who constantly is in control of the vehicle and who must refrain from all other activities than driving. For instance, it is forbidden in several countries to use the mobile phone while driving. Such an activity is exactly what developers of autonomous cars wish to enable and changes of regulations is therefore necessary to allow higher autonomy.

10.5.2 Liability

When a car is able to drive itself without human input it raises an interesting question as to who is liable in the event of an accident. If the driver does not influence the driving it is questionable whether he or she really can be seen as having the liability. Since it is the technology that is failing it seems more reasonable to blame the manufacturer of the car or perhaps the Tier-1 suppliers. Car manufacturers and suppliers undoubtedly anticipate this problem and might be unwilling to accept crash liability being imposed on them. Alternatively, carmakers might incorporate the cost of the risk of liability in the price of the autonomous cars.

The issues of liability is likely to have an impact on the roll-out of autonomous cars of Level 3 or higher even though some actors, like Volvo Cars for instance, already now state that they will assume liability for any accident their self-driving vehicles cause. Especially difficult situations are those that involve a lot of human machine interaction as is the case with Level 3 autonomous vehicles. It might be hard to conclude whether it was the human driver or the technology that made the mistake leading to an accident.

10.6 Public acceptance

Although most people agree that self-driving cars is a fascinating idea, surveys have indicated that many are reluctant to trust a vehicle to safely drive by itself. People in general are reluctant to change – already adaptive cruise control is by some believed to make driving too easy and monotonous resulting in inattentive driving.

The main reason behind some people's unwillingness to ride in a driverless car is the fact that they like to stay in control by themselves and do not trust the technology to be reliable. This problem is further enlarged since people will probably not be satisfied by autonomous cars having an equal incident rate as the average person since a majority of people (ironically) believe they are better than the average driver. In fact, the accident rate among autonomous cars would most likely need to be much lower than the average driver for people to accept them. When accidents happen, people must be willing to accept that it was a technological malfunction that caused it, something that might be harder to do than accepting a human error.

Another problem is the ethical dilemmas that occur once cars become highly intelligent. Suppose computer vision has reached such an advanced level that an autonomous car is able to perceive everything in its immediate surroundings perfectly and is able to correctly classify each object and its intention to a very high reliability. Then imagine a scenario with only bad outcomes, like when the car has to choose between hitting a concrete wall and thus injuring all of its passengers, or hitting a lady with a baby carriage crossing the street or perhaps an old man by the side of the road. These situations are of course not common but they can occur and when they do, they provide a serious dilemma which propagates back to the software engineers who have to program the car into making a decision. Actors involved in the making of self-driving vehicles have responded to this problem by first of all assuring that they will make sure these situations almost never occur. Secondly they have stressed that this type of dilemmas are age-old philosophical questions that have no good answer and that a human driver has no perfect way to deal with such a situation either. Nevertheless, this type of problems might have an influence on people's acceptance of autonomous cars.

10.7 Car longevity

Even if the automotive manufacturers are right in their statements that autonomous cars of Level 3 or even Level 4 capability will be available already in 2020, it will take a long time before the technology is widely used worldwide. Second to buying a house, a car is in many cases the largest investment made by an individual. This implies that most people want to make their cars last for as long as possible for cost reasons. A modern car has a lifetime of 10–18 years.

One of the most proclaimed advantages with autonomous cars is their potential positive impact on lowering the number of accidents and their magnitude. However, this is unlikely to have a large impact on the regions with the highest accident rates since these regions coincides with the regions of low-income population who will not acquire the technology for many years. Traffic injuries is therefore certain to be a major problem for yet a long time, at least in some regions.

11 Autonomous cars initiatives

There are many actors in today's automotive industry as well as new entrants that are investing in research and development of autonomous technology. The purpose with this chapter is to summarize the actions of the most important players in this field. Particular focus will be put on the large automotive manufacturers as well as some technology companies that have initiated projects. The chapter ends with summarized cases of smaller players, such as suppliers' activities.

It should be mentioned that since this report is limited to deal with autonomous cars, neglecting trucks and other self-driving initiatives, this chapter will have a distinct focus on cars only. There are many projects going on with an aim to develop autonomous technology for trucks but so far they have not reached further than initiatives in self-driving cars. Those projects should therefore not affect the development of autonomous cars in any significant way although some synergy benefits may be obtained in some cases when an actor develops both autonomous cars and trucks.

For initiatives taken by automotive manufacturers it makes sense to separate autonomous technology from advanced driver assistance systems (ADAS) since the automakers already have such systems available. The separation line between ADAS and autonomous is drawn between SAE Level 2 and Level 3. The main purpose of this chapter is to identify different actors' initiatives to reach autonomy of SAE Level 3 or higher. However, it is also relevant to map how far the automakers have reached in terms of ADAS development since that provides a basis for further steps toward more autonomous systems. Each case describing an automaker therefore starts with a general description of the company and how far it has reached in its ADAS development before focus is shifted to the company's approach to and progress in the development of autonomous technology.

11.1 Overview of initiatives

When it comes to OEMs, autonomous driving has up till recently been pursued almost entirely by luxury car makers such as Tesla, Volvo Cars, Audi, BMW and Mercedes-Benz but now, brands from the mid-market car segment is starting to enter the race, in particular including Nissan, Toyota, GM and Ford. Automakers, however, are not the only companies developing driverless cars. Since autonomous cars will rely heavily on advanced software, the traditional automotive manufacturers are starting to see competition from new entrants that have never dealt with the car industry before.

Alphabet (former Google) was very early in launching a fleet of prototypes which have been tested on roads in the proximity of its headquarters in Mountainview, California for the past six years. Moreover, Alphabet is certainly not the only software developer that is targeting autonomous cars. Google's Chinese counterpart, Baidu, has also started invested in this field. Apple has revealed nothing about its car project but is undoubtedly developing a vehicle that probably will be electric and possibly also autonomous. Uber, which certainly has a close connection with the car industry but nevertheless never has built nor acquired cars, is now getting interested in driverless cars as well. Furthermore, a lot of startups and SMEs with expertise in specific areas such as computer vision, image processing, software-on-a-chip and sensor technology are starting to become important suppliers to the automotive industry.

The general attitude from brands devoted to sports cars have been reluctant to autonomous technology which makes sense since what they sell is more of an experience than a means of transportation. Nevertheless, some semi-autonomous functions have made their way into high performing cars as well.

However the central belief among these marques is that people enjoy driving and the partially autonomous functions should therefore aid the driver rather than do the actual driving.

Many automakers leverage on their electric vehicles as platforms for autonomous driving. There are two main reasons for this. First and foremost, alternative propulsion methods are becoming increasingly important in the automotive industry and one future technology benefits from being paired with another. The second reason is that an electrified system is somewhat easier for engineers to make autonomous since the driving system relies on drive-by-wire technology and ECUs.

The following table lists the world's 20 largest automakers in terms of revenues from passenger car sales. Toyota maintains its lead as the automaker with highest total revenues as well as revenues from the passenger car market. However, both Volkswagen and General Motors have higher unit sales of passenger cars and light commercial vehicles than Toyota.

Figure 19. Top 20 passenger car manufacturer by revenues (World 2015)

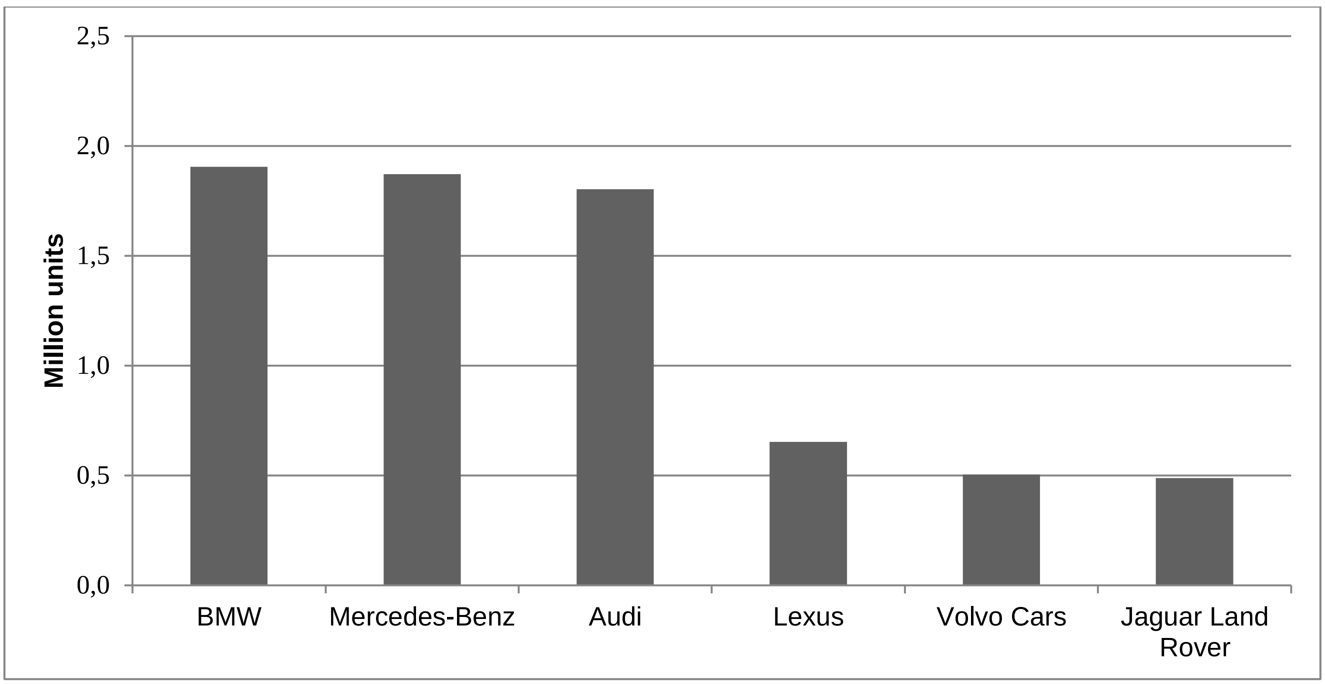
Group	Revenues, € million		Change	New registrations		Change
	2014	2015		2014	2015	
Toyota	191,929	202,265	5.39%	8,947,000	8,809,000	-1.5%
Volkswagen	164,065	174,703	6.48%	9,491,000	9,321,000	-1.8%
General Motors[1]	135,424	130,796	-3.42%	9,925,000	9,958,000	0.3%
Ford[1]	121,670	125,970	3.53%	6,323,000	6,635,000	4.9%
FCA[1]	93,640	110,595	18.11%	4,601,000	4,602,000	0.02%
Nissan	91,676	98,346	7.28%	5,318,000	5,423,000	2.0%
Honda	78,724	86,948	10.45%	4,367,000	4,743,000	8.6%
BMW	75,173	85,536	13.79%	2,118,000	2,247,000	6.1%
Daimler	73,584	83,809	13.90%	1,723,000	2,001,000	16.1%
Hyundai	54,599	54,852	0.46%	4,962,000	4,965,000	0.1%
Renault	38,874	43,108	10.89%	2,712,000	2,802,000	3.3%
PSA[1]	36,085	37,514	3.96%	2,938,000	2,973,000	1.2%
Kia	35,523	37,348	5.14%	2,907,000	2,915,000	0.3%
Jaguar-Land Rover	28,370	28,870	1.76%	462,000	522,000	13.0%
Subaru	22,030	24,817	12.65%	911,000	958,000	5.2%
Suzuki	22,033	23,474	6.54%	2,707,000	2,746,000	1.4%
Mazda	20,385	23,329	14.44%	1,196,000	1,307,000	9.3%
Mitsubishi Motors	17,701	18,435	4.14%	1,090,000	1,048,000	-3.9%
Volvo Car Group	14,832	17,683	19.22%	466,000	503,000	7.9%
Daihatsu	14,845	13,814	-6.94%	989,000	897,000	-9.3%

[1]*Including light commercial vehicles*

The luxury car market is important for automotive manufacturers which is why several large automakers have incorporated brands specifically targeting this segment. Examples include Volkswagen's Audi and Porsche, Daimler's Mercedes-Benz and Toyota's Lexus. Between 2014 and 2015 the market size for luxury cars grew over 14 percent from around € 350 billion to approximately € 400 billion. The strong growth is driven by the segment of increasingly affluent customers in emerging markets like China, India, the Middle East and Brazil. In addition, the US market is still important for luxury car brands.

The luxury car manufacturers lead the current development of ADAS and are also targeting autonomous cars most heavily. The three German luxury brands have the strongest position in this market indicating that autonomous technology is important for them to maintain their lead. This graph shows new registrations of the six largest luxury car producers in 2015.

Figure 20. Top 6 Luxury car manufacturers by new registrations (World 2015)



11.2 Jaguar Land Rover Automotive

As this report was created in cooperation with Berg Insight, some parts of this study have been copied from another Berg Insight report. The introductory text below and the following section (11.2.1) have been copied from the Berg Insight report *The Global Automotive OEM Telematics Market* but updated with new numbers and other changes where applicable. The text has also been indented to highlight this. For more details see chapter 3.3.

> Jaguar Land Rover Automotive, headquartered in the UK, manufactures premium cars under the brands Jaguar, Land Rover and Range Rover. The company has been a subsidiary of the Indian vehicle manufacturer Tata Motors since 2008. Jaguar and Land Rover was integrated into a single business by the former owner – Ford Motor Company – in 2002. Ford had acquired Jaguar in 1989 and Land Rover in 2000. Jaguar was founded in 1922 and has become one of the leading companies in designing and manufacturing premium sedans and sports cars. Land Rover is the second oldest four-wheel drive car brand in the world, launched by the Rover Company in 1948 with a single model called the Land Rover. Today, the brand has been extended to a range of four-wheel drive cars, including military vehicles. Jaguar Land Rover has six main facilities for R&D, manufacturing and assembly, of which five are located in the UK and one in India. The Chery Jaguar Land Rover joint-venture saw the opening of an additional assembly plant in China in July 2014. Jaguar Land Rover is the sixth largest luxury car manufacturer in terms of unit sales behind BMW, Mercedes-Benz, Audi, Lexus and Volvo Cars. Total unit sales of Jaguar Land Rover cars increased 13 percent to 522,000 worldwide in fiscal year 2016 driven by successful model updates and increased demand in all major markets. Company revenues grew almost 2 percent to £ 22.2 billion (€ 28.9 billion) in the fiscal year ended in March 2016.
>
> Jaguar Land Rover (JLR) markets its vehicles in 178 countries through over 2,600 franchise dealers. Europe is the largest market for JLR, accounting for 38 percent of car unit sales in 2015, followed by Asia-Pacific that accounted for 31 percent of sales and North America that accounted for 17 percent of car sales. The three largest countries in terms of Jaguar Land Rover car unit sales in 2015 were China, the UK and the US, accounting for about 25 percent, 19 percent and 18 percent of total sales respectively. Total unit sales of Jaguar cars increased 23 percent to 94,449 vehicles worldwide in the fiscal year ended in March 2016, following a positive reception of the new Jaguar XE and Jaguar XF models. Total unit sales of Land Rover vehicles grew 11 percent to over 427,000 cars worldwide driven by the new Range Rover Sport and Discovery Sport models, as well as continued success of the Range Rover Evoque.

11.2.1 Overview of Jaguar Land Rover passenger car models

> Jaguar cars have a tradition of performance, design excellence and unique British style, while the Land Rover four-wheel drive vehicles are known for simplicity, ability, luxury and durability. Current Jaguar models include the E-segment XF sedan and estate, the F-segment XJ luxury sedan, the F-Type coupé and convertible sports car, as well as C-segment Jaguar XE. The XE sedan and estate are the best-selling Jaguar models, accounting for 39 percent of total Jaguar unit sales in 2015. Jaguar plans to extend the model range in 2016 with the launch of the F-Pace SUV and the 2017 Jaguar XE compact luxury sedan.

The current Land Rover model range includes five models: the Land Rover Discovery mid-size premium SUV, the new Land Rover Discovery Sport compact SUV, the Range Rover Evoque compact luxury crossover SUV, the Range Rover Sport mid-size luxury SUV and the Range Rover full-size luxury SUV. Production of the classical Land Rover Defender off-road utility vehicle ended in January 2016, 68 years after launch. Production of the Land Rover Freelander was discontinued in 2014. The Range Rover Evoque is currently the most popular model, accounting for 26 percent of total Land Rover unit sales worldwide in 2015, followed by the Discovery Sport that accounted for over 22 percent of unit sales the same year.

11.2.2 Jaguar Land Rover and ADAS development

Compared to the top three German luxury brands and Volvo Cars, JLR has not yet reached an equal level of ADAS development although it still features a significant amount of systems to aid the driver. Available systems help the driver by controlling one aspect of the dynamic driving (i.e. steering or braking and acceleration. JLR offers adaptive cruise control, lane departure warning, lane keeping assist, driver monitor system, blind spot monitor with rear cross traffic alert, traffic sign recognition with speed limiters and automatic emergency braking. Available systems varies from different models with the top line XJ Jaguar models having the most sophisticated functionality.

JLR has also developed a parking assistant that when activated takes control over the steering for both perpendicular and parallel parking while the driver handles the pedals and transmission. Land Rover also offers a wade sensing system that detects the water depth through ultrasonic sensors in the side mirrors when traversing shallow water crossings. This system helps the driver by showing the current depth together with the maximum wading capability on the vehicle's display unit. The system warns the driver if the water level gets to deep. Wade sensing is available on the Discovery, Range Rover, Range Rover Evoque, Range Rover Evoque Convertible and the Range Rover Sport models.

In June, 2015, Land Rover showcased a smartphone app for a modified Range Rover Sport that uses the system for semi-autonomous parking already in place to enable remote control of the car. Through a wireless connection, the app lets the driver start the car and control the throttle and brakes as well as steering in speeds up to 4 mph from outside the vehicle. A safety system prevents the application to be used further away than ten meters from the car. This feature can be used when negotiating tricky off road terrain or when exiting a narrow parking spot with limited space to open the doors. The technique effectively lets the driver be his or her own spotter which is especially practical for large vehicles like SUVs. The system is not autonomous since the driver still controls all the vehicle's movements, but it does enable the driver to leave the car and relies on semi-autonomous technology to work.

Figure 21. Land Rover remote control app

Source: The Verge

11.2.3 Jaguar Land Rover's approach to autonomous driving

Jaguar Land Rover is pursuing an incremental approach to autonomous driving. It plans on developing increasingly autonomous features based on enhancements of its current ADAS together with image processing developments. The company believes it is important to remember that driving is not only a means for transportation but also a way to have fun. By developing techniques for autonomous driving the company wants to achieve a solution where the driver can choose to engage in the driving or let the vehicle do it by itself. JLR wants its customers to be able to choose among different levels of autonomous driving features. Over the next three years, JLR plans to invest $ 7.9 million in autonomous technology.

11.2.4 Jaguar Land Rover and autonomous technology

Simultaneously with the showcase of the remote control driving app, the company also demonstrated a second more autonomous system which automatically turns another modified Range Rover Sport vehicle 180 degrees when activated. The car takes control over the steering, brakes and throttle and uses its ultrasonic sensors to detect objects such as pedestrians or crash barriers to perform an about-turn without hitting any obstacles. The system can be used for turning around on a deserted road where there is no room for a U-turn or to perform a multi-point turn on a narrow dead end road.

Both the remote controlling app and the multi-point turn feature are in line with JLR's view on autonomous driving as a way to make driving safer and more enjoyable by removing some of the tedious parts of it. At the same time, the incremental solutions are believed to be small but important steps toward a fully autonomous vehicle. JLR is also participating with five cars in the UK-CITE (UK Connected Intelligent Transport Environment) project. The project's aim is to develop UK's first so called connected corridor where V2I and V2V communication technologies will be tested together with autonomous cars. The test route is 41 miles long and located around Coventry and Solihull. Up to 100 cars of different brands will be tested on the road corridor to analyze how smart cars can leverage on being connected to each other and to roadside infrastructure.

JLR is also pursuing a project with the purpose to log drivers' behavior in different driving situations. The gathered data will then be used as learning input for robots to make them drive and behave more like humans. This is an important field to investigate since autonomous cars will diffuse incrementally to the consumer market which will result in fully autonomous vehicles, partly autonomous vehicles and regular human operated vehicles having to coexist and cooperate on the roads. Driverless cars that operate similar to real people should make it more comfortable for other human drivers. JLR also aims at adapting the autonomous driving style to individual drivers by logging each driver's preferences and ways of driving. The purpose with this approach is to make the autonomous driving experience more comfortable for the person sitting in the driver seat.

During April 14, 2016, JLR demonstrated its progress in autonomous technology to the EU transport ministers during an unofficial meeting in Amsterdam. The ministers met to discuss standardization and regulative aspects of testing and selling autonomous vehicles. The JLR demonstration included a car that featured hands-free driving which indicates that JLR is picking up speed in the development of more advanced autonomous research cars. JLR has said that it will begin testing its systems for autonomous driving on public roads this year and that it will be available to the market in ten years from now.

In April, 2016, Jaguar Land Rover announced a new business unit called InMotion which will focus on developing new solutions for mobility. InMotion will for instance launch a car sharing program and leverage on connected devices. The firm is owned by JLR but will act on its own accord to enable the flexibility and speed associated with a start-up company.

11.2.5 Jaguar Land Rovers' position in the autonomous car development

JLR has lagged behind somewhat in the development of ADAS as well as in the testing of autonomous driving technologies. However, the company is starting to pick up pace with the top luxury brands to maintain its relevance on the market. The recent actions, with the announced participation in the UK-CITE project and the establishment of the InMotion venture indicates that JLR is taking both the trends of autonomous vehicles as well as alternative solutions for mobility seriously.

Both Jaguar and Land Rover are brands with strong and important heritage which might explain the somewhat hesitant approach to self-driving technologies and that JLR wants the autonomous features to adapt to individual drivers.

11.3 Volvo Car Group

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Volvo Cars is based in Sweden and markets premium passenger cars in about 100 countries worldwide. The company, which manufactured its first car in 1927, has been owned by the Chinese automotive manufacturer Zhejiang Geely Holding (Geely) since 2010. Volvo Cars formed part of the Volvo Group until 1999, when the company was acquired by Ford Motor Company. Volvo Cars head office, product development, marketing and administration functions are mainly located in Gothenburg. Since 2011, Volvo Cars has offices in Shanghai and Chengdu, China. The new Volvo Cars China headquarters in Shanghai includes a technology center as well as sales and marketing, manufacturing, purchasing, product development and supporting functions. Volvo Cars operates five manufacturing plants in Sweden, Belgium and China and one assembly plant in Malaysia. Three of the plants are located in China and have been erected after 2009. Starting in 2018, Volvo Cars will also manufacture cars in its new factory being constructed in North Carolina. In 2015, Volvo Cars' revenues grew 19.2 percent to SEK 164 billion (€ 17.7 billion), and sales of cars increased almost 8 percent to 503,000 units.

The long-term goal is to sell 800,000 cars annually by establishing China as the company's second home market. Volvo cars are marketed and sold by regional market companies and national sales companies through about 2,300 local dealers in 100 countries. The most important market for Volvo Cars are Western Europe, China and the US that accounted for 54 percent, 16 percent and 14 percent of total car unit sales respectively in 2015. Volvo Cars' unit sales climbed 8.7 percent in Western Europe (excluding Sweden which climbed 16 percent) in 2015 and as much as 24.3 percent in the US. Sales in China were almost identical to the previous year. The five largest countries for Volvo Cars in 2015 were China with 16.2 percent, Sweden with 14.2 percent, the US with 13.9 percent, the UK with 8.6 percent and Germany with 7.1 percent of total unit sales.

11.3.1 Overview of Volvo passenger car models

Volvo Cars currently produces car models in three versions: Sedans (S60, S80), Versatile estates (V40, V60, V70) and Cross Country crossover and SUVs (XC60, XC70, XC90). Production of the C30 hatchback and the C70 convertible was stopped in 2013. The S60 D-segment and S80 E-segment sedans accounted for 15 percent of total unit sales in 2015, while the V40 C-segment, V60 D-segment and V70 D-segment estates accounted for 39 percent of total sales. Sales of the XC60, XC70 and XC90 crossover and SUVs accounted for 46 percent of Volvo Cars' total unit sales in 2015 much thanks to the popular XC60 and the positive market reception of the all new version of the XC90. The XC60 has over the last few years been the company's most popular model, with almost 160,000 units sold worldwide in 2015. The second most popular model is the V40 with 83,000 units sold the same year. In 2016 two new models will be introduced on the market; the S90 sedan and the V90 versatile estate.

11.3.2 Volvo Cars and ADAS development

Volvo Cars is one of the leading carmakers in terms of offering ADAS to customers. The reason for this is Volvo Cars' strong dedication to passenger safety which is one of the brand's key selling points. A general principle for Volvo Cars' semi-autonomous systems is that the driver always has the possibility to override the automatic driving by demonstrating active and aware behavior (i.e. steering aggressively or applying the pedals). Such engaged behavior can also postpone the warning signals slightly to avoid unnecessary and disturbing warnings.

Volvo Cars' various auto braking systems are together termed City Safety - a system that nowadays is standard on all new models. The system has the capability to detect other vehicles, pedestrians, cyclists and even larger animals in speeds up to 50 km/h and automatically brake to avoid or reduce the impact of a collision. If an emergency is detected the driver gets warnings through an audio signal, a blinking light in the lower part of the windshield and a short braking pulsation. Should the driver respond to the warning by applying the brakes, the system is programmed to automatically add extra braking power if necessary since many drivers have a tendency not to apply full pressure on the brakes even in an emergency. If the driver does not respond to the warnings at all, the vehicle will automatically initiate braking and once the car is about a second from colliding with the obstacle, the car engages full braking power. The driver can always regain control of the vehicle by steering, braking or accelerating aggressively which overrides the automatic system.

The first City Safety system relied on lidar sensors that scanned the area in the immediate front of the vehicle and was able to completely avoid collisions if the relative speed between the car and the object in front was less than 15 km/h. The second generation of City Safety, introduced in the V40 during 2012, has significant upgrades and uses both radars and cameras in addition to the lidar sensors to extend the cars ability to detect obstacles. Today, the system can avoid collisions with pedestrians that walk out in front of the car in speeds up to 45 km/h.

The City Safety system does not respond to oncoming traffic but a new feature in the City Safety package provides the ability to detect oncoming vehicles when turning left in intersections and automatically apply the brakes if the turn otherwise would result in a collision. This system requires functionality beyond the usual since the sensors have to detect oncoming vehicles from an angle (when halfway through the turn) as opposed to right in front of the car. Volvo Cars was first among automotive manufacturers to have this specific functionality. Thanks to a new camera with an advanced exposure control mechanism, the latest update of the City Safety system also allows it to function in darkness.

As a part of Volvo Cars' safety focus, the company has developed a pedestrian airbag that automatically inflates and covers the lower part of the windshield's external surface if a pedestrian is hit with the front bumper.

Volvo Cars has a park assist system that relies on ultrasonic sensors and acoustic signals to indicate how close the car is to other vehicles and other objects when parking. The system is dubbed Park Assist Pilot and helps the driver by first checking whether a parking space has appropriate size and then shows what operations the driver should do through text messages, graphics and symbols on the center display. The system can also aid when leaving a parallel parking space.

The all new XC90 has an integrated highway autopilot system called Pilot Assist that lets the vehicle drive autonomously (steering, throttle and braking) in stop-and go-traffic in speeds up to 50 km/h. The car occasionally reminds the driver to apply steering to keep the driver alert. At the heart of the XC90's infotainment system is a nine-inch touchscreen, called Sensus, which is used as the main interface and control center. The XC90 also has a run-off road protection feature that detects if the vehicle departs from the road and automatically tightens the front row safety belts to keep the occupants in the safest possible position.

11.3.3 Volvo Cars' approach to autonomous cars

As an inventor of the modern three point safety belt, Volvo Cars has always put lot of effort into passenger safety. The company has declared its vision that by 2020, no one shall be killed or seriously injured in a new Volvo car. In line with the safety focus, the company is currently going through a major transformation connected to the corporate and brand strategy “Designed Around You” which has the focus to put the consumer in the center. The company aims to establish itself as a leading brand in the luxury and premium segments, focusing on safety, contemporary Scandinavian design, environmental care and clever functionality.

Since Volvo Cars' brand is heavily associated with safety and self-driving cars in general are believed to provide much safer driving, it follows that the development of an autonomous car is important for the company. Volvo Cars' non-fatality vision for 2020, almost demands the development of an at least partially autonomous car that always avoid collisions by emergency braking or taking over the steering. However, that is probably not enough since reckless driver behavior can cause hazardous situations that are impossible for any safety system to negotiate. The promise of self-driving cars is that they will never end up in such irrevocable scenarios and that is a major reason to Volvo Cars' large interest in them.

11.3.4 Volvo Cars and autonomous technology

For the next XC90 model scheduled for launch in 2017 as well as the upcoming S90 and V90 models, Volvo Cars has developed an enhanced Pilot Assist system that will make it more comfortable and safer to drive. The new system is called Pilot Assist II and will integrate a lane keeping assist with an adaptive cruise control just like the current Pilot Assist but the new version will function in speeds up to 120 km/h and will not require a preceding vehicle to follow. New versions of the S90 and V90 models will mirror the technologies used in the XC90.

In 2017, Volvo Cars will, in collaboration with the Swedish Transport Administration, the Swedish Transport Agency, Lindholmen Science Park, Chalmers University of Technology and the City of Gothenburg as well as multiple suppliers, start a large-scale trial of autonomous cars in a real-life environment. The project is called Drive Me and will see a total of 100 XC90s equipped with a new system of sensors and software for partially autonomous driving tested by Volvo Cars' customers on specific suburban commuting roads around Gothenburg. In particular, the project will feature a highway autopilot dubbed IntelliSafe Autopilot which allows transition between conventional and autonomous driving by integrating relevant information in the Sensus interface. The roads chosen have certain attributes that make driving less complex, such as separated lanes or few intersections. The average speed on these roads is, on the other hand, around 70 km/h and thus the cars will have to behave in a reliable way to not cause any dangerous accidents. This test is unique in the sense that it involves actual customers instead of being performed solely by company engineers.

Some of the reasons behind the project are to analyze what traffic situations are suitable for autonomous cars, what infrastructure will be required and what economic and societal benefits can be achieved. Another purpose with the trial is to analyze people's trust in self-driving cars and the interaction between human drivers and robot drivers. An interesting aspect is that the autonomous driving system is programmed to always keep the speed limit which is far from true about most human drivers. This might result in people being annoyed over the slow pace of the autonomous vehicles causing an increased number of potentially dangerous attempts to pass them.

Figure 22. Drive Me project routes for autonomous mode

Source: Volvo Cars

Early in 2016, Volvo Cars bought a few hundred of the technology company Nvidia's supercomputer developed specifically for autonomous driving, Nvidia DRIVE PX 2. This computer has about the same processing power as 150 Macbooks and is not bigger than a lunch box. Most previous test vehicles for autonomous driving have been equipped with multiple computers taking up a lot of space. The new computer from Nvidia will be integrated with a system of cameras, radars, lasers and ultrasonic sensors that is based on technology already available in the new XC90. However, during the Drive Me project, this system will continuously be improved to increase the cars' capabilities.

In the beginning of the project, each driver will be responsible at all times for any incident that the test vehicle might cause. However, the goal is to, at some point in the project, be able to switch responsibility to Volvo Cars when the car is in autopilot mode. This step is what Volvo Cars highlight as the big challenge. ADAS that makes driving in specific situations, such as in congested traffic, more comfortable are already available from most large car manufacturers. However to go from this step to actually be able to tell the drivers that they in specific situations can let go of the wheel and read a newspaper instead is a significant challenge. With the Drive Me project, Volvo Cars wish to achieve this within a few years' time. However, the company stresses that the system first must be safe and reliable with redundant systems that provide back-up if the standard systems fail. To develop a car that has this level of ultra-reliability is what Volvo Cars sees as the most significant challenge since it demands a holistic approach where multiple systems must be integrated and never allowed to fail. According to Volvo Cars, once the autopilot is said to be fully autonomous, the car can never demand the driver to take over control even if it does not understand what is happening in a specific situation. Instead the autopilot must be able to deal with the problem on its own or in worst case slow down and come to a halt by the side of the road before handing control back to the driver.

Volvo Cars is planning to widen the scope of the Drive Me project by including testing in London in addition to Gothenburg. The London project differs from the trial in Gothenburg by allowing ordinary families (not employees at Volvo Cars) to test-drive the vehicles. The London project will begin initial testing in 2017 and then include 100 modified XC90 models in 2018. Volvo Cars plans to log data from the test drives to adapt its technology for self-driving vehicles to normal driving conditions.

Volvo Cars has also plans to initiate a self-driving car project, similar to Drive Me, in China. The company plans to begin discussions with Chinese cities that are interested in hosting trials for self-driving vehicles and select the cities with most suitable regulations and infrastructure for testing of its autonomous technology. According to Volvo Cars, the testing will involve up to 100 vehicles and thus be the largest trial with autonomous cars so far in China. The company also wants to speed up the process of implementation of new regulations concerning autonomous cars in China.

People in general prefer to stay in control in most situations and Volvo Cars believes that goes for autonomous cars as well. In line with this attitude, Volvo Monitoring and Concept Centre in Camarillo, California, has developed Concept 26 - an interior design and platform concept for an autonomous car. The name comes from the 26 minutes the average US commuter spends on each journey between home and work and calls attention to how these 26 minutes could be used in a better way. The design concept has three different modes: Drive, Create and Relax of which the last two features fully autonomous mode. Volvo Cars believe that fully autonomous driving will (at least in a first stage) only be allowed on specific roads, such as some freeways, making seamless transition between driving and autopilot an important attribute.

11.3.5 Volvo Cars' position in the autonomous car development

Volvo Cars is one of the automakers that have reached furthest in the development of semi-autonomous technology and clearly aims to develop increasingly autonomous systems in the near future. The launch of Pilot Assist II scheduled for 2017 is one indication since that system will feature SAE Level 2 autonomous capabilities. Perhaps more telling, though, is the ambitious Drive Me project that will start in Gothenburg in 2017 with similar projects planned for London and for China. Volvo Cars has declared the goal that no one shall be killed or seriously injured in a new Volvo Car by 2020. The company's development of safety systems and, in the extension, autonomous cars goes hand in hand with this vision.

Volvo Cars has an edge to other carmakers from having emerged as the leading car brand in terms of safety. The company has significant know-how in developing safety systems and ADAS and can leverage on these skills to develop autonomous cars. Volvo Cars has an additional advantage in its close collaboration with both the Swedish government as well as academic institutions in the area of Gothenburg which together creates a so called triple helix that fosters innovations.

11.4 Tesla Motors

As this report was created in cooperation with Berg Insight, some parts of this study have been copied from another Berg Insight report. The introductory text below and the following section (11.4.1) have been copied from the Berg Insight report *The Global Automotive OEM Telematics Market* but updated with new numbers and other changes where applicable. The text has also been indented to highlight this. For more details see chapter 3.3.

> Tesla Motors develops and manufactures electric cars and electric drivetrain components. The company, headquartered in Palo Alto, California, was founded in 2003. Tesla uses proprietary technology, design and manufacturing processes to create a new generation of electric cars. The company has also provided development services and powertrain components to Daimler and Toyota. Tesla currently operates a manufacturing plant in California and an assembly plant in the Netherlands. Moreover, in order to remove the cost of purchasing batteries, Tesla and strategic partners including Panasonic have begun construction of the so called Gigafactory in Nevada that will produce car batteries. The Gigafactory will also produce battery packs intended for use as stationary storage in both business facilities and residences. Tesla expects to begin cell production in the Gigafactory in 2017 and reach full capacity in 2020 at which time the factory will produce more lithium ion batteries than the entire global market did in 2013. The ambition is to power the factory entirely with renewable sources.
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> Tesla uses a distribution model based on company-owned sales and service centers in order to ensure the best customer experience and benefit from short customer feedback loops. In April 2016, the company operated a total of 215 retail outlets in North America, Europe and Asia Pacific. In 2017 the number of outlets is expected to grow to a total of 441 locations. In 2015, Tesla Motor’s revenues grew 26.5 percent to US$ 4.05 billion primarily as a result of increased sales of the Model S. Worth noting is that Tesla has so far not been profitable and during 2015 the net loss was US$ 890 million. The reason behind this is mainly the large investments put into the Gigafactory and other facilities.
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> Retail deliveries of the Tesla Model S started in the US in June 2012 and Canada at the end of 2012. The Model S was released in Europe in August 2013, starting in Norway, Switzerland and the Netherlands. Since then, availability has been extended to 30 countries in North America, Europe and Asia-Pacific. In 2015, Tesla delivered 50,580 cars to customers worldwide - an increase of over 50 percent from last year's sales of 33,157 units. The top three individual countries in terms of revenues in 2015 were the US with over 48 percent, Norway with nearly 9 percent, and China with just below 8 percent of total revenues. Cumulative deliveries of the Model S surpassed 107,000 by the end of 2015. As a comparison the all-time best selling all-electric highway-capable car Nissan LEAF passed the 200,000 unit mark in December, 2015 but the Model S seems to be catching up as it overtook Nissan LEAF's position as the best-selling all-electric car in the US and globally in terms of new registrations in 2015.

11.4.1 Overview of Tesla passenger car models

> Tesla released its first model in 2008 – the Tesla Roadster sports car based on the Lotus Elise. The model has since been discontinued. Deliveries of Tesla’s second car model, the Tesla Model S

sedan, commenced in June 2012. The first deliveries of the third model, the Tesla X crossover, started in early October 2015 in the US.

Tesla aims to deliver between 80,000 and 90,000 Model S and Model X cars in 2016. The Tesla Model S is an F-segment premium sedan available in five variants with either rear-wheel or all-wheel drive and different battery capacity. Depending on battery size and engine power, the Model S has a range of up to 420 km to 500 km. In the second quarter of 2015, Tesla launched a 90 kWh battery option that extends the range up to 6 percent.

Tesla's third generation car, scheduled for introduction in late 2017 is called Model 3, a D-segment sedan with a base price of US$ 35,000 (half of the base price for the Model s). The new model will help the company to reach its target of selling 500,000 cars per year by 2020. In April, less than a month after its revelation, the Model 3 had according to Tesla received close to 400,000 pre-orders indicating the strong demand for the new vehicle.

Tesla has started to build its own network of Supercharger charging stations to enable customers to travel efficiently between cities along well-travelled highways. Superchargers provide half a charge in 20 minutes. In March 2016, Tesla had opened 604 Supercharger stations in North America, Europe, China, Japan and Australia.

11.4.2 Tesla and ADAS development

Tesla has received a lot of attention for its autopilot system which was released in autumn 2015. Every Model X vehicle and all Model S vehicles produced after October 2014 have been equipped with software that can receive incremental upgrades of Tesla's autopilot system. The highway autopilot essentially enables SAE Level 2 autonomous driving where the driver still remains responsible at all times although the car handle most of the driving in some use cases.

Tesla is careful to remind its customers that the autopilot is a semi-autonomous system not very different from the autopilot used in airplanes and that the driver should be engaged at all times. The purpose with the autopilot is, according to Tesla, to relieve the driver of the tedious parts of driving and also to make it safer. The system is based on a forward looking radar, a camera facing the same direction and 12 long-range ultrasonic sensors. Worth noting is that Tesla's autopilot unlike semi-autonomous system from most other car makers does not include any lidar. In fact, Elon Musk (Tesla's CEO) has said that he does not think lidar will be necessary to achieve fully autonomous driving.

So far, the autopilot is only intended for freeways or similar relatively confined driving conditions. The system is quite reliable as long as lane markings are clear but once the autopilot fails to recognize any lane markings, or is confused in any other way, the system gives the driver a warning to take over control of the steering. If the driver does not take over the driving after several alerts, the car automatically slows down and eventually comes to a halt by the side of the road. The autopilot also assist in lane changing after the driver has tapped the turn signal but the driver needs to hold the steering wheel as a means of precaution. The adaptive cruise control has the regular features of setting a desired speed and a fixed distance to another vehicle in front of the car.

A useful feature that follows from the wireless connection to the cloud is that the autopilot continuously learns from other cars' experiences. Tesla collects field data from all the sensors as well as the GPS and analyze this before sending upgrades to the software that improves the autopilot's performance.

Figure 23. Tesla Autopilot display

Source: Tesla

Although many Tesla owners are very happy with the autopilot functionality, Tesla has also received a lot of criticism. The main argument for the critics is that Tesla are using people as real-life test subjects to test its systems for autonomous driving and that it seems more important for Tesla to be the first to release an autopilot than developing a safe system. Other car manufacturers have performed extensive in-house testing before releasing ADAS and the systems released have included safety features such as a requirement to keep a hand on the steering wheel even when in ACC mode. Despite the fact that Tesla encourages their drivers to always stay alert and reminds them that they are responsible for any accidents, people are still making dangerous experiments with the autopilot as evidenced by numerous YouTube-videos of Tesla owners filming an empty driver seat from the second row of their car. However, following public criticism and also concerns by Elon Musk himself, Tesla made some updates to the autopilot software in beginning of January, 2016. The update made autopilot unavailable on city streets and on streets with no dividing center line and also set the top speed to 8 km/h above the allowed speed when in autopilot mode. Nevertheless, some think that Tesla's launch of the autopilot came too early and was an irresponsible way of getting increased publicity. However, it seems like most drivers of Tesla appreciate the autopilot feature and it is worth stressing that the drivers carry the legal responsibility.

Simultaneous with the update of the autopilot in January, 2016, Tesla also launched one of the most advanced systems for automatic parking. It is called Summon and lets the driver exit the car while the vehicle automatically opens the garage door and parks itself. However, it is only supposed to be used at private property. Tesla believes Summon is an important starting point from which to create more advanced autonomous features. Other ADAS offered by Tesla include adaptive headlights, rain sensing automatic windshield wipers, blind spot warning and lane departure warning.

11.4.3 Tesla's approach to autonomous cars

Tesla is a major advocator of self-driving cars as evident by its highway autopilot which is the most capable semi-autonomous system available on the market today. It is a part of Tesla's strategy to brand itself as an innovative company which cars have the best range and performance of any electric car manufacturer - which also is true. Tesla also wants its brand to be associated with safety and advanced technology. It is therefore no surprise that Tesla puts a lot of effort into developing self-driving vehicles - in fact, it would be more surprising if it did not.

Tesla's approach to developing autonomous cars can, similar to other automakers, be categorized as a step-by-step process. Through incremental innovations, Tesla aims at making its cars increasingly better at driving on their own. However, Tesla's attitude is somewhat different from its automotive competitors in two ways. First of all, Tesla is simply bolder - the company is not afraid to launch beta versions of its technology to its customers, something most automakers are very reluctant to do. The second aspect is that Tesla relies on its existing base of customer vehicles for developing systems with greater autonomy. Tesla is at least not openly putting a lot of effort into developing new cars or prototypes for testing of autonomous features like some other actors. Instead it leverages from the constant connectivity to the Model S and Model X vehicles to gain data and to send over-the-air software updates. The implication of this is that, should the sensors in the Model S and the Model X be sufficient, Tesla can potentially transform its customers' cars into fully self-driving vehicles once the software for that is developed without requiring them to buy a new model.

Elon Musk has on several occasion talked very positively about autonomous cars and clearly sees them as an integral part of the automotive industry in the future. He has said that autonomous vehicles is a key technology to improve mobility in cities. Musk has also given very optimistic estimations as to when Tesla will have a ready solution for full autonomy, as early as 2018 has been indicated but with the acknowledgment that regulatory approval probably take an additional 1-3 years. On the other hand, Musk has been known to largely underestimate the time for bringing Tesla's models to market.

11.4.4 Tesla and autonomous technology

As mentioned above, Tesla's main development of autonomous cars is currently occurring at a software stage rather than a hardware stage (at least publicly). The underlying reason for this is that Tesla potentially already have most of the necessary hardware for relatively advanced autonomy installed in the Model S and Model X. Undoubtedly, Tesla is also looking at further hardware developments for future vehicle generations since the current hardware is probably not going to be enough. Nevertheless it is the software progress that is most relevant to the company's current endeavor of increasing the autonomy of the Model S and the Model X.

As of May, 2016, Tesla has gathered 780 million miles of vehicle data of which about 100 million miles have been driven with the Autopilot engaged. Currently there are around 70,000 Tesla vehicles with Autopilot mode enabled which collectively increase Tesla's database with approximately a million miles of data every ten hours. To put in perspective, Google which started its self-driving car project in 2009, has logged about 1.6 million miles in total, although its prototypes admittedly collects more data per mile since it includes lidar data and most of the driving is done completely autonomous.

The data collected by Tesla can be used to analyze situations and also as a basis for testing software updates before these are transmitted to Tesla drivers. Tesla can even use data from situations when the cars are not using the Autopilot or the Summon features thanks to an inert mode that indicates what the car would have done if those systems had been engaged.

Tesla relies on several suppliers for the autonomous hardware in its vehicles but one of the more distinguished collaborations has been with Mobileye. The Israeli company provides Tesla with a camera system with integrated computer vision capabilities. It is this system that is key to the Tesla cars' semi-autonomous features. However, this is not an off-the-shelf solution for autonomy - Tesla has refined and adapted the computer vision system to its cars. In July, 2016 it became apparent that Mobileye and Tesla is parting ways following a fatal incident that occurred in Florida with a Model S vehicle in Autopilot mode. It is yet not certain when the contract between Tesla and Mobileye ends but it is not unlikely that Tesla begins developing its own chips for computer vision instead.

There have been rumors regarding Tesla's Model 3 as taking the next step with autonomous technology. After the Model 3 was unveiled on March 31 this year, Elon Musk hinted on Twitter that it was only the first part of the Model 3 revelation and that a second next level part is to come. On the other hand, the Model 3 is supposed to be Tesla's affordable model and it would be somewhat strange to equip it with more advanced autonomous features than the expensive Model S and Model X. Furthermore, the head of Tesla's Autopilot technology, Sterling Anderson, has said that Model S and Model X will stay in the lead of the company's autonomous development for a while.

Earlier this year, on May 7, an unfortunate incident happened with a Model S that had the Autopilot mode engaged and resulted in the death of the driver. The accident happened in Florida when a tractor trailer crossed the road the Model S was driving on. Neither the Autopilot, nor the driver observed the trailer and the Tesla car hit it at high speed. Allegedly the trailer was positioned against a brightly lit sky which might be why both sensors and the driver failed to see it. According to Elon Musk, the car's radar interpreted the big rig as an overhead road sign and thus did not initiate emergency braking. The incident is certainly not good for Tesla's and its Autopilot's publicity which already has received criticism. Some has argued that since the Autopilot handles most of the driving so smoothly, drivers are prone to believe that the system can handle more situations than it actually is capable of. On the other hand, according to Musk, logged data from its cars with the Autopilot available has indicated that the risk of being in an accident is 50 percent lower when the Autopilot is engaged compared to when it is not. In fact, when the incident occurred, Tesla cars had driven more than 130 million miles with Autopilot engaged while the average distance between each traffic fatality is 94 million miles in the US and 60 million miles worldwide.

11.4.5 Tesla's position in the autonomous car development

Tesla is arguably the carmaker that has reached furthest in terms of ADAS development thanks to its Autopilot system. Tesla has an edge to many other carmakers because numerous customers see Tesla as an innovative and bold company. The Tesla brand speaks to early adopters since it encompasses both the world's highest performing electric cars and the vehicles closest to autonomous that are available today.

Tesla's decision to install devices for constant internet access in their cars has proven to be of principal importance since the logged data is key to Tesla's development of the Autopilot while the updates also are easy to transfer to the customers. Compared to other carmakers, Tesla is a more software-inclined company which can be an advantage in the future when autonomy is increasingly dependent on software progress. On the other hand, Tesla is still a relatively small car manufacturer and does not have the same resources as the large carmakers. Furthermore, Tesla has been reluctant to equip its cars with as many sensors as most other actors developing self-driving technology. Most notably is the absence of lidar sensors which might prove practically necessary for development of fully autonomous cars.

Another important aspect to consider is that Tesla already has a lot on its plate in the near future. In 2017, the company is launching Model 3 which has received more reservations than Tesla will be able to satisfy in both 2017 and 2018. Tesla is currently also building the world's largest battery factory. Despite Musk's optimistic statements, it might be hard for Tesla to engage in all the activities it wants to.

The fact that a fatality occurred with a Model S while the Autopilot was engaged might raise questions about Tesla's autonomous technology. Tesla has on numerous occasion stated that the driver is always responsible over the control of the vehicle. In a juridical sense that is hard to prove wrong but people might question whether Tesla actually should carry some liability since the Autopilot leads drivers to believe they can divert their attention from driving.

11.5 Mercedes-Benz

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> Mercedes-Benz is a subsidiary of the Daimler Group and the second largest manufacturer of premium and luxury cars, behind BMW, while Daimler Group has the position as the world's largest manufacturer of commercial vehicles. The origins of the company date back to 1883 when Karl Benz founded Benz & Company. The company introduced the world's first automobile with internal combustion engine in 1886. Today, the group markets the brands Mercedes-Benz, Mercedes-AMG, Mercedes-Me, Smart, Freightliner, Western Star, BharatBenz, Fuso, Setra and Thomas Built Buses in nearly all countries globally. The Maybach line of luxury cars was discontinued in 2012, but the name is now used as a sub-brand for the most exclusive versions of the Mercedes-Benz S-Class models. The Daimler Group has 284,000 employees and manufacturing facilities in 19 countries on five continents. Daimler Group's divisions include Mercedes-Benz Cars, Daimler Trucks, Mercedes-Benz Vans, Daimler Buses and Daimler Financial Services. Daimler Financial Services provides financing, leasing, fleet management, insurance and mobility services. In 2015, Daimler Group revenues increased 15 percent to nearly € 149.5 billion, while revenues for the Mercedes-Benz Cars division grew 14 percent to over € 83.8 billion.
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> With the "Mercedes-Benz 2020" growth strategy, the Mercedes-Benz division aims to become the leading manufacturer of premium and luxury cars before the end of the decade. The company intends to be the leader in terms of brand image, product range, unit sales and profitability. In 2015, the group sold a record 1.88 million Mercedes-Benz premium and luxury passenger cars worldwide which marked the fifth year of consecutive record unit sales. The growth in 2015 was mainly attributable to the increased popularity of the C-Class and the positive reception of the new SUVs. The most important markets for Mercedes-Benz Cars in 2015 (including sales of cars from the Smart brand) were Western Europe with almost 39 percent of unit sales, North America with nearly 21 percent of unit sales and Asia with over 23 percent of unit sales. The three largest individual countries in terms of unit sales were China with 20 percent of unit sales followed by the US with almost 18 percent of unit sales and Germany with nearly 15 percent of total unit sales.

11.5.1 Overview of Mercedes-Benz passenger car models

Mercedes-Benz markets a range of different models under the following sub-categories: A- and B-Class compact cars; C- and E-Class sedans, wagons and coupes; S-Class sedans, coupes and convertibles while SUVs and Sports cars make up categories of their own. The company also sells an AMG coupe, a B-Class and an S-Class electric car, an E-Class cabriolet and two roadster models. The division of Mercedes-Benz Cars also incorporates the brand Smart under its operations, although this brand is separated from the Mercedes-Benz brand.

In terms of unit sales, SUVs is now the most important segment for Mercedes-Benz. Sales of vehicles from the SUV segment increased by over 27 percent to 543,000 in 2015. The C-Class models also saw a significant increase of over 37 percent to reach 470,000 unit sales. Sales of vehicles from the A- and B-

Class model series grew 9.8 percent to 425,000 units while sales of both the E-Class and the S-Class declined slightly, the E-Class with 7 percent to 306,000 and the S-Class with almost 8 percent to 106,000 total unit sales, however the S-Class still has the position as the best-selling luxury sedan in the world. Smart cars saw a significant increase of almost 32 percent to reach 121,000 unit sales.

11.5.2 Mercedes-Benz and ADAS development

Mercedes-Benz is one of the automotive manufacturers that have diverted most efforts into developing ADAS as well as telematics and infotainment systems. The company was also early in beginning the development of these systems. Its first adaptive cruise control came already in 1998 but it all started even earlier with the PROMETHEUS project where Daimler-Benz played a key role. The project was a part of the Eureka research initiative between 1986-1994 that eventually saw a test drive of a semi-autonomous Mercedes-Benz S-Class around Paris which featured automatic tracking of other vehicles and changing of lanes to overcome slower vehicles.

Today, Mercedes-Benz offers ADAS across many models. An advanced ADAS package developed by Mercedes-Benz for production cars is termed Intelligent Drive and is offered in the new S-, E-, and C-class models as well as in the new CLS models.

Intelligent Drive is essentially a collection of all Mercedes-Benz' various safety features that the company offers across its models. The package includes for instance an adaptive cruise control named DISTRONIC PLUS which can be extended with a steering assist and thereby provides safe distance to the vehicle in front and prevents the driver from unintentionally diverting from the lane. The system works in speeds between 0-200 km/h and also keeps the car in the center of the lane through slight bends. In slow speeds the system is able to use the vehicle in front to calculate the lane position and aids steering even if the markings are unclear or absent. An unusual feature with this system is that it also prevents the driver from accidentally overtaking on the right in speeds above 80 km/h, which easily can happen when a traffic jam is opening up. The car's radar detects vehicles in the fast lane and adjust the car's speed to avoid it from passing them on the right-hand side.

Although the autopilot feature, described in the previous paragraph, is not far from letting the car drive by itself, Mercedes-Benz still wants the driver to stay engaged. The company has therefore equipped the wheel with pressure points to know if the driver lets go of the wheel in which case a visual warning is issued and prompts the driver to regain control. If the driver does not respond, an acoustic warning signal sounds and the lateral guidance system is switched off. The purpose with this is to prevent the driver from engaging in unsafe behavior since the system is not able to deal with every situation that might occur. The technique with built-in pressure points in the wheel is well in line with Mercedes-Benz view on semi-autonomous technology since the company wants to relieve drivers of the tedious parts of driving without negotiating their attentiveness. The ADAS are simply a means to make it more comfortable for the drivers, not a way for them to let go of control.

Another feature offered by Mercedes-Benz is the Brake Assist Plus system that increases the pressure on the brakes if the driver applies the brake pedal too lightly. The Brake Assist is a part of the PRE-SAFE package that also features Pedestrian Detection that warns if a person walks out in front of the car and if necessary applies emergency braking automatically. The system can completely prevent collisions in speeds up to approximately 30 mph and significantly decrease severity of collisions in up to 45 mph.

Mercedes-Benz' advanced driver assistance systems rely on radars, cameras and ultrasound sensors. A typical car uses one multi-purpose rear looking radar and three different forward looking radars with short-, mid- and long range (200m, 60m and 30m effective range respectively). The radars also feature different beam angles which make it possible for the car's intelligence to cross-reference information of what it sees and provide a more precise model. A similar strategy is used in the Stereo Multi-Purpose Camera (SMPC) mounted in front of the rear-view mirror which uses two lenses to improve the sense of the spatial area for the camera. The camera sees in three dimensions up to 50 meters in front of the car and 500 meters in two dimensions.

11.5.3 Mercedes-Benz upcoming E-Class models

In January this year at the North American International Auto Show, Mercedes-Benz revealed the new generation of its E-Class sedan models which will feature the company's (as well as one of the world's) most intelligent car series developed for consumer production so far. Prior to the revelation, Mercedes-Benz received permission for autonomous test driving in everyday traffic on the roads of Nevada for three of the new E-Class sedans. This makes the E-Class sedans the world's first series-produced cars to receive such a permission.

So far, only an E300 model (and an E300 4MATIC version of it) has been released of the new E-Class sedans. These cars however feature a system called Drive Pilot which takes one step closer to autonomous driving by offering highly sophisticated driving assistance systems that enable partially autonomous driving on highways and arterial roads. The Drive Pilot is essentially a highway autopilot that takes over both control of speed and position of the car in the lane in speeds up to 130 mph and can even change lanes after the driver has tapped the turn-signal lever. Mercedes-Benz is careful to inform that the driver must at all times remain vigilant to handle situations the car does not know how to tackle. After 60 seconds of no steering input the car prompts the driver to touch the steering wheel and automatically slows down if the request is not meet.

The E-class models will also get a parking assist that can be triggered via a smartphone app to get in and out of tight parking spaces. The smartphone can also host the car key by taking advantage of already built-in radio technology. The E300 already has a parking pilot that controls gear shifting, steering and braking for both perpendicular and parallel parking spaces. The E300 is also equipped with V2X communication technology - a feature that might not be very useful immediately but can come of relevance once other cars and road infrastructure are equipped with similar technology to transmit warnings and other information. Mercedes-Benz says that all the new features will bring increased safety and comfort and decrease stress levels among its customers.

11.5.4 Mercedes-Benz' approach to autonomous cars

Although Mercedes-Benz stresses the statement that driving is fun and that it produces cars for humans to drive, the company still believes this can be combined with autonomous driving. Mercedes-Benz believes that through the help of autonomous driving, its cars can be seen as not only a means of transportation but also as a "private retreat". Its future cars will ideally offer drivers more freedom by giving them time to do other things than just driving. Furthermore, the parent company Daimler is picking up on the digitalization trend and has said that it is currently undergoing a transition from an automotive manufacturer to a provider of networked mobility services.

Mercedes-Benz has stated that it aims to have fully autonomous technology ready by 2020. Even if the technology might be able to handle most scenarios, self-driving mode will most certainly only be applicable in certain types of situations (such as when driving on motorways). The main reason for this, as pointed out by Daimler, is that legal and ethical questions will probably lag behind the technological development. The company has therefore put an effort into promoting cross-disciplinary dialogues about this. For instance, Daimler has hosted a symposium about the legal and ethical issues associated with autonomous driving to speed up this process.

11.5.5 Mercedes-Benz and autonomous technology

In 2013, a Mercedes-Benz test car drove autonomously a distance of approximately 100 km between the two German cities, Mannheim and Pforzheim. This stretch was the same route that Bertha Benz (the wife of Mercedes-Benz' founder Karl Benz) drove 125 years earlier as a demonstration of the benefits of an automobile. The car that autonomously covered the distance was developed from the S-Class series and is called S 500 INTELLIGENT DRIVE. Before the actual test drive with the research vehicle, Mercedes-Benz had spent the previous year testing the route with three different E- and S-Class vehicles. These cars used the same sensor systems that were fitted in the production cars while the new research vehicle uses a new system with eight radars and three cameras to observe the environment and combines this with digital maps and GPS information to make decisions. The test drive in 2013 became the world's first long distance autonomous drive that also featured intercity driving. The S 500 INTELLIGENT DRIVE is now being tested in California since the traffic conditions in America are different from those in Germany.

Mercedes-Benz recognizes that even if the technical capacity for cars to drive autonomously in certain situations exists, it is still necessary to increase people's confidence in the technology. Mercedes-Benz' Customer Research Centre recently made a study where it investigated 100 test persons views on autonomous driving. The test persons were aged between 18 and 60 and initially showed skepticism to the idea of self-driving cars due to disbelief in the technology performance. However, after experiencing a driving simulator that featured autonomous driving, most of the study participants changed their opinions.

A team of designers and engineers spanning many fields of knowledge at Mercedes-Benz has developed a concept car for an autonomous future. The concept car is called Mercedes Benz F 015 Luxury in Motion and is not as much about autonomous driving as about what implications it brings to people in motion. In other words, the research vehicle says very little about how the car should be able to drive itself but instead focuses on exploring the benefits for its passengers and surrounding vehicles. With the concept car, Mercedes-Benz wants to stress the fact that it is not only the technology in itself that matters but rather how it changes people's lives and that this is something the automotive manufacturers must address.

Mercedes-Benz has, in line with the concept car, brought forward a model of the so called "City of the Future 2030+" where the company envisions future cities where urbanization has led to even more dense traffic and living than today. To have the car as a private retreat will be even more important then and could possibly be realized through self-driving cars. Furthermore, autonomous vehicles could help improving the scarcity of space and reduce the dense traffic by, for instance, autonomously parking outside of the city core. Mercedes-Benz also suggests the development of "safety zones" where only self-driving cars are allowed, not very different from today's low-emission zones in some cities

Figure 24. F 015 Luxury in Motion interior design

Source: Mercedes-Benz

The F 015 Luxury in Motion is a fuel-cell plug-in hybrid concept car that features four lounge chairs where the two seats in front can be turned to face the back seat. It also has six touch displays around the inside of the car (one on each door, one in front and one in the rear wall). Mercedes-Benz wants to make the car into a "digital living space" where connectivity to media and internet is a constantly available option. Furthermore, the car has both visual and acoustic exterior signals that can show pedestrians and other drivers the car's intention. In today's traffic, drivers communicate with eye-contact and hand gestures. When in autonomous mode the concept car will use its outer front and rear displays to indicate the same and additional information as drivers of today. For instance if the car has to come to a sudden halt because it encounters a traffic jam, the rear screen displays the word 'stop' in a flashing manner. Through a laser projector directed to the front, the car is able to project virtual pictures on the ground. This can be used to project a zebra crossing to indicate to a pedestrian that the car is waiting for him or her to cross the street. Moreover a spoken message can tell the pedestrian that it is safe to cross.

Another of Mercedes-Benz' recent design ideas is the Vision Tokyo concept car that follows in the footsteps of the F 015 Luxury in Motion. This vehicle features similar autonomous driving as the F 015 Luxury in Motion but is even more focused on the digitization trend and turning the car into a companion that through machine learning develops increased knowledge of its passengers preferences. Mercedes-Benz has noticed society's current digital transition and has proclaimed that the company has given the same strategic importance to this trend as to the transformation from fossil fuel driven to emission free vehicles. The parent Daimler has also recognized that hand in hand with the digital development follows issues of data security. The company claims to put an effort into ensuring the security and privacy of their customers on a digital level by taking such aspects into account already at the vehicle development stage.

Despite the very futuristic F 015 Luxury in Motion and the Vision Tokyo concept vehicles, Mercedes-Benz has expressed that it does not want to build a special vehicle for the purpose of autonomous driving in a first stage. Instead, the carmaker wants to develop technology that can be fitted to its standard cars.

Although this report is limited to autonomous cars, excluding commercial vehicles, it is meaningful to mention a few things of Daimler's activities in heavy trucks due to the close connection to the Mercedes-Benz brand. In fact, Daimler has already made significant progress in developing trucks that can drive by themselves. In 2014, Daimler became the first company to test a completely autonomous truck on a closed-off highway road in the vicinity of Magdeburg, Germany. Since then, Daimler has developed two Freightliner Inspiration Trucks that have been granted permission to drive partially autonomously on the highways of Nevada. The system is called Highway Pilot and is similar to those used in today's semi-autonomous cars, with adaptive cruise control, emergency braking and lane keeping assist. In October, 2015, Daimler Trucks had its first series-production partially autonomous truck, the Mercedes-Benz Actros, drive on Autobahn in Germany among real-life traffic. More recently, in the beginning of 2016, Daimler Trucks gave a live presentation of platooning through V2V connection which marked yet another step towards autonomous driving in commercial vehicles. Daimler believes it can have a fully autonomous truck ready by 2025.

In December, 2015, Daimler together with the two other giant German luxury-car manufacturers, BMW and Audi, invested € 2.8 billion for the acquisition of the maps and location service company HERE from its previous owner Nokia. Each party of the car consortium acquired an equal part of HERE and all have agreed not to pursue a majority ownership of the company shares. The acquisition is a clear indication of these car manufacturers' belief in digital maps as an important part of the automotive future, especially as an aid for autonomous driving. In addition, digital maps will be of importance for the consortium regardless of the members' driverless car projects since benefits from navigation information and customer-oriented location-based services are increasing. The three German automakers see HERE as a possible independent platform for the entire automotive industry allowing all car manufacturers to equip their cars with access to detailed real-time information about navigation and road conditions. This would increase road safety and comfort for everyone. In fact, the consortium plans to reduce their own stakes in HERE by letting other investors acquire shares in the mapping company. It is worth mentioning that both Uber and Baidu (two other companies targeting autonomous driving) also were bidding to obtain the map maker.

11.5.6 Mercedes-Benz' position in the autonomous car development

Mercedes-Benz is one of the automobile manufacturers that have reached furthest in the development of an autonomous car. A self-driving car's benefits in terms of increased performance and especially comfort goes hand in hand with Mercedes-Benz' business model. Furthermore, Mercedes-Benz has long embraced the idea of autonomous vehicles and has early performed relevant projects to push the development forward. The company's investment in HERE might prove to be an important strategic move in the future.

Technology-wise, Mercedes-Benz is clearly at the forefront of autonomous innovation as evident by the E-Class sedan models that come with an advanced highway autopilot and capability for V2X communication. Even without the E-Class, Mercedes-Benz has one of the most extensive range of available ADAS available on the market.

An interesting aspect for the future developments of autonomous driving is that Mercedes-Benz has an advantage from being a subsidiary of Daimler Group since the parent company is targeting self-driving also in commercial vehicles under the Daimler Trucks division. What is interesting with this is that there are synergy effects to be realized since Mercedes-Benz can benefit from technological breakthroughs at Daimler Trucks and vice versa. Moreover, the brand of Mercedes-Benz can get more easily acquainted with autonomous technology if both cars and commercial vehicles with the same logo offers such systems.

11.6 Audi

Audi was founded in 1909 and subsequently bought by Volkswagen Group in 1965. Audi is currently the third largest luxury car brand worldwide, behind BMW and Mercedes-Benz. In 2015, Audi delivered over 1.8 million cars to customers in 115 countries, an increase of 3.6 percent to last years' previous all-time high sales. The growth was mainly attributed to positive receptions of the new A3 sedan and TT models along with continuous demand for the SUV models. The main markets were China, Germany, the US and the UK.

As a subsidiary of Volkswagen Group, Audi has quite a lot of resources to develop new high-performing technology including autonomous cars. Volkswagen Group is the second largest vehicle manufacturer worldwide and the largest carmaker in Europe in terms of unit sales. In terms of revenues from passenger car sales, Volkswagen Group is second behind Toyota. In 2015, the Group's total revenues grew 5.4 percent to € 213 billion.

The group's goal is to offer attractive, safe and environmentally sound vehicles which can set world standards in their respective classes. The Group's "Strategy 2018" focuses on positioning the company as a global economic and environmental leader among vehicle manufacturers. Each brand owned by the group covers an independent entity of the market and the different brands span the entire automotive market from small city cars and mass market passenger cars, to luxury cars, sports cars and supercars. Audi is the brand that targets the premium and luxury segments of the automotive market.

In September 2015, the Environmental Protection Agency (EPA) announced that several of Volkswagen's diesel cars sold in America had been equipped with what is called a defeat device. The device (or rather the software) was programmed to detect when the car was being tested and in such circumstances enters a sort of safety mode with much lower emissions than during normal driving. Following EPA's revelation of the defeat device, VW publicly admitted that 11 million cars worldwide had been equipped with the software. Mostly, models of the Volkswagen brand was affected but also the popular Audi A3 model was disclosed as having been equipped with the device. The CEO, Martin Winterkorn, resigned from Volkswagen Group in September and subsequently from his post as chairman of the supervisory board of Audi in November following revelations of further emission falsifications concerning VW's gasoline-powered cars.

The scandal is likely to have a significant effect on VW and thereby Audi in 2016, especially since the company has put large efforts to advertise itself as environmental friendly. In the third quarter of fiscal year 2015, VW allocated € 6.7 billion to cover costs for recalled vehicles which resulted in the company making a quarterly net profit loss for the first time in 15 years (the loss was € 2.5 billion). In addition to this, the EPA has the possibility to infer a significant fine on Volkswagen and private car owners might want to apply lawsuits to the automotive giant.

11.6.1 Overview of Audi passenger car models

As this report was created in cooperation with Berg Insight, some parts of this study have been copied from another Berg Insight report. The text below has been copied from the Berg Insight report *The Global Automotive OEM Telematics Market* but updated with new numbers and other changes where applicable. The text has also been indented to highlight this. For more details see chapter 3.3.

Audi makes about 50 different car models and variants, ranging from compact hatchbacks and sedans to SUVs and sports cars. Examples include the Audi A1 B-segment hatchback, the A3 C-segment hatchback, sedan and cabriolet, the A4 D-segment sedan and estate, the A6 E-segment sedan and estate, the A8 F-segment luxury sedan, the A5 D-segment and A7 E-segment coupés, the Q3 and Q5 compact SUVs, the Q7 full-size SUV, as well as the TT and R8 sports cars.

11.6.2 Audi and ADAS development

Audi has developed and launched several sophisticated systems for assisted driving which come in different packages and differ from model to model. Especially the latest version of the Q7 has been equipped with numerous ADAS. The functions are offered in form of three bundled packages called "Parking", "City" and "Tour". The Parking package includes a 360 degree view of the surroundings and the park assist system which helps the driver get into both parallel and perpendicular parking spaces by automatically steering the car while the driver controls the gas and the brake pedals. The City package comes with a rear cross traffic alert which warns the driver of crossing traffic when reversing in slow speeds. It also includes an exit warning feature that indicates if there is a vehicle approaching from behind before the driver opens the door. The tour package includes more advanced systems for increased autonomy, especially an adaptive cruise control. The top version of the ACC includes a traffic jam assist feature that in addition to the standard gas and brake function also take over the steering in congested traffic in speeds up to 65 km/h.

Audi has also developed a standard safety system called the Pre Sense City system which uses cameras to monitor what happens in front of the car and has integrated acoustic and visual warning signals that go off when a threat of collision is detected. If the driver does not respond immediately, a braking pulse is automatically initiated and if this also receives no response from the driver, the system applies emergency braking by itself. The system prevents collisions with pedestrians and other vehicles in speeds up to 40 km/h.

One of Audi's more sophisticated systems, the Turn Assist, monitors oncoming traffic after the driver has activated the blinker. If the driver tries to turn despite another vehicle approaching in front, the system will automatically apply the brakes and make the car come to a halt. The system uses input from two forward looking radars and a mono-camera behind the windshield on top of the rear mirror. When the car realizes that there is a risk for a collision or detects unusual lateral acceleration (such as when running of the road) the seat belts are automatically tightened and the sunroof and the side windows are closed to prevent debris from entering the car.

Audi has announced that in 2017 it will launch a new model of the Audi A8 which will be equipped with Audi's most advanced piloted driving technology developed so far. The A8 will be fully capable of driving on its own in stop and go traffic on highways, although the driver will have to stay attentive at all times.

11.6.3 Audi's approach to autonomous cars

As one of the most renowned marques for luxury cars, Audi sees large potential in autonomous driving. Since Audi already is one of the leading car brands in terms of offered ADAS the company has strong incentives to continue the development of refined and more autonomous systems. Much like other luxury car manufacturers, Audi is taking an incremental approach to the development of autonomous driving. Audi has been early to achieve permissions to test its self-driving cars in those European countries and American states that have opened legislation for it. Audi was the first carmaker to receive permissions to test autonomous cars in California and Nevada and it was also the first brand to start testing on Florida's expressway for connected cars.

Audi wants autonomous driving to be something the driver can select when wanted. The company has therefore expressed its determination to avoid developing a type of autonomous car that diminishes people's sense of freedom and the fun of driving - a logical standpoint as a maker of sports cars.

11.6.4 Audi and autonomous technology

In October 2014, Audi demonstrated an autonomous sports car on the Hockenheimring in Germany. A modified Audi RS 7 completed a lap at racing speed around the course during the season finale of the Deutsche Tourenwagen Masters. The car used GPS and a 3D camera and compared the collected information to a digital map of the course to pin point its position and decide on what line to follow. This event surely was good for publicity but it should be mentioned that although the autonomous car kept an impressive speed (up to 240 km/h) it drove in a very specific and undisturbed environment where no other vehicles, pedestrians or traffic signs were present. However, over the last year, Audi has done several additional projects with autonomous driving (or piloted driving as Audi calls it) including another RS 7 racing multiple laps at Sonoma Raceway, California.

Figure 25. Audi RS 7 autonomous race car

Source: Audi

In 2015, Audi took its "piloted driving" project a step further by having a specially developed semi-autonomous Audi A7 drive selected journalists on different stretches of the road from Stanford, California, to Las Vegas, Nevada, where it arrived to participate in the annual CES (Consumer Electronics Show). The car featured fully autonomous mode only on the open highways and in speeds below 70 mph where it was able to maintain a safe distance to a car in front but also to change lane to pass a slower vehicle. The car used radar sensors that already are part of the adaptive cruise control and redundant laser scanners. A 3D camera was also used to monitor lane markings. The sensor data was coupled with the navigation system which also had the capability of receiving information about traffic conditions ahead and thus warn the driver to take over control if necessary.

The Audi A7 research vehicle (dubbed Jack) has now been tested and programmed over tens of thousands of kilometers to be able to deal with difficult scenarios like potholes in the road, smog and heat hazes and animals crossing the street. The car has been tested on the autobahn where the autonomous function can be turned on by touching two buttons below the steering wheel. The activation is confirmed with an acoustic signal and the LEDs around the dashboard turn blue instead of red while the steering wheel also withdraws a bit. Jack is then able to cruise along in a speed of 130 km/h which engineers at Audi believes is an optimal speed for semi-autonomous cars since it is fast enough to keep a high traffic efficiency while also giving sufficient time for the driver to take over the control. When the car approaches an exit, it warns the driver with a recorded voice that says the pilot is turning off, 15 seconds before it returns to manual mode. The interior LEDs also turn red to indicate that the car is back in manual mode and the wheel reaches out to the driver again. If the driver does not respond to the transition, the car turns on the hazard lights and comes to a stop at the road shoulder. Audi says that a version of Jack created for the consumer market will not be ready within the ten years to come.

Audi was one of the three parties (the others being BMW and Daimler Group) that together bought HERE in December, 2015. For more information, see the ending paragraph under Mercedes-Benz and autonomous technology above.

11.6.5 Audi's position in the autonomous car development

As the third largest manufacturer of luxury cars and a position as a highly innovative company, Audi has a promising position for future development of autonomous cars. It can be argued that it has somewhat lagged behind the development of its main competitors of BMW and Mercedes-Benz but it seems like Audi is trying to catch up. The Audi A8 with the highway autopilot, scheduled for release in 2017, is one indication of that. However, the revelation of Volkswagen's use of a defeat device might pose problems for Volkswagen in the near future and thus delay the development of autonomous cars.

Although Audi is a brand with several sports cars, its approach with testing autonomous sport vehicles on race tracks is slightly unexpected. The relevance of autonomous sports cars seems to be negligible when compared to the more compelling market of luxury vehicles with autonomous functions for commuting. On the other hand, Audi's testing of autonomous high performance vehicles is rather unique in the industry (although BMW has done some similar testing) and shows that Audi can take its own creative approach to autonomous cars. Audi has said that different actors in the field take different approaches and thus acquire various skills and emphasizes that collaborations will be important.

11.7 BMW

As this report was created in cooperation with Berg Insight, some parts of this study have been copied from another Berg Insight report. The introductory text below and the following section (11.7.1) have been copied from the Berg Insight report *The Global Automotive OEM Telematics Market* but updated with new numbers and other changes where applicable. The text has also been indented to highlight this. For more details see chapter 3.3.

> Bayerische Motoren Werke Aktiengesellschaft (BMW AG) is the parent company of the BMW Group. The German company, which dates back to 1916, develops and manufactures engines, cars and motorcycles under the BMW, MINI and Rolls-Royce brands. The company is focused on the premium and luxury segments of the international automotive markets and aims to be the leading provider of high-end products and premium services for individual mobility. BMW Group puts large emphasis on engineering and innovation to deliver products meeting the highest standards in terms of aesthetics, dynamics, technology and quality. The group is present in more than 140 countries and has 30 production facilities located in 14 countries and R&D centers located at 13 locations in five countries. The distribution network comprises 3,250 BMW, 1,550 Mini and 130 Rolls-Royce dealerships.
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> In 2015, BMW Group revenues increased 14.6 percent to nearly € 92.2 billion of which the automotive segment revenues grew 13.8 percent to over € 85.5 billion. In 2015, the BMW Group saw its fifth year of consecutive increasing unit sales with almost 2.25 million new car registrations worldwide, an increase of 6.1 percent attributable to growth in the BMW brand and MINI brand sales. Sales included 1.905 million BMW cars (+5.2 percent), 338,000 MINI cars (+12.0 percent) and 3,785 Rolls-Royce cars (-6.8 percent). Sales were fairly evenly distributed across geographical regions with Europe accounting for almost 45 percent of unit sales, Asia constituting nearly 31 percent of unit sales and the Americas accounting for 22 percent of total unit sales. The five largest individual countries in terms of unit sales were China, the US, Germany, the UK and France that accounted for 20.6 percent, 18.1 percent, 12.7 percent, 10.3 percent and 3.5 percent of total sales respectively.

When it comes to development in autonomous technology, it is the BMW brand of the group that performs the activities. The fact that MINI is not pursuing development of autonomous cars might not be very surprising. However, it is slightly less obvious that the luxury carmaker Rolls-Royce also avoids it. Still, considering that Rolls-Royce produce just about 4,000 vehicles per year and has a very specific and narrow target market, the company's lack of interest in driverless cars makes more sense.

11.7.1 Overview of BMW brand passenger car models

> Current BMW models include the 1-, 3- and 5-series sedans and estates, the 7-series sedans, the 2-, 4- and 6-series coupés and convertibles, the X-series SUVs, the Z4 roadster and M-series performance cars. The company has also started to deliver the new i3 electric car and the i8 plug-in hybrid sports car. In terms of unit sales, the most important models were the D-segment 3-series with 444,000 vehicles sold, the E-segment 5-series with 347,000 vehicles sold and the C-segment 1-series with 182,000 vehicles sold worldwide in 2015. Total sales of the X-series SUVs grew 4.1 percent to 527,000 cars in 2015.

11.7.2 BMW and ADAS development

BMW has put a lot of effort into developing semi-autonomous systems to make driving of a BMW both safe and comfortable. The company's systems for driving aid are integrated with its telematics system, ConnectedDrive, which is one of the leading solutions for in-vehicle connectivity and through the integration also features a wide range of ADAS.

As is the case with most of the leading premium car manufacturers, BMW offers different ADAS across different models and many functions are also optional rather than standard. However, the company offers a Driver Assistance package in many models (with some individual variations for specific models) which is based on the cars' camera systems. It features lane departure warning that alerts the driver by a vibration in the steering wheel and a graphical warning on the instrument display when an unintentional lane departure is imminent. The package also includes a collision avoidance system that detects potential vehicle collisions and is further extended with a system called Preventive Pedestrian Protection that detects pedestrians. Both systems warn the driver when a risk of collision is detected and if the warning is meet with no response a third system, called City Collision Mitigation, automatically applies the brakes. For parking, the system displays a birds-eye view of the car where distances to objects in front and behind is indicated by color coded markings as well as with acoustic warnings. BMW also offers an enhanced package called Driver Assistance Plus that in addition to the Driver Assistance package includes camera based surround view of the car, information of current speed limit and a blind spot monitor.

The latest models of the BMW 7 series (the sixth generation) was released to market at the end of October, 2015, and is so far the company's most advanced car in terms of integrated driver assistance systems as well as infotainment systems and mobile connectivity. The new generation has a heads-up display (HUD) where key information such as current speed and navigation directions as well as warning signals are projected onto an opaque screen on the windshield, directly in the driver's line of sight. Another feature is that speaker volume can be altered with a twisting hand gesture while phone calls can be answered or rejected with other gestures. When it comes to semi-autonomous functions, the new generation features a highway autopilot called Active Driving Assistant Plus which comes with an adaptive cruise control with stop & go function that keeps a set speed or distance to the car in front and also keeps the car in its lane. The car is also capable of keeping to its lane even when there is no preceding vehicle to track. If the driver let go of the steering wheel for more than three seconds, a graphical warning message tells the driver to replace the hands on the wheel. If the driver refrain from doing so in the following seven seconds, the highway autopilot system shuts down. Other benefits in the 7 series include autonomous emergency braking and blind spot monitor.

One of the most advanced systems BMW offers is its parking assist. The system includes fully autonomous parallel parking, meaning that the driver does not have to steer, throttle, brake or change gears after having activated the system. However, the driver must keep a button pressed during the parking exercise and is still responsible for accidents that occur when the system is active. For the next generation of the 7 series, it will be possible to perform the parking also in perpendicular spots and from outside the vehicle by pressing a button on the touch display of the car key. The remote control of today only works with straight in and out parking, which nonetheless can be beneficial when entering or exiting a tight parking space.

11.7.3 BMW's approach to autonomous cars

BMW is one of the most aggressive pursuers of autonomous cars in the industry which is not unexpected since it is the world's largest luxury car manufacturer in terms of annual new registrations. BMW Active Assist is the company's main project for developing autonomous cars. The goal is to increase customer safety, comfort and efficiency by letting the car take over the driving task in certain conditions. BMW is targeting European motorways for automated driving including crossing between national borders which makes for some interesting challenges such as dealing with different regulations and road sign symbols and colors. BMW believes that by 2020 the technical development will have reached a sufficiently advanced level to enable highly automated driving within standard production cars. What exactly is meant by highly automated driving is less clear but it should at least indicate a system that lets the driver take his or her hands of the wheel and eyes of the road for periods of time when the car is able to drive by itself (on specific motorways for instance) equal to Level 3 or possibly even Level 4 autonomy.

The CEO at BMW, Norbert Reithofer was replaced in May, 2015, by Harald Krüger. Krüger wants the company to take a more digital approach and BMW is, as a part of this, looking to transform its research and development team to consist of fifty percent software engineers. BMW sees ownership of the most intelligent car as a core competence and wants to maintain its business model despite threats from new entrants in the shape of software developers like Google. BMW has stated that it does not want to turn into a marginalized supplier of hardware (i.e. vehicles) to an internet giant who does the design and produces the software. The company is afraid of the loss of power that follows from being just another producer of hardware, like the case with Foxconn which manufactures the hardware to Apple's products.

11.7.4 BMW and autonomous technology

BMW's journey towards autonomous driving can be said to have taken off in 2011 when the company began testing a modified 330i vehicle on a closed circuit. The autonomous functions back then were rather unsophisticated compared to today's research vehicles. The car used GPS signals coupled with a repeater to increase accuracy combined with digital maps to find its way around the race track. The car was also trained by a race driver who showed the car the right line.

The next step was taken when BMW showcased a 6 series Gran Coupe on the 2014 Las Vegas Consumer Electronics Show. BMW invited journalists to ride in the car while it was racing around a closed circuit with parts of the track hosed in water. Compared to the test in 2011, the car used less pre training and instead relied on sensors. The reason behind these type of racing tests was (in addition to the publicity) to see how well the systems worked when the cars were pushed to their limits. It also put focus on the importance of algorithms that can handle changing traction conditions such as when drifting through a curve covered in water.

During the 2015 CES in Las Vegas, BMW showed yet another advancement in self-driving cars when the company presented journalists to a modified i3 vehicle that was able to autonomously drive around a course while avoiding hitting obstacles placed in its way. It also featured a system for remote valet parking activated by a smart watch. Based on information from laser sensors and digital site plans of the multi-story car park building the i3 was able to avoid obstacles and find an empty space to park in. The car could then be summoned to the car park exit through an app on a smart watch. Still, BMW acknowledged that this system was years from sufficiently reliable to be available on the market.

At the 2016 CES, BMW took a new approach by presenting the BMW i8 Vision Future Interaction which featured a cloud-based digital assistant called BMW Connected that for instance has the capability of controlling smart-home functions. BMW recognizes connectivity as a major trend in the automotive industry and wants to make the car a part of its customers' digital lifestyle. BMW has also presented its new vision called BMW VISION NEXT 100 that features a fully autonomous car which communicates its intentions to people outside the vehicle through displays and lights. When the car is in "Boost mode" meaning that the autonomous mode is off, the driver still leverages on several advanced driver assistance systems that informs the driver of potential hazards via a heads-up display and a flashing instrument panel.

Figure 26. BMW VISION NEXT 100 concept car with heads-up display

Source: BMW

For BMW's current prototype test cars the company uses a wide range of different sensors including: laser scanners to measures distance to as well as size and speed of other objects; a camera mounted in the rear view mirror to keep track of lane markings and to detect other objects and interpret them as passenger cars, trucks, motorcycles or pedestrians; one radar in front and two in the back to detect other vehicles' position, trajectories and speed; several ultrasound sensors to detect objects close to the car; a GPS integrated with advanced digital maps and the camera to locate the car's exact position within the lane; finally the luggage compartment contains the sensor fusion intelligence that merge information from the sensors into a 360 degree 3D model of the vehicle's surroundings and use this information to make decisions and subsequently take action to control the car's steering, acceleration and braking.

In 2014, BMW went into a partnership with Baidu to test autonomous cars in China. BMW sees China as one of the key markets for highly autonomous systems in the future due to the sheer amount of people who commute along with the high levels of congestion. BMW brought two 3 series Gran Turismo models equipped with top mounted lidars and other sensors while Baidu provided the software, called AutoBrain. Baidu has access to high-resolution digital maps for China, which BMW lacks, and additional software programming capabilities. On the other hand, Baidu does not know much about making cars and thus the partnership seems beneficial for both parties. In the end of 2015 the two companies were able to complete a first real-world road test where a research vehicle drove 18.6 miles through city streets and highways in Beijing and was able to autonomously turn right and left and overtake slower cars as well as merging onto and exiting highways.

BMW was one of the three parties (the others being Audi and Daimler Group) that together bought HERE in December, 2015. For more information, see the ending paragraph under Mercedes-Benz and autonomous technology above. BMW has also teamed up with Intel and Mobileye in a partnership that aims to develop an open platform for autonomous technology and an autonomous car by 2021.

11.7.5 BMW's position in the autonomous car development

As the largest manufacturer of luxury vehicles, the trend of autonomous cars is highly relevant for BMW. The company has for the last five years performed several autonomous car projects and is today one of the leaders in the field, both in terms of available ADAS and in regard to progress of autonomous technology. BMW has one of the car industry's most advanced highway autopilot systems as well as one of the most autonomous parking assist functions.

BMW clearly sees the competition from software companies as a threat which explains the partnership with Baidu. BMW is taking a rather holistic approach by not only focusing on the sensor technologies but also integrating future trends like increased connectivity and smart homes in its projects. The acquisition of HERE is another indication of BMW's wish to add customer value and remain at the forefront of vehicle innovation.

BMW's particular focus on China is interesting as most other carmakers place their testing of autonomous vehicles in the US or in Europe. China is believed to be a large market for autonomous cars and surveys have also shown that the Chinese people are more interested in adopting self-driving cars than Germans, Britons and Americans.

11.8 General Motors

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> General Motors (GM) was founded in 1908 as a holding company for the Buick Motor Company. Today, GM sells cars and light trucks under ten brands worldwide and provides automotive financing services through General Motors Financial Company. GM ranked as the leading global vehicle manufacturer for 77 consecutive years from 1931 through 2007. After having emerged from a Chapter 11 reorganization in 2009, the company again managed to reach the leading global position in terms of passenger car and light truck unit sales in 2011. Through regional subsidiaries and nearly a dozen joint ventures – mainly in China – GM markets vehicles under the brands Chevrolet, Buick, Cadillac, GMC, Opel, Vauxhall, Holden, Baojun, Jiefang and Wuling. GM discontinued the Saturn, Pontiac and Hummer brands in 2009. At the end of 2015, GM had manufacturing and assembly plants, distribution centers, offices and warehousing operations spanning 59 countries. The company has about 215,000 employees working on six continents. The distribution network comprises 20,252 authorized dealerships in 140 countries. Total revenues declined 2.3 percent to US$ 152.4 billion in 2015.
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> Total retail sales of GM passenger cars and light trucks climbed 0.3 percent to almost 9.96 million vehicles worldwide in 2015. In 2015, the North American market accounted for over 36 percent of GM's vehicle unit sales. Europe accounted for nearly 12 percent of sales, South America almost 6.5 percent, and the Asia-Pacific together with the Middle East and Africa regions accounted for over 45 percent of total unit sales. The five largest countries in terms of unit sales in 2015 were China with over 3.7 million vehicles sold, the US with 3.0 million vehicles sold, Brazil with 388,000 vehicles sold, the UK with 312,000 vehicles sold and Canada with over 260,000 vehicles sold. In 2015, GM was estimated to be the market leader in North America and South America with 17 percent and 15 percent market share respectively. GM was also estimated to be the largest vendor of vehicles in China with 15 percent market share but only number seven in the EU28+EFTA area with 6 percent of total market share.

11.8.1 Overview of the main GM passenger car brands

> Chevrolet is GM's mainstream value brand, offering vehicles ranging from hatchbacks, sedans, sports cars and crossovers, to SUVs, light trucks and vans. Chevrolet is present in nearly every market worldwide, except Oceania where the Holden brand is used. The Chevrolet brand was phased out in Europe during 2015, with the exception of a few models like the Chevrolet Corvette, to instead focus on the overlapping brands of Opel and Vauxhall. Sales of Chevrolet vehicles in the US grew 4.5 percent to 2,125,000 units.
>
> Chevrolet Volt is so far the best selling plug-in hybrid of all time. In December 2015, cumulative global sales of the vehicle were approximately 106,000, about 14,000 more than the total sales of the second bestselling plug-in hybrid, Mitsubishi Outlander P-HEV. Chevrolet is currently taking the next step with the under-development Chevrolet Bolt which is a fully electric crossover

vehicle. The car is scheduled for release to market in late 2016 and will have an estimated range of over 200 miles.

GM’s luxury car brand Cadillac markets sedans, estates, coupes, crossovers and SUVs in 37 countries worldwide. The main markets are the US, Canada and China where Cadillac sold about 267,000 of its total 277,900 cars in 2015 (a 7.5 percent increase of global sales from the previous year). Current models include the Cadillac ATS C-segment sedan, the ELR C-segment plug-in hybrid, the CTS E-segment coupe, sedans and estates, the XTS F-segment sedan, as well as the SRX crossover and Escalade SUV.

Buick is GM’s premium car brand, selling sedans, crossovers and SUVs in the US, Canada, Mexico and China. Sales of Buick vehicles reached a third consecutive year of global record sales with about 1.2 million vehicles sold in 2015 driven by increased sales in China. GMC sells Crossovers, SUVs, pickup trucks, as well as commercial vehicles in the US, Canada, Mexico and the Middle East.

11.8.2 General Motors and ADAS development

When it comes to ADAS, GM has been behind the front players like the top three German automakers and Volvo Cars. However this trend has started to change somewhat and GM is now trying to catch up.

For the 2013 year models of Cadillac ATS and XTS, GM developed the world's first vibrating seat warning system for collisions and lane departures. These cars also saw the implementation of a number of other driver assistance systems including: adaptive cruise control, forward collision and rear cross-traffic alerts, intelligent brake assist, automatic preparation before a collision and front and rear automatic emergency braking. The cars rely on cameras both in rear and front and ultrasonic and radar sensors. Some of the driver assistance features like ACC can be found in GM's other brands including Chevrolet and Buick.

In September, 2014, GM's CEO Marry Barra announced plans to have a semi-autonomous Cadillac model on sale in the fall of 2016. GM has since then revealed that it will be a CT6 sedan model that will have the driver assistance package but the release date has now been postponed to sometime in 2017. The company has stressed that getting the technology right and, especially, safe is of greater importance than delivering to date and has not been able to give a new date for the release. The semi-autonomous system is called Super Cruise and has been under development at least since 2012 when reporters were invited to a demonstration at GM's test track in Michigan. Once released, the system will take care of the highway driving both in stop & go and regular traffic by maintaining a safe speed and keeping the car in its lane.

The Super Cruise system will essentially be a highway autopilot that combines an adaptive cruise control with a lane keeping assist and can be seen as a Level 2 autonomous technology since it takes care of throttle, braking and steering but will require the driver to stay alert to respond to potential hazards. Thus, the Super Cruise will not be very different from what some of the top luxury-car manufacturers already have on the market. This shows that GM is indeed lagging behind when it comes to autonomous driving but on the other hand; the CT6 also demonstrates that the company is trying to catch up. Moreover, the CT6 Super Cruise is definitely not GM's only project in the area of autonomous driving, as will be described further below.

11.8.3 General Motors' approach to autonomous cars

Although GM was one of the first companies to start testing autonomous driving it has nevertheless pursued a slower development of autonomous cars when compared with the top luxury-car brands. This is not very surprising since GM is not foremost a luxury carmaker, despite its ownership of Cadillac. However, more recently, GM has entered the race to autonomous cars through a number of aggressive activities. By the end of January, 2016, GM announced that it had assembled a special group called the Autonomous and Technology Vehicle Development Team. The team's mission is to make GM a leader in autonomous technology through development of strategies for engineering as well as by looking for suitable partnerships and investments.

GM's first step towards self-driving cars was taken almost a decade ago when Carnegie Mellon University won the 2007 DARPA Urban challenge with a modified Chevrolet Tahoe. Following the victory, GM donated $ 5 million to fund the establishment of a collaborative autonomous driving research lab. However, despite this initiative, GM has not put much additional effort into autonomous technology until more recently. The company has now sketched a three stage conceptual road map for its rollout of autonomous technology. In the first stage the driver is solely responsible of the driving; at the second step, which will begin in 2020, the driver is only mostly in charge; finally in the third stage, around 2025, the car takes over full responsibility.

Figure 27. Chevrolet Tahoe modified vehicle at the DARPA Urban Challenge

Source: General Motors

11.8.4 General Motors and autonomous technology

In July, 2015, GM opened a new active safety test facility at its Milford Proving Ground. The 52-acre facility will be used as a test ground for cars deployed with new ADAS. In addition to safety and assistance systems, the facility will also be used to test V2V communication which is something GM believes will be important for autonomous vehicles as a complement to the typical cameras, radar, lidar, and ultrasonic sensors.

In October, 2015 GM announced that it will launch a project with autonomous Chevrolet Volts during 2016. The ambition is to produce a fleet of self-driving 2017 model Volts and deploy them for testing on the carmaker's Global Technical Center campus in Detroit. The campus covers about a square mile and has 20,000 employees who will be used as test subjects during the project. The employees will be able to call one of the car from the fleet through a smartphone app and have it transporting them to the requested destination. The campus is almost like a little city on its own and features intersections, roundabouts and other vehicles as well as pedestrians and cyclists. The goal with this real-world test is to accelerate the company's knowledge and skills in autonomous driving essentially through learning by doing. To use a hybrid car like the Volt is beneficial since an electrified system tends to make it easier for engineers to alter the controls, but perhaps more important is the PR-value from combining one important technology for the future with another. Furthermore, it is not unreasonable to think that GM in a not so distant future might use the Chevrolet Bolt as a platform for further steps in autonomous driving.

In January this year, GM launched a car-sharing service called Maven. Maven combines multiple car-sharing programs pursued by GM under a single brand. The service works through a smartphone app where the users can choose between different stations to reserve and pick up a car. When the user is done with the renting of the car it must be returned to the same location it was collected. GM has recognized that consumers' behavior is changing as they become increasingly interested in leveraging on ridesharing and car-sharing. Furthermore, GM tries to personalize the vehicles by making them connected so that people can bring their own digital lives with personal attributes such as their own music when renting the car. Maven was at launch only available in Ann Arbor, Michigan, but has since then been deployed in Chicago and the plan is to expand the service to more US cities including Boston and Washington DC later this summer. GM already has existing car-sharing programs in New York and in Germany which will be adopted into the Maven service.

11.8.5 General Motors strategic investments

The car-sharing service, Maven, was unveiled just weeks after GM announced a partnership with Lyft that came with a $ 500 million investment for a 9 percent equity in the ride-hailing company. The short-term goal is to leverage on the partnership to expand the Maven ride-sharing service with national hubs where Lyft drivers can rent GM vehicles. In a longer perspective the plan is to develop a network of autonomous cars available in a car-sharing format in the US. Exactly how the network will be constructed and what the business model will look like is still very open. That is not very surprising since it is still a lot of technological and regulative issues that need to be sorted out before such a network can be installed. What can be concluded is that GM certainly sees this post privately-owned cars future as an important business and it is prepared to enter collaborations as a means to reach this as evident by the Lyft partnership.

Another indication of GM's shift towards autonomous driving came in March, 2016, when it announced that it would acquire Cruise Automation which is a company from San Francisco that develops autonomous technology for vehicles. Cruise Automation is most known for working with the development of an aftermarket solution for Audi A4 and S4 models that makes autonomous highway driving available. That plan has been discontinued after the announcement of GM's acquisition of the company. Cruise Automation is now instead targeting the creation of the world's largest fleet of driverless vehicles and has started looking for new employees with expertise in artificial intelligence, cyber security and computer vision for instance. The final price for the acquisition has yet not been revealed but it is believed to be around $ 1 billion which is about ten times the price at which the company was valued prior to the acquisition indicating GM's strong belief in the company and in autonomous technology.

11.8.6 General Motors' position in the autonomous car development

Although GM, as stated above, for many years has lagged behind in the development of semi-autonomous systems; that does not mean it has lost the race. GM is taking both the trend with ridesharing and self-driving cars very seriously and perhaps its greatest strength is that it is pursuing a very holistic approach. It is important to remember that GM managed to stay the number one automotive producer in terms of unit sales for 77 consecutive years and has been able to become a profitable brand despite the bankruptcy of the old GM. Needless to say, the US government's bail out of the company was necessary for the turnaround but on the other hand, the fact that the US government supports GM to some extent also adds to the company's strength. Furthermore, GM has a strength in its well-developed telematics service, OnStar, which can be utilized for V2X communication. For instance, GM has plans to install mapping software from Mobileye in the cars' cameras and use OnStar to transmit the recordings to a cloud service to create a bank of updated and detailed digital maps. Embedded connectivity is also widely believed to be important for aiding in autonomous driving in which case OnStar might prove very useful.

Despite the recent aggressive activity, it is important to remember that GM's most profitable area of business continues to be its SUV and light truck divisions. These branches targets country-side customers while ride-hailing on the other hand is more suitable for more densely populated areas. GM might find it difficult to stay competitive in more than one field, especially since actors in the automotive industry in general is becoming increasingly specialized. On the other hand, GM is a large brand and even if the light truck division constitutes the largest profit share, its sales of smaller city-vehicles are still important, especially in regional markets. The B-segment is for instance relatively large in Europe where Opel last year launched the car-sharing program CarUnity.

GM is, regardless of the recent activity, taking an incremental and relatively cautious approach to autonomous driving. It is also important to remember that GM has yet some distance to cover before it has a ready solution for even a semi-autonomous car. Moreover, the Super Cruise system is just a small initial step on a long journey to fully autonomous cars but together with the strategic acquisitions it seems like GM is speeding up and becoming increasingly ready for the future.

11.9 Ford Motor Company

As this report was created in cooperation with Berg Insight, some parts of this study have been copied from another Berg Insight report. The introductory text below and the following section (11.9.1) have been copied from the Berg Insight report *The Global Automotive OEM Telematics Market* but updated with new numbers and other changes where applicable. The text has also been indented to highlight this. For more details see chapter 3.3.

> Ford Motor Company was founded in 1903 by Henry Ford who introduced mass scale manufacturing in the automotive industry. Today, the company sells cars and light commercial vehicles under the Ford brand and luxury cars under the Lincoln brand. Ford also provides financial services through Ford Motor Credit Company. Local Ford subsidiaries in Australia and Brazil own the performance car manufacturer FPV and the off-road vehicle manufacturer Troller respectively. Moreover, Ford owns a 2.1 percent stake in Mazda and a 32 percent stake in Jiangling Motors, in addition to several joint ventures. Ford sold Jaguar Land Rover to Tata Motors in 2008 and Volvo Cars to Geely in 2010. Ford also discontinued sales of premium cars under the Mercury brand in 2011. These divestments were a result of the One Ford strategy that was adopted after the financial crisis in 2008-2009 which Ford (unlike GM and Chrysler) managed to survive without government intervention. Ford has about 199,000 employees and 67 manufacturing plants worldwide. The distribution network comprises almost 12,000 dealerships globally. In 2015, Ford Motor Company's total revenues climbed 3.8 percent to $ 149.6 billion of which revenues from the automotive sector alone increased 3.5 percent to $ 140.6 billion.
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> Ford Motor Corporation is the fourth individual largest global manufacturer of passenger cars and light trucks in terms of both revenues and unit sales. Ford is the third largest car and light truck vendor in North America (preceded by GM and by a small margin also Toyota) with about 14 percent unit market share and the fourth largest in the EU28+EFTA area with a 7.7 percent market share. 2015 marked the sixth year of consecutive positive profits for the company and an all-time record of $ 10.8 billion in pre-tax profit. Ford sold more than 6.6 million vehicles worldwide in 2015 on a wholesale basis, up 4.9 percent compared to 2014. Sales in North America increased over 8 percent to 3.07 million vehicles. Wholesale volumes in South America continued the downward trend and fell over 17 percent to 381,000 vehicles, while sales in Western and Eastern Europe climbed more than 10 percent to 1.53 million vehicles. Wholesale volume in the Asia-Pacific region increased about 1.7 percent to 1.46 million vehicles, mainly driven by sales in China that grew more than 3.9 percent to 1.16 million vehicles. The five largest individual countries in terms of unit sales in 2015 were the US, China, the UK, Canada and Germany that accounted for 40.3 percent, 17.5 percent, 6.7 percent, 4.3 percent and 3.9 percent of total sales respectively.

11.9.1 Overview of Ford passenger car models

> Historically, Ford has sold a large number of vehicle models based on platforms developed by local Ford subsidiaries in different world regions. As part of the One Ford strategy, the company is now shifting towards developing products based on 8 global platforms to introduce new car models rapidly and efficiently across global markets. From 2007 until 2015, Ford reduced the number of platforms from 27 to 12 and is on track to have 9 global platforms by 2016.

Examples of current Ford models include the Fiesta B-segment hatchback and Focus C-segment hatchback and estates, the C-Max compact MPV, the Fusion D-segment sedans and station estates, the Explorer, Escape, Expedition SUVs, the Edge midsize crossover SUV, as well as the F-150 and Super Duty series pickup trucks. In 2015, Ford sold over 780,000 F-Series trucks in North America, mainly attributable to the new F-150 pickup truck. The F-150 models have been the best-selling pickup trucks in the US for 39 years and best-selling vehicle in America for 34 years.

During 2015, Ford launched 15 new or upgrades of current vehicle models worldwide. For 2016 the company aims to launch 12 new products including the new F-Series Super Duty, Ford GT, Fusion, Escape/Kuga, Lincoln Continental and the Focus Electric which will come with a new fast-charge technology that makes it possible to charge the battery to 80 percent in about 30 minutes. Furthermore, the company aims to have an additional 12 electric vehicles by 2020.

The Lincoln Motor Company, which sells premium and luxury vehicles under the Lincoln brand, has been a subsidiary of Ford since 1922. Lincoln vehicles are mainly sold in North America and the Middle East. The brand is also present in South Korea and was launched in China in 2014. Current models include the Lincoln MKZ D-segment and MKS E-segment sedans, the MKC compact crossover, the Lincoln MKX midsize and MKT full size crossovers as well as the Lincoln Navigator SUV. In 2015, Lincoln reintroduced the Continental model.

11.9.2 Ford and ADAS development

Since Ford's main target market is not made up by the luxury segment, it is not very surprising that the company does not have a leading position in development of ADAS. Even when accounting for Ford's own luxury brand, Lincoln Motors, the company has not reached the same advanced level as the top players. It is worth noting that the Lincoln brand, after all, is a relatively small luxury brand.

On the other hand, Ford is not as far behind in the development as might be expected of a company with relatively low interest in the luxury segment. In fact, what makes Ford a bit different is its commitment to launch driver assistance systems across a large range of cars including more affordable models such as the Ford Fiesta. Ford believes semi-autonomous functionality provides the building blocks for autonomous vehicles. The company is determined to combine this technology with its strategy of providing affordable cars to a broad market (a history that goes back to Henry Ford's introduction of the mass produced model T). This may well be easier said than done since even partially autonomous technology still is rather expensive. On the other hand, cost of camera sensors is declining and Moore's law keeps pushing down the price of microchips and thereby computer power.

Despite the push to offer some driver assistance functionality across the entire vehicle fleet, Ford's top ADAS systems are not as good as the current leaders in this development. However, the new Ford Fusion 2017, available on the market this spring, claims to have 20 driver-assist features across the Fusion models lineup. One system included is Ford's first ever adaptive cruise control with stop-and-go functionality available in North America. This system will also be integrated in three new Ford vehicles within the coming two years.

Another important vehicle for Ford in terms of ADAS development is the new Lincoln Continental which is believed to become the new flagship model of the Lincoln brand. The new Continental was showcased as a concept car at the 2015 New York International Auto Show and revealed in its final shape during this year's North American International Auto Show in Detroit. The final version of the car is surprisingly similar to the concept and is a lavish luxury vehicle with features like 30-way adjustable massage leather seats. Driver assistance systems include adaptive cruise control, collision warning systems and autonomous emergency braking with pedestrian detection that also responds to potential rear end collisions and a 360 degree camera system with a bird's view display that aids in parking.

11.9.3 Ford's approach to autonomous cars

Although Ford for many years has been rather unresponsive to the trend with autonomous vehicles, it has recently realized that the automotive market is about to change and possibly on a disruptive level. Ford has recognized that this era of change calls for a transformation of the company on a large scale. Ford's response to the changes has been to create a strategic plan structured into five subcategories in which the company wants to achieve leading positions. The plan is called Ford Smart Mobility and includes the following categories: Connectivity, Mobility, Autonomous Vehicles, Customer Experience and Data Analytics. The company has started initiatives in all these categories.

Ford sees the five areas as emerging opportunities that will have great influence on the automotive market. What is noticeable with this plan is that Ford does not view self-driving cars as the only area for advancement. It is a means to an end rather than an end in itself. Ford sees the five highlighted categories as connected and believes that the largest benefits are achieved when they are combined. For instance, autonomous cars work better when connected and they can be coupled with ride-hailing mobility. This holistic approach to the future of the automotive industry somewhat distinguishes Ford from its competitors.

In 2015, Ford initiated 25 global mobility experiments with the purpose to anticipate how the future transportation industry will look in terms of customer needs and demands. The experiments are designed around four global trends - population growth, an expanding middle-class, air quality and public health, and changing customer attitudes. The experiments are well in line with the Ford Smart Mobility Plan and further indicates the company's seriousness and holistic approach to the emerging trends in the automotive industry. One of the experiment is based in London and uses the car-sharing service GoDrive to gain insight into customers' car-sharing preferences.

Ford CEO, Mark Fields recently said that Level 4 cars will emerge around 2020. However, although Mr. Fields said that Ford is working very hard on self-driving technology, he also acknowledged that Ford may not be the first company to launch a Level 4 autonomous car. His estimate was based on the current rate of progress of sensor technologies and advancements in software algorithms.

11.9.4 Ford and autonomous technology

Ford is developing a fleet of fully autonomous research cars built on the basis of current semi-autonomous systems with additional lidar technology for creation of real-time three-dimensional models. The vehicles used for testing are of the Ford Fusion Hybrid sedan model and have been tested on the company's own proving ground and on public roads in Michigan as well as in M-city - a simulated urban road network at the University of Michigan. In January, 2015, Ford opened a research and innovation center in Palo Alto, California, and the same year in December, Ford announced that it had secured a permit for testing of its Fusion Hybrid autonomous cars on public roads in California starting in 2016. The research lab now has more than 100 employees trying to realize the Ford Smart Mobility plan. The creation of the facility indicates Ford's determination to avoid becoming obsolete through competition from other carmakers as well as new entrants in the shape of technology companies such as Google and Uber. By locating the research lab in Silicon Valley, Ford hopes that the innovative environment will help employees take notice of new trends and technology developments quickly and react accordingly.

At the 2016 year's CES event in Las Vegas, Ford announced that it will triple its fleet of autonomous Fusion Hybrid test cars to consist of 30 vehicles making it the largest car fleet for self-driving testing of any automaker so far. The test fleet uses Ford's third generation of autonomous vehicle platforms. The third generation has been equipped with redundant systems for power, steering and brakes and with Velodyne's newest Lidar sensor, the Solid-State Hybrid Ultra PUCK Auto. With a range of 200 meters this sensor outperforms previous versions and has the advantage that it can be mounted on the side-view mirrors due to its small size. A direct implication of this is that Ford can reduce its four top mounted lidars to just two side-view mirror mounted PUCK lidars - one on each side - without compromising the data input to the decision-making unit.

Figure 28. Ford Fusion Hybrid autonomous test car

Source: Ford Motor Company

Ford is the first automaker to conduct testing of autonomous vehicles in snowy conditions - a further indication of the company's ambition to deliver autonomous technology to a broad market. However, Ford also realizes that fully autonomous driving at a first stage only will be available in areas with favorable environmental conditions for the sensors currently used. Moreover, Ford believes high-definition mapping must initially be available to enable fully autonomous driving. In April, 2016, Ford engineers made a Ford Fusion test car drive around a test track in Arizona in complete darkness. The car relied on lidar only to perceive its surroundings while test drivers equipped with night vision goggles ensured that the car did not do anything unexpected. The purpose was to put attention to how an autonomous vehicle behaves in a situation that humans find difficult.

Ford was relatively early in realizing the advantages of tapping into and analyzing customer data and use this to increase customer experience. In 2007, Ford released its first version of Ford Sync - an integrated infotainment system which featured embedded communication capabilities. Today the system has seen many updates and can for instance be controlled by voice control. Ford Sync is since 2014 standard on most Ford models and all Lincoln models in North America. Ford is definitely not unique in offering an infotainment system but Ford has been unusually successful in observing its customers' behavior and in understanding their preferences. Ford has been able to leverage on this knowledge to create a closer relationship to its customers. Another important aspect of this is that the company has been quite successful at engaging customers in social media and in company specific apps. This strategy is also well in line with Ford's recognition of the 18-24 year olds as an important growth segment. By collecting small pieces of information about Ford owners the company has built a large warehouse of data and applied big data mining to this resource to attain valuable information about its customer’s opinions and other important patterns. Ford has also recognized connectivity as an important part of the digital hub that cars are becoming and has already put itself in a leading position in terms of embedded connectivity. All these early steps has given Ford a valuable advantage for the future.

To increase customer experience, Ford has recently developed a smartphone app called FordPass. This digital platform will feature four elements that its customers can benefits from - a *Marketplace* where apps for mobility services such as booking and payment of parking will be available, *FordGuides* for telephone service about the platform, *Appreciation* to reward loyal customers and *FordHubs* that will showcase Ford's latest innovations.

11.9.5 Ford's Position in the autonomous car development

Ford seems to have recognized the importance of collaborations to deal with an uncertain future. At the 2016 CES, a rumored alliance between Ford and Google failed to take place but instead, Ford announced a partnership with Amazon that will develop connectivity between Ford cars and smart homes. At the same event, Toyota informed that it will start integrating Ford's in-car technology in its vehicles. Ford is expanding its research collaboration with Stanford and has initiated relationships with other universities such as University of California, Berkeley; Carnegie Mellon University; San Jose State University; Santa Clara University and also RWTH Aachen University in Germany. Ford is in addition participating in the UK Autodrive consortium which is a project with the aim to establish the UK as a hub for autonomous vehicle development and to investigate how autonomous vehicles can be integrated in people's everyday life through trials in urban environment.

Coming from a state of lagging technology development in the autonomous field, Ford has certainly made a turnaround over the last year. The company now takes the trend with autonomous vehicles and threats from new entries in the shape of technology companies very seriously. What somehow distinguishes Ford among other automakers is its holistic approach to future mobility. At the same time the company has clearly stated that it is not competing to become the first automaker to offer a fully autonomous car. Instead, Ford aims at developing autonomous vehicles that are accessible for everyone - a goal that is well in line with the company's business model. Whether this cautious but attentive attitude will be the best strategy should begin to be discernible in a couple of years from now.

11.10 Toyota Motor Corporation

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> Toyota Motor Corporation is the largest motor vehicle manufacturer – including passenger cars, trucks and buses – both in terms of revenues and unit sales. Toyota is also the leading company in terms of revenues from the passenger car market although both GM and Volkswagen have higher annual unit sales. In addition to automobile production, Toyota is also involved in telematics services, boats and marine engines, housing, financial services and biotechnology. Toyota Motor Corporation was founded in 1937 as a spinoff from Toyota Industries to manufacture automobiles. Today, the company markets vehicles under the Toyota, Lexus, Ranz, Scion and Hino brands in more than 170 countries. Toyota holds a 50.1 percent stake in Hino Motors, a 16.5 percent stake in Fuji Heavy Industries, a 5.9 percent stake in Isuzu, a 3.58 percent stake in Yamaha Motor Company and a 0.27 percent stake in Tesla, in addition to ownership in several joint ventures. Toyota acquired Daihatsu Motor by share exchange in August, 2016. Toyota previously held a 51 percent stake in Daihatsu Motor but by making it a fully-owned subsidiary it enables the adoption of a unified strategy for the small car segment.
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> Toyota conducts its business worldwide with 53 overseas manufacturing companies in 28 countries and regions. Total revenues in the fiscal year ended in March 2016 rose 4.3 percent to JPY 28,403 billion (€ 232.5 billion). Revenues from automotive operations totaled JPY 25,924 billion (€ 202.3 billion), an increase of 5.4 percent year-on-year.
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> Toyota aims to produce reliable vehicles and achieve sustainable growth, leveraging the company's lean production system that focuses on quality, productivity and cost efficiency. Toyota sold almost 10.1 million vehicles worldwide in 2015, including nearly 9.0 million Toyota, Daihatsu, Lexus, Ranz and Scion passenger cars. Toyota's primary markets based on vehicle unit sales were Asia-Pacific that accounted for 42 percent of sales and North America with nearly 33 percent of unit sales followed by Europe with almost 10 percent of sales.

11.10.1 Overview of Toyota and Lexus passenger car models

> Toyota markets approximately 50 different passenger car models in over 170 countries, ranging from small hatchbacks and sedans to MPVs, crossovers, SUVs and pickup trucks. Examples of models available in most major markets worldwide include the iQ A-segment hatchback, Yaris B-segment hatchback and sedan, the Auris C-segment hatchback, the Corolla C-segment sedan, the Camry D-segment sedan, the Prius D-segment hybrid car, the Toyota 86 compact sports car, the Previa MPV, the RAV4 compact SUV, the 4Runner mid-size SUV, the Land Cruiser full-size SUV and the Hilux compact pickup truck. The Scion marque was discontinued in August, 2016, since Toyota no longer believes the brand is relevant for the targeted youth segment of the market as indicated by unsatisfactory margins. Selected models of Scion will be re-branded under the Toyota brand in 2017.

Toyota launched the Lexus brand for its luxury cars in the US in 1989. Availability has since been expanded to about 70 countries worldwide. North America and China remain the main markets for Lexus, accounting for over 65 percent of total Lexus unit sales in 2015. With 652,000 cars sold in 2015 (an increase of 12 percent compared to the previous all-time high in 2014) Lexus is the fourth largest luxury brand worldwide behind BMW, Mercedes-Benz and Audi. Current Lexus models include the CT C-segment hybrid hatchback, the HS C-segment hybrid sedan, the IS C-segment sedan and convertible, the ES E-segment sedan, the GS E-segment sedan, the LS F-segment sedan, the new NX compact crossover, the RX mid-size crossover, the GX mid-size SUV and the LX full-size SUV.

11.10.2 Toyota and ADAS development

When it comes to driver assistance systems, the Lexus brand of Toyota has, as could be expected, most features to offer. However, the Toyota brand has for some time had an increased focus on safety and has thus started to incorporate ADAS also in the core brand. Included safety systems varies across different models with the more expensive models in general having more systems included. However, many systems are optional for the less costly models and it is also possible to purchase packages of multiple systems.

Toyota has started to offer inexpensive safety packages for its more affordable car segments. The pricing is significantly lower than virtually any similar offering from other carmakers. Toyota has recently launched a package called Toyota Safety Sense that is offered in the 2016 models of the Land Cruiser, Prius, Avalon, Avalon Hybrid, RAV4 and RAV4 Hybrid. The package includes adaptive cruise control, autonomous emergency braking with pedestrian detection, lane departure warning and adaptive high beam control and only costs an extra US$ 500. A similar package but with fewer functions is available for US$ 300 on some compact models such as the 2016 Prius c.

A similar pricing strategy has been initiated for some of the more inexpensive Lexus models. For Lexus RX and ES models the company offers a package called Lexus Safety System Plus which has a price of US$ 500 and US$ 635 respectively (the dual pricing is due to some minor differences in the systems included). The package features adaptive cruise control, autonomous emergency braking with pedestrian detection, lane departure warning with steering assist and adaptive high beam control. As a comparison, the price tag of the Lexus Advanced Pre-Collision System package, optional on the LS models, amounts to US$ 6500. Toyota believes that the introduction of the autonomous emergency braking system is part of the Lexus brand's strong sales in 2015.

11.10.3 Toyota's approach to autonomous cars

Toyota has for many years kept a hesitant attitude to autonomous technology much because of the CEO, Akio Toyoda's reluctance to self-driving cars. In 2011 the company restated its old slogan "Fun to drive" with the addition of ", again" in the end. Akio Toyoda is known for his interest and participation in car racing and the slogan fits well with his view on driving and his aim to invigorate the Japanese people in the joy of driving. However, the slogan does not fit as well with self-driving cars. Moreover, Toyota has been struggling with several crisis starting with the economic downturn in 2009 and the unintentional acceleration incident that resulted in US$ 2 billion in fines and settlements which was then followed by the earthquake and tsunami that struck Japan in 2011. What is interesting is that Toyota has made a turnaround and is now heavily targeting autonomous technology.

The big change came in the fall of 2015 when Toyota announced that it would spend US$ 1 billion over the next five years on establishing the Toyota Research Institute in Silicon Valley aimed at studying artificial intelligence and robotics. It should be mentioned here that the company in fact has done projects regarding autonomous driving before. The turnaround was not so much on a technological or 'research-wise' level as on a conceptual and strategic level. For instance Google has been using the Toyota Prius as well as the Lexus RX450h as test vehicles and Toyota engineers have been working on self-parking technology at a technical center in Japan long before the announcement of the Toyota Research Institute. Furthermore, a team of Toyota employees solely dedicated to autonomous cars was brought together already in 2014. The team, though, did not use the word "autonomous" or "self-driving" in its name but was instead called the Business Reform Intelligent Vehicle Development Department. A clear corporate focus on autonomous technology has thus not been apparent before the announcement in the fall of 2015.

Toyota's immediate goal with autonomous technology is to reduce the number of casualties in traffic as well as other accidents. In a longer perspective, the company aims to improve people's everyday lives though increased mobility. Akio Toyoda has said that Toyota is not only investing in technology innovation because it can but also because it should. The underlying meaning is that the self-driving cars is not just a way of increasing security and comfort but also a way to enhance mobility for old, handicapped or otherwise restricted people. This perspective makes sense especially when considering the fact that the population of Japan is aging. Since Japan is one of the key markets for Toyota, the company has realized that it needs to do something about the problem with an aging customer base. One solution would be to develop self-driving cars to increase mobility for elderly people who are unable to drive by themselves. Another of Toyota's plans are to use its knowledge in vehicles and mobility as a basis for creating indoor robots that can support seniors in their homes. It is worth noting that both these efforts do not suit very well with the "Fun to drive, again" slogan targeted to the Japanese people. There still seems to exist some ambivalence in the company regarding autonomous driving and whether the technology shall take over the entire driving or just step in to avoid accidents. Perhaps it is not unreasonable to develop both kind of systems. Akio Toyoda has said that cars must offer freedom - that is their main purpose regardless of whether they are autonomous or not.

Toyota has declared that it will have an autonomous car ready in 2020 in which the driver will be able to divert attention from driving. The technology will be based on current work being done on a fleet of Lexus GS test vehicles and Toyota hopes it will be ready in time for the Tokyo Olympic Games which Toyota will sponsor. The Olympic Games will provide a chance for Toyota to attract the public's attention to its mobility solutions including vehicles with alternative propulsion and autonomous technology.

11.10.4 Toyota and autonomous technology

Toyota is teaming up with both Stanford and MIT through the establishment of research centers that will target the development of artificial intelligence and autonomous driving technology. Each of the universities received funding of US$ 25 million. The Stanford center will focus on computer vision and machine learning as well as on analysis of human behavior, including both how the driver and pedestrians behave in different situations. The MIT center has a similar purpose in developing decision-making algorithms but the researchers take a somewhat unconventional approach by developing a system where the driver has to stay alert all the time but where the technology steps in and takes over control to prevent any accident. The goal is to eventually build a car that is incapable of having an accident.

Toyota is planning to establish a third research center in America in addition to the two at Stanford and MIT. The new center will be located in Ann Arbor and was announced in April, 2016, simultaneously with the revelation of a partnership with the University of Michigan Transportation Research Institute. The aim with the partnership is to invest in and further develop the Ann Arbor proving ground for connected vehicles. Ann Arbor has become an international hub where connected cars can be tested in a real-world environment that goes by the nickname M-City. Toyota will deploy autonomous research vehicles for testing at the proving ground.

Contradicting the previous statement that Toyota is lagging behind in development of autonomous cars is the fact that the company holds more patent related to self-driving technology than any other actor in this field. At the beginning of this year, it was estimated that Toyota held over 1400 patents related to autonomous vehicles which was more than twice as much as any other company. However, this number might be misleading since it does not say anything about the individual patents' quality. Furthermore it is questionable to what extent the number of patents indicates technological leadership in this case since it is still a relatively young field of research with multiple angles and subcategories. A lot of breakthroughs has still to take place, especially in software programming before self-driving cars become a reality and the number of current patents thus does not seem to play a very significant role.

During the Las Vegas CES in 2013, Toyota showcased a Lexus LS that was equipped with cameras, radar, GPS and a top mounted spinning lidar. The car was able to perform autonomous driving to some extent but was presented as a research vehicle for increased safety and called the Advanced Active Safety Research Vehicle. This focus on safety was well in line with the company's previous reluctance to aim for autonomous driving.

Toyota is now testing modified versions of the Lexus GS 450h in Japan that feature self-driving capabilities. Unlike the Lexus LS presented in 2013, the new type of research vehicle has concealed the sensors inside the vehicle body (in the grill and in the bumpers for instance). The car is called Highway Teammate and is able to perform autonomous driving on highways including maintaining distance to the vehicle in front, maintaining and changing lanes, merging onto and exiting the highway and overtaking other vehicles. The car has a center display that shows a top view of the car and what is going on around it in real-time. As is the case with other carmakers' autonomous test cars, the system alerts the driver with a visual and an acoustic signal when it encounters situations it does not know how to handle and simultaneously hands the control back to the test driver.

The Lexus GS 450h test vehicle is a part of the Mobility Teammate Concept that highlights Toyota's belief of an autonomous system as a co-pilot (or a driver's best friend to use Toyota's own words) combining the fun in driving with the utility and safety associated with autonomy. The ultimate goal with the concept is to reach a society where mobility is characterized by efficiency, safety and freedom. To achieve this goal, Toyota believes three areas of intelligence must be developed: driving intelligence (meaning computer interpretation of the surrounding environment and decision-making systems), connected intelligence (i.e. V2X connectivity and communication) and finally interactive intelligence (which the company sees as the integration between human and machine).

Toyota is also mapping the highway roads of Japan since the self-driving system needs to be fed with updated and accurate maps to work in a safe manner. Toyota showcased software during the 2016 CES in Las Vegas that was able to collect mapping data from its production vehicles' current GPS devices and cameras. Such a method is much less expensive than the conventional way to map with the use of dedicated vehicles that perform 3D scanning with lidar sensors. Since the method leverages on a large volume of constantly driven vehicles, it also results in more updated maps.

Toyota has also taken steps in the development of V2X technology. Last autumn, Toyota introduced ITS Connect for the domestic Crown model. ITS Connect is a system for V2X communication that utilizes a specific radio frequency (760 MHz) allocated by the Japanese government specifically for the automotive industry. In addition to the Crown model, ITS Connect will be offered on the new Prius model and the Lexus RX 450h as well and will cost around € 2000 extra. Pedestrians constitute about a third of all traffic related fatalities that occur in Japan. The aim is that ITS Connect shall decrease pedestrian fatalities by introducing communication between pedestrians and vehicles. Toyota is investigating the idea to let people's smartphones send out warnings to approaching vehicles. Another method could be to leverage from cameras and sensor at road crossings which could communicate what they see to Toyota's vehicles. Such a sensor could for instance detect pedestrians that are blocked from a vehicle's vision behind a wall or another obstacle and transmit a warning to the driver. Another use case for ITS Connect is communication between cars on the road to allow them to keep shorter distance to each other.

11.10.5 Toyota's position in the autonomous car development

Toyota has for a long time been reluctant to respond to the trend of autonomous cars. The company has been developing technology for autonomy but it has been aimed towards increased safety rather than allowing a self-driving mode. Since last year, though, Toyota has decided to also target the development of fully autonomous cars. However, Toyota's initial approach is still focused around safety and is based on the Mobility Teammate Concept which takes a different perspective than most other carmakers' initiatives. Other OEMs are developing autonomous systems that are either on or off. Toyota aims to develop something that is a little bit of both, an ever present co-pilot that takes over the control when the system deems it necessary.

Even though the Mobility Teammate Concept is probably only a first step, the unconventional approach still indicates a certain level of internal ambivalence in the company. It is not clear whether the company aims to develop a fully autonomous autopilot in addition to the co-pilot. The Tokyo Olympic Games along with company statements acknowledging the utility of fully autonomous cars indicates that it does find the development of such vehicles important but the large focus on the Mobility Teammate Concept indicates otherwise.

Despite an apparent ambivalence in the company, Toyota has still capacity of being one of the major forces behind a transition to autonomous cars. Toyota's main advantage comes from the fact that it is the world's largest vehicle manufacturer with significant resources at hand. As evident by the projects described above, Toyota is definitely starting to take autonomous driving seriously.

11.11 Honda Motor Company

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> Honda Motor Company was founded in Tokyo in 1946. The company started to manufacture motorcycles in 1948 and passenger cars in 1963. Today, Honda is the leading vendor of motorcycles and internal combustion engines worldwide. In 1986, Honda became the first Japanese car manufacturer to release a luxury brand – Acura. Today, Acura cars are sold in the US, Canada, Mexico, Hong Kong, China and Russia. Besides motorcycles and cars, Honda manufactures marine engines, personal watercraft, garden equipment and power generators. The company has also entered new markets including the aerospace industry, as well as the robotics and solar cell markets. Honda operates around 40 wholly owned manufacturing facilities in about 17 countries. Total revenues grew 9.6 percent to JPY 14,601 billion (€ 119.5 billion) in the fiscal year ended in March 2016. Honda's automotive revenues grew 10.45 percent to JPY 10,625 billion (€ 86.9 billion).
>
> Honda is now the eighth largest car manufacturer based on unit sales and the seventh largest manufacturer based on revenues. In the fiscal year ended March 31, 2016, Honda sold more than 4.74 million passenger cars under the Honda and Acura brands. The largest market was North America, where Honda sold more than 1.9 million cars, followed by Asia where Honda sold over 1.7 million vehicles. Honda is the second largest car manufacturer in Japan (behind Toyota) with 668,000 cars sold in the fiscal year 2016. In the same period, Honda sold 172,000 cars in Europe.

11.11.1 Overview of Honda and Acura passenger car models

> Honda markets passenger cars in more than 130 countries worldwide. In addition to models available on a global basis, the company also markets several models and variants for local markets such as China and Japan. Current global car models from Honda include the Fit/Jazz, Civic, Accord and CR-V. The B-segment Honda Fit/Jazz is available with a hatchback body style, while the C-segment Honda Civic is available as a hatchback, sedan and coupe. The D-segment Honda Accord is the company's bestselling car, available in sedan and estate body models. The Honda CR-V is a compact SUV, first introduced in 1995. Honda also sells hybrid cars, including the CR-Z sports car and hybrid versions of the Accord, Civic and Fit/Jazz. However, Honda has ended production of the hybrid version of the Honda Insight C-segment hatchback and the Honda Fit EV electric car due to low sales. The current Acura model range of luxury vehicles include the ILX compact sedan, TLX mid-size sedan, RLX full-size sport sedan, RDX crossover and MDX mid-size SUV.

11.11.2 Honda and ADAS development

The new Honda Civic LX features extensive ADAS features and stands out among other brands since the car has a price tag of only $ 22,240. The low price makes it possible for young drivers to attain the increased safety that follows with driver assistance systems. Since ADAS' main benefit is to take control over the vehicle at times when the driver misses something (often caused by a distraction) the technology is probable to have an important impact especially on young and inexperienced drivers. The ADAS package includes lane keeping assist, adaptive cruise control and autonomous emergency braking.

The new Honda 2016 Pilot features the company's most comprehensively ADAS equipped Honda model so far. The car has been equipped with Honda Sensing which is a suite of systems that increase the driver's awareness and control in various situations and also detects and mitigates hazardous situations. The suite incorporates forward collision warning, autonomous emergency braking, adaptive cruise control, lane departure warning, lane keeping assist, road departure mitigation, blind spot monitor and rear cross traffic alert.

Safety has historically been an important aspect of the Acura brand and that trend continues today. All Acura sedans and SUVs of model year 2016 offer "AcuraWatch" as an optional safety package. The package is the sibling of the Honda Sensing suite and essentially offers the same features. The available features do not come as standard neither in the Honda Pilot model nor the Acura models - they have to be bought through bundled packages.

11.11.3 Honda's approach to autonomous cars

Just a week before the Tokyo Motor Show in October 2015, Honda announced that it is developing a self-driving vehicle and that it plans to have it available on the market by 2020. The car will only feature autonomous driving on highways and only in Japan at the outset but the plan is to expand to other regions as well. Before the announcement, Honda had been quite secretive about its efforts in autonomous driving. Honda is still not very outspoken about its activities and neither seems to be one of the most active companies pursuing autonomous driving. The CEO of Honda, Takahiro Hachigo, has said that he is not denying the trend with autonomous cars but that his company has yet to identify how Honda can make something unique to differentiate itself from other developers of autonomous technology.

There are indications on Honda aiming to offer its self-driving technologies across a wide range of its models. The fact that the new Civic has been equipped with several driver assistance functions is one such indication, although the Acura models still have more sophisticated systems. Honda believes the technology can offer different benefits to different types of drivers. Active safety systems help all drivers but perhaps mostly those with little driving experience while more skilled drivers benefit more from smart systems that instead increase the vehicle performance.

One of the main reasons for its development of autonomous technology is according to Honda to improve safety. Honda's mission is to reduce collisions involving Honda vehicles by 50 percent in 2020 and completely eradicate them by 2040.

One of the company's more creative ideas lead to the "Honda. Great Journey" concept which was developed by the design studio Map in London with collaboration from the Japanese studio Mori, Inc. Honda requested a conceptual design for a vehicle that would be able to take passengers around the world in a relatively near time frame, i.e. without being too futuristic. Honda did not want a palpable or ready solution but rather new visionary ideas. The two design studios came up with a concept based on humanity's longest migration - from Nairobi in Kenya via the Middle East, India, China, Japan, the Kamchatka Peninsula, the west coast of North America and Central America to finally end in Manaus in Brazil. The idea was to design a vehicle that autonomously could take its passengers along the migration path regardless of the various biotopes encountered. Such a vehicle, however, proved to be unfeasible even at a conceptual stage and the studios instead created seven prototypes, the size of remote-controlled cars, to showcase how each could tackle a different environment. The seven prototypes consisted of: a savannah vehicle with attached lawnmowers to cut its own tracks; a hydrogen fuel cell powered desert train leveraging on the water byproduct for drinking; a mountain climber with extendable legs to walk across landslide debris on the roads of Himalaya; an amphibious vehicle for the alternating sea and island journey between China and the Kamchatka Peninsula; a tundra sled to ride across the icy conditions in Alaska; a road tripper with large windows for the scenic route along the North American west coast and finally the jungle jumper for traversing the rain forest of Amazonas.

What is interesting with the great journey concept is that Honda is introducing a different view to autonomous and modern technology. Most projects and future visions concentrate on the impact driverless technology can have on urban infrastructure. The conversation is all about alleviate tedious commuting driving in short perspective and transforming cities in the longer perspective. With this concept, Honda wants to elicit people's lust for adventure and highlights another advantage with autonomous vehicles - the ability to go on long journeys without having to drive.

11.11.4 Honda and autonomous technology

Despite the launch of the ADAS equipped Honda Civic LX and the apparent aim to introduce self-driving features across both expensive and affordable models, the company's main efforts in autonomous driving is performed at the Acura brand. This is similar to most other automotive manufacturers (e.g. Volkswagen's Audi and Daimler's Mercedes-Benz) where the luxury brands tend to be significantly more inclined to autonomous driving than the mass market brands.

In 2003 Honda established Honda Research Institute USA in Silicon Valley. The institute conducts research in materials and computer science and has the aim to discover new technologies and find suitable partners for development of new innovations. In 2015, the research institute started testing the Automated Acura RLX Development Vehicle at the GoMentum Station which is a proving ground for autonomous and connected vehicles in the San Francisco Bay Area. The proving ground has 20 miles of paved roads and contains buildings and other objects that provide a realistic city environment. In May, 2016, Acura revealed a second generation of the RLX Development Vehicle which has replaced the roof-mounted rotating lidar with several lidars facing different directions. In general, all the sensors have been upgraded for the new research vehicle, including better radar, GPS, cameras as well as more advanced CPUs and GPUs.

Honda is not only performing research with typical sedans crammed with sensors but it has also developed some unusual concept vehicles. The Honda Omni Traction Drive System is one example that features a wheel that is able to spin both forward and backward as well as sideways. The wheel actually consists of a large wheel for forward-backward movement while several small wheels mounted perpendicular to and outside the larger wheel provide the motion from side to side. The wheel is thus also capable of spinning around its own axis. The technology has been used in Honda's U3-X electric vehicle that is similar to a unicycle except that it is self-balancing and can move sideways. Another vehicle that leverages on the Omni Traction Drive System is the Wander Stand pod vehicle concept. The small pod is supposed to autonomously or by the use of a joystick transport a maximum of two passengers in low speeds among pedestrians. The name wander is derived from the fact that the pods can move freely in all directions just like a human.

Figure 29. Honda Wander Stand pod concept vehicle

Source: Honda

11.11.5 Honda's position in the autonomous car development

Honda had up until the Tokyo Motor Show in October, 2015, not revealed much of its initiatives in autonomous driving. Since then, Honda has announced the goal to have a partly autonomous car available by 2020 and has also set the target to reduce the number of Honda involved collisions by 50 percent the same year. Moreover, it has revealed that it is performing test drives with a modified Acura RLX sedan. On the other hand, it seems like Honda is doing these projects with a bit of reluctance. The company does not seem to know exactly where it is going with autonomous technology. However, Since a lot of other companies are targeting self-driving cars and several have reached further in the development, it is not strange that Honda wants to find a way to differentiate itself from the competition.

An indication of Honda's creativity and search for differentiation can be found in the "Honda. Great Journey" concept that offered a new perspective on what driverless technology can be used for. Many believe that self-driving cars will eradicate the tedious parts of driving, giving us the opportunity to do work in our cars instead of controlling them. However, some also fear that it will remove the fun in driving. Perhaps Honda's view on the future provides a new way to look at this by highlighting the fun in riding in a vehicle that autonomously traverses difficult terrain. Honda tells us that the actual riding experience can be something to enjoy even without driving the car.

11.12 Hyundai Motor Group

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The Hyundai Motor Group was formed in 1998 when Hyundai Motor Company acquired a stake in Kia Motors in the wake of the Asian financial crisis. Hyundai Motor Company currently owns almost 34 percent of the shares in Kia Motors. The Hyundai Motor Group is the third largest industrial conglomerate in South Korea. In 2015, Hyundai Motor Group was the tenth largest manufacturer of passenger cars worldwide in terms of revenues and the sixth largest in terms of unit sales. Hyundai Motor Company (HMC), headquartered in Seoul, was founded in 1967. HMC's total revenues increased 3.0 percent to KRW 91,959 (€ 69.2 billion) in 2015, while automotive revenues grew 0.5 percent to KRW 72,680 billion (€ 54.9 billion). Hyundai vehicles are sold in over 190 countries through roughly 6,000 dealerships, with the notable exception of Japan, where HMC suspended passenger car sales in 2011. Kia Motors, the second largest car manufacturer in South Korea, was founded in 1944 and produced its first car in 1974. The vehicles are now sold through a network of more than 3,000 distributors and dealers in 172 countries. In 2015, Kia Motors' total revenues increased 5.1 percent to KRW 49,521 billion (€ 37.3 billion).

In 2015, Hyundai Motor sold almost 5.0 million passenger cars and light commercial vehicles, an increase of 0.1 percent compared to 2014. In 2014, the Asia-Pacific region accounted for almost 52 percent of Hyundai's vehicle unit sales, while North America accounted for almost 32 percent of sales and Europe accounted for over 14 percent of total unit sales (corresponding numbers for 2015 are unavailable). Kia Motors sold 2.9 million passenger cars and light commercial vehicles in 2015, an increase of 0.3 percent year-on-year. The three largest countries in terms of Kia Motors' vehicle unit sales in 2015 were the US, China and South Korea, which accounted for 21 percent, 21 percent and 18 percent of total sales respectively.

11.12.1 Overview of Hyundai and Kia passenger car models

Hyundai produces a broad range of mass market, premium and luxury passenger cars and SUVs as well as light commercial vehicles. In order to reduce development time and cost while still increasing the number of car models offered, Hyundai has introduced integrated platforms. The company is also increasing its focus on green cars, with the aim to offer 22 green models by 2020, including 12 hybrid electric vehicles, 6 plug-in hybrids, 2 battery electric vehicles and 2 fuel cell electric vehicles.

Examples of current Hyundai models are the i10 A-segment hatchback, the i20 B-segment hatchback, the i30 C-segment hatchback and estates, the Veloster C-segment sports car, the C-segment Elantra sedan and coupes. Hyundai also sells the D-segment i40 sedan and estates in Europe. Examples of premium passenger cars include the Sonata D-segment sedan and the Azera E-segment sedan. Luxury passenger car models include the Genesis E-segment sedan and coupes and the Equus F-segment luxury sedan. Other models include the Tucson/ix35 compact crossover, as well as the Santa Fe and Grand Santa Fe SUVs.

By focusing on distinctive design and reliability, Kia has set a goal of becoming a tier-1 automotive brand by 2016. Examples of current models include the Picanto A-segment hatchback, the Rio B-segment hatchback and sedans, the Forte C-segment hatchback, sedan and coupes, the Optima D-segment sedan, as well as the Cee'd C-segment hatchbacks and estates for the European market. Premium and luxury cars include the Cadenza E-segment sedan and Quoris/K900 F-segment sedan. Examples of MPVs, crossovers and SUVs include the Venga mini MPV, the Soul C-segment crossover, the Carnival/Sedona MPV, the Sportage compact crossover and the Sorento mid-size SUV. Kia also launched the all-electric Kia Soul EV model in the second half of 2014. In 2014, A-, B- and C-segment cars accounted for 52 percent of sales, D- and E-segment cars accounted for 13 percent of sales, while crossovers, MPVs and SUVs accounted for 30 percent of sales.

11.12.2 Hyundai and ADAS development

Hyundai offers some ADAS but so far mostly as additional packages rather than as standard. Only the more high-end models such as the Genesis - the brand's flagship sedan - the Santa Fe SUV and the Azera sedan come with various ADAS as optional features. However, Hyundai's most luxurious vehicle, the Equus sedan, has the entire range of the automaker's available ADAS as standard.

Included in Hyundai's ADAS package are adaptive cruise control, automatic emergency braking with pedestrian detection, lane departure warning as well as a lane keeping assist, heads-up display and blind spot monitor. The ADAS offered by Hyundai are relatively basic compared to the more luxury inclined brands. However, the company describes itself as a fast follower that never leads the deployment of semi-autonomous functions but on the other hand maintains a steady six month lag to the leaders. An advantage with this strategy is that it removes much of the need for developing own innovations. A disadvantage is that the it is hard to achieve the top position and the price of the systems must therefore be lower compared to the leaders.

The ADAS are mainly developed by Hyundai's supplier Hyundai Mobis but the automaker also collaborates with other suppliers. The various ADAS rely on radar sensors and optical cameras as well as ultrasonic sensors for a parking assist feature.

When the Hyundai Genesis EQ900 launches in Korea this summer it will be equipped with a Highway Driving Assistance system. The system works similar to other highway autopilots by coupling adaptive cruise control with lane keeping assist and autonomous emergency braking. The same model will come to other markets as well but will be branded as Genesis G90 and the highway autopilot system might not be included initially. The car is the first of Hyundai's new Genesis luxury brand and effectively replaces the Hyundai Equus. In addition to the Highway Driving Assistance, the car will be equipped with a range of other ADAS.

Although mainly the more expensive Hyundai models offer ADAS technology and usually as additional packages, the company is starting to target a broader implementation. The company wants to make the systems standard as regulations are becoming increasingly strict.

Kia's approach to ADAS is essentially the same as Hyundai's. Kia models feature similar systems with adaptive cruise control, autonomous emergency braking, lane departure warning, lane keeping assist, forward collision warning and blind spot monitor. At the 2016 CES, Kia announced that it will launch a new sub-brand called Drive Wise which will have the sole purpose of developing ADAS for increased safety and convenience. The division will also develop systems that enhance human machine interface.

11.12.3 Hyundai's approach to autonomous cars

Hyundai wants to develop autonomous technology with the main purpose of increasing its customer’s safety. Hyundai has stressed that it is not pursuing autonomous cars for the sake of self-driving but rather to keep its customers safe. Nevertheless, the group wants to develop fully autonomous cars.

2020 is aimed to be a milestone for the company with the introduction of highly autonomous technologies while full autonomy is aimed to be reached by 2030. Hyundai has together with its affiliate Kia allocated a budget of US$ 9.75 billion for this and the next four years to the R&D for autonomous technology. Of that sum, US$ 2 billion was assigned to Kia's Drive Wise division for this and the following two years to develop sophisticated ADAS and employ more engineers. Drive Wise's ADAS development will progressively move towards autonomous technology. Drive Wise aims at increasing safety not only for the car's driver and passengers but also for pedestrians as well as for people in other cars.

11.12.4 Hyundai and autonomous technology

At the 2015 CES in Las Vegas, Hyundai showcased various ADAS that the company said have high probability to be ready for production in a near future. Included were a remote automatic parking system that would feature driverless autonomy for parking once developed. Hyundai also showed a number of new driving aid systems such as traffic jam assist, highway autopilot and a system called "emergency stop" that detects if the driver is impaired and guides the vehicle to a safe position by the side of the road. The emergency stop relies on a certain wristwatch that Hyundai calls "the wearable" that monitors the driver's health condition.

Hyundai also put a lot of attention to V2X connectivity in which it included vehicle to pedestrian (V2P) communication. Hyundai has also developed a sophisticated heads-up display (HUD) that utilizes augmented reality to show dynamic animation for navigation information in the drivers' line of sight. The system for instance shows arrows appearing as if they were flowing over the road, significantly more advanced than simply projecting information on the windshield.

Along with the announcement of Kia's Drive Wise sub-brand at the 2016 CES, the company also showcased its concepts for a highway autonomous driving system as well as a separate system for urban autonomous driving. Kia also displayed a system called "preceding vehicle following" which is an enhanced lane keeping assist that calculates its route by monitoring the vehicle in front when lane markings are unclear. Furthermore, Kia presented an emergency stop system similar to Hyundai's but with the difference that it would work in combination with Kia's driver monitoring system instead of the wristwatch. The driver monitoring system records the driver's face and detects if the driver shows signs of straying attention. In such case, the emergency stop system can automatically make the car come to a halt by the side of the road. A traffic jam assist was also presented as well as a concept for an autonomous valet parking system that can be remotely activated by a smart key or a smart watch and thus allows the driver to exit the car before it parks itself. Furthermore, the R&D at Kia has a large focus on V2X communication since the company believes this will be an integral part of autonomous technology in the near future.

In December last year, the state of Nevada granted Kia a permission to test its autonomous technology on public roads. Modified versions of Kia's Soul electric vehicle is being used as test car for Drive Wise's new technologies.

At the 2016 CES Hyundai Mobis demonstrated experiential exhibits were people for instance could see various use-cases for seven different ADAS as well as the supplier's idea for an autonomous car cockpit. The concept vehicle was dubbed the i-Cockpit Car and included simulation of partially autonomous driving conditions to give visitors a feel of what autonomous driving could be like. Integrated in the simulator was also Kia's next-generation of HMI technology featuring a fingerprint touchpad as well as gesture recognition for operating various controls of the car. Based on the driver's fingerprint or smart watch the car recognizes the driver and automatically adjusts cabin ambience, music, displayed information and other settings according to the driver's preferences.

Hyundai has created an augmented reality app that it calls the Virtual Guide to increase owners' knowledge and make maintenance of their cars easier. Based on where the smartphone's camera is directed, the app explains the function of different parts of the engine and how to perform maintenance work on them. It can also be used for the interior of the car with tutorials for how to use various controls. The technology is a complement to the written manual and was also demonstrated at the 2016 CES. Hyundai Motor Group has also identified that autonomous cars will require a lot of additional semiconductor chips compared to today's cars and has therefore revealed plans to develop its own chips specifically for autonomous cars through its subsidiary Hyundai Autron.

In June 2014, Hyundai went viral with a video that showed a convoy of six Genesis cars driving on a deserted road at Hyundai's proving ground in California. The video shows how five of the test drivers one by one exit their vehicles by climbing out of the roof and jumping on to a truck's madras equipped trailer. The driver in the leading vehicle then covers his eye with a mask, puts his hand in his lap and waits as a lorry positions itself in front of the convoy before it suddenly brakes. All of the Genesis models apply emergency braking and come to a complete halt in succession. Although the stunt was performed in a closed-off and well-planned environment Hyundai wanted to show how its technologies for adaptive cruise control, lane keeping assist and autonomous emergency braking could be trusted upon.

Figure 30. The empty car convoy

Source: Hyundai Motor Group

11.12.5 Hyundai's position in the autonomous car development

Hyundai is one of the large automakers that are targeting autonomous cars. The company is targeting full autonomy by 2030 which is somewhat defensive compared to several other actors. Hyundai has, on the other hand, been clearer than many others by saying that by 2020 it will have high autonomy available and that it will take an additional ten years to reach full autonomy. Considering all the challenges associated with developing these cars it is not a defensive statement per se, only in comparison with more aggressive actors. The investment of $ 9.75 billion for the development of autonomous cars also indicates Hyundai's determination to be a part of this field.

An interesting aspect of Hyundai Motor Group is that it is open to the development of unconventional technologies or technologies that are somewhat peripheral to the automotive industry such as a smart watch or an app for augmented reality. This innovativeness might prove valuable for the development of autonomous technology. Hyundai is also quick at reacting to changes in the industry - it is a fast follower that does not lead the development but does not lag far behind either.

11.13 Renault-Nissan Alliance

Since Renault and Nissan have entered an alliance and are collaborating in the development of autonomous cars, the brands have been allocated to the same chapter in this report. The purpose with this is to avoid repetition and confusion regarding the alliance's goals with autonomous driving which are shared across both companies. However, for the aspects of the brands that are separable, the text will initially describe Nissan before shifting attention to Renault.

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11.13.1 Overview of Nissan Motor Company

Nissan Motor Company is headquartered in Yokohama, Japan. The company was founded in 1933 and develops and manufactures passenger cars and light commercial vehicles as well as marine engines and boats. Nissan is the fifth largest car manufacturer in the world in terms of unit sales, operating production plants in 20 countries. The company sold over 5.4 million vehicles under the Nissan, Infiniti and Datsun brands in 2015. Total revenues for the fiscal year ended in March 2016 increased over 7 percent to JPY 12,190 billion (€ 98.3 billion).

In 1999, Nissan signed an alliance with the French car manufacturer Renault to enable deep cooperation regarding R&D, purchasing, manufacturing and logistics as well as human resources. Carlos Ghosn now serves as President and CEO of both Nissan and Renault, as well as the Renault-Nissan Alliance Board. The ties between the two companies are built upon cross-ownership where Renault holds a 43.4 percent stake in Nissan, while Nissan owns 15.0 percent of Renault shares. Moreover, in 2012, Renault-Nissan acquired a majority stake in Alliance Rostec Auto, a joint venture with Russian Technologies, which now controls 74.5 percent of AvtoVAZ.

Nissan sells passenger cars under the Nissan, Infiniti and Datsun brands through about 9,600 dealerships in 160 countries and territories worldwide. The Nissan brand is used for mass market cars sold globally. Nissan introduced the Infiniti brand for luxury cars in North America in 1989. Since then, sales of Infiniti cars have been expanded to 50 countries worldwide. In 2014, Nissan re-introduced the Datsun brand for sales of affordable cars in high-growth markets including India, Indonesia, Russia and South Africa. Total sales of Nissan, Infiniti and Datsun vehicles grew 2 percent in 2015. The Asia-Pacific region accounted for 40 percent of unit sales in 2015, followed by North America with 37 percent. Europe (including Russia) accounted for 14 percent of unit sales in 2015. The Middle East, Latin America and Africa regions accounted for the remaining 9 percent of unit sales. The three largest individual countries were the US that accounted for 28 percent of Nissan’s total unit sales in 2015, followed by China with 23 percent and Japan with nearly 11 percent of total unit sales. Nissan is the largest Japanese brand in China and the largest automotive brand in Mexico.

11.13.2 Overview of Nissan and Infiniti passenger car models

In total, Nissan markets about 50 different passenger car and SUV models under the Nissan brand. Examples of passenger cars sold in most markets globally include the Micra B-segment hatchback, the Tiida/Versa C-segment hatchback and sedans, the Sylphy/Sentra C-segment sedan, the Altima D-segment sedan and Maxima E-segment premium sedan. Nissan crossovers, MPVs and SUVs include the Note mini MPV, the Quest full-size MPV, the Juke mini SUV, the QASHQAI compact crossover, the X-Trail/Rouge compact SUV, the Murano and Pathfinder midsize SUVs and the Navara/Frontier pickup truck. Current sports cars from Nissan include the 370Z and GT-R. Nissan introduced its first mass produced electric car, the Nissan LEAF, in December 2010. Cumulative sales of the LEAF C-segment hatchback passed 200,000 units in December, 2015. The second electric car model from Nissan, the e-NV200 compact van, was launched in June 2014.

Nissan markets eight Infiniti luxury car models in more than 50 countries. North America is the main market, accounting for nearly 69 percent of the 215,250 Infiniti cars sold worldwide in 2015. Current Infiniti models include the Q50 D-segment sedan, the Q60 coupé and convertible, the Q70 E-segment sedan. Crossovers and SUV models include the QX50 compact crossover, the QX60 midsize SUV, the QX70 midsize crossover and the QX80 full-size SUV. Infiniti also launched the new Q30 compact car and QX30 compact crossover this year.

11.13.3 Overview of Renault Group

The Renault Group, headquartered in France, has manufactured automobiles since 1898 and is now the third largest vendor of passenger cars and light commercial vehicles in Europe behind Volkswagen Group and PSA Peugeot Citroën. Renault Group offers three complementary brands: the global brand Renault, the regional brand Dacia and Renault Samsung Motors which is a local brand only present in South Korea. Renault has over 120,000 employees and 33 industrial sites, where it manufactures vehicles and powertrain parts. RCI Banque, a wholly-owned Renault subsidiary, provides financing services to the customers and networks of Renault, Nissan, Dacia, and Renault Samsung Motors in 36 countries. In 2015, total sales of Renault Group vehicles increased 3.3 percent to 2.8 million units worldwide. Total revenues grew over 10 percent to € 45.3 billion in 2015.

The Renault Group sold 2.41 million passenger cars and 387,000 light commercial vehicles in 2015. A total of 2.12 million Renault vehicles were sold in 125 countries through nearly 12,000 points of sale. Sales of Dacia vehicles climbed 7.7 percent to 551,000 units in 2015.

Sales of mid-range, luxury and SUV models under the Renault Samsung Motors brand remained stable at 80,100 units in 2015 (an increase of 0.1 percent from the year prior). The most important market region for the Renault Group in 2015 were the European region with almost 58 percent of unit sales while the three markets made up by Eurasia; Latin America; and Africa, Middle East and India each accounted for almost 13 percent of unit sales. The Asia-Pacific region accounted for 4 percent of unit sales. The five most important countries of the Renault Group in terms of vehicle unit sales in 2015 were France with 21.7 percent, Brazil with 6.5 percent, Germany with 6.3 percent, Turkey with 5.8 percent and Spain with 5.6 percent of sales.

11.13.4 Overview of Renault and Dacia passenger car models

The Renault Group markets over 30 models under the Renault brand worldwide, including 15 models mainly available in Europe. Examples include the Twingo A-segment hatchback, the Clio B-segment hatchback and estate, the Mégane C-segment hatchback, estate and cabriolet, the Kadjar C-segment crossover, the Talisman D-segment saloon, the Laguna D-segment hatchback, coupé and estate, the Scénic and Kangoo compact MPVs, the Espace full-size MPV, the Captur B-segment crossover and the new Kadjar compact crossover. At the end of 2012, Renault introduced the Renault Zoe electric car. Cumulative global sales of the Zoe model reached 39,200 units by the end of December 2015. The first Dacia vehicles were manufactured in Romania in 1966. Dacia was acquired by Renault in 1999 and now serves as the Renault Group's value brand, marketed in over 40 countries in Europe, North Africa, Turkey and Israel. The main Dacia models are the Sandero B-segment hatchback, the Logan C-segment sedan and estate, the Duster SUV, the Dokker mini MPV and the Lodgy MPV.

11.13.5 Nissan and ADAS development

Nissan Safety Shield is the colloquial name of Nissan's range of driver assistance technology. The Safety Shield package relies on four cameras and three radars. Specific systems included differ among different models but overall Nissan's Safety Shield includes ADAS such as adaptive cruise control that in addition to keeping the distance and following a set speed decelerates the vehicle when approaching a curve, blind spot monitor, lane departure warning, and forward collision warning with autonomous emergency braking (sometimes capable of detecting the behavior of the vehicle in front of the immediately preceding vehicle). Some models also offer lane keeping assist, cross traffic alert, 360 degree view from above, automatic switch between high beam and low beam, hill start assist, and road sign identification (only speed and overtaking signs though). About half of all Nissan vehicles sold in 2015 were equipped with some of the Safety Shield functions.

The system's four cameras can detect and warn about moving objects when driving in slow speeds to make tight maneuvers such as parking safer. Available is also a detection system for when the driver gets drowsy. An initial system relied solely on detectors in the seat that kept track of how long the driver had been driving and issued an acoustic- as well as a visual signal to remind the driver that it is time for a break. A later version of the system in addition monitors the steering input of the driver and compares this to an established baseline of how the driver normally drives. Nissan also has a parking assist that takes over the steering but requires the driver to handle the pedals according to instructions.

Nissan's luxury brand Infiniti has, just as can be expected, more sophisticated ADAS than the Nissan core brand. In addition to the systems mentioned above, Infiniti includes for instance Lane Departure Prevention. This system does not take control over the steering wheel but instead applies gentle braking to the wheels on the opposite side of the direction of the lane crossing. This results in the car getting back to the middle of the lane without the driver experiencing any uncomfortable forced turning of the steering wheel. However, the main difference between the brands is that Infiniti vehicles come with more ADAS as standard while similar systems are available as extensions on selected Nissan cars.

Overall, Nissan offers extensive driver assistance features although it does not have the most sophisticated systems. Nissan believes semi-autonomous technology is a first step towards fully autonomous vehicles.

The Infiniti Q50 is one of the brands most technology advanced models in terms of autonomous features. The model can be equipped with a highway autopilot (although Infiniti is careful not to market is as an autopilot and instead calls it Active Lane Control) that relies on adaptive cruise control, lane keeping assist and autonomous emergency braking to drive without human input on highways although the driver has to remain attentive at all times. The system works best on fairly straight roads and only in speeds above 45 mph. Unlike similar systems from other carmakers, the Infiniti Q50 does not require the driver to keep a hand on the steering wheel to function, although the company strongly advices it. The Active Lane Control system will be adopted by other models of Infiniti in a soon future.

11.13.6 Renault and ADAS development

Renault is also offering driver assistance, especially on the more expensive models such as Talisman, and the new Espace. These cars feature typical ADAS including adaptive cruise control, autonomous emergency braking, lane departure warning, blind spot monitor, automatic switching between high beam and low beam, traffic sign recognition and hill start assist. The Espace model is equipped with a forward looking camera mounted on the rearview mirror, a rear camera in the back of the car, eight short range- and four long range ultrasonic sensors and two radars. The Espace model also has a parking assist system that requires the driver to apply the pedals but controls the steering automatically to enter both parallel and perpendicular parking spaces. The latest Megane model has the same parking assist feature and also comes with a heads-up display.

In general, since Renault mainly targets the broad market with affordable cars, there is not much room to induce extra costs by adding semi-autonomous technology. Some features like lane departure warning are available, though, even on relatively inexpensive cars.

11.13.7 Nissan-Renault's approach to autonomous cars

The main reason why Nissan-Renault develops autonomous technology is to offer increased safety as evidenced by the motto "zero emissions, zero fatalities" that the alliance has started to target. An additional aim is to improve comfort and make driving less tedious. However, the alliance wants to enhance the experience of driving rather than eliminate it. Nissan-Renault stresses that the driver always will have the freedom to stay in control of the vehicle if desired.

The CEO of the Renault-Nissan Alliance, Carlos Ghosn has said that the goal is not to develop a fully self-driving car but rather to develop a car that avoids accidents and can take over the driving in specific situations. He does not believe that a completely self-driving car is what most drivers want. He has also pointed out regulations as a problem and that there is a difference in customers being offered a fully self-driving car and for them to be able to use it as such - the technology might be ready before the regulations.

Nissan-Renault is planning to target autonomous driving to a broad market with affordable vehicles. This is certain to be a challenge since most of the technology used to build autonomous features are expensive to develop and integrate with the cars. Nevertheless, this goal fits the strategy of the alliance to focus on the less expensive car segment (Infiniti being a notable exception). It is also well in line with the success of both Nissan LEAF, the EV that has been sold in largest volume worldwide, and Renault Zoe, the bestselling EV vehicle in Europe in 2015. These cars feature both advanced emission-free technology and relatively inexpensive price tags. The alliance therefore aims to continue this approach also in the field of autonomous driving.

Nissan-Renault believes that most people are conservative in adopting new technologies and has therefore decided to take a careful and incremental approach to autonomous driving by diffusing new technologies step by step. Over the next four years, the company plans to offer more than ten vehicles that come with various types of autonomous technology under the Nissan Intelligent Driving plan. According to Ghosn, the alliance will offer its so called Piloted Drive 1.0 that will enable the car to drive without human input in stop-and-go traffic in a single lane on highways, by the end of 2016 in Japan. The technology will drizzle out to different Nissan, Infiniti and Renault models in succession. The next major step planned to debut in 2018 is a highway automatic system that is capable of avoiding hazards and changing lanes. Finally in 2020 the goal is to have a car that is capable of driving without help from the driver in multiple situations, even in cities to some extent. The goal to offer a close-to-fully autonomous car by 2020 is almost in parity with the more aggressive developers that target the luxury market. This makes for somewhat of a discrepancy when considering the alliance's statements of being precautious. However, the alliance has acknowledged that the development of such a vehicle is not unlikely to be delayed beyond 2020.

A problem with an incremental approach is that the intermediate steps with partly autonomous functions lead to situations where the driver somewhat can let go of the control and thus also easily gets distracted. Nissan-Renault aims to deal with this by developing driver monitoring systems that ensure the driver is ready to regain control at all times. A proposed technique is to use a wristband that monitors the driver's biometrics to detect when he or she becomes tired or inattentive.

In 2011, the Nissan-Renault alliance established a research center in Silicon Valley with the aim to identify and develop promising automotive innovations such as autonomous technology and solutions for connected services. The research center has for instance tested prototypes of an autonomous Nissan LEAF on the roads of Sunnyvale. By locating the facility in Sunnyvale, the alliance hopes to leverage from being neighbors with innovative start-ups. The Nissan part of the research center has also entered a partnership with NASA to jointly work on solutions for remote controlling and other technologies.

11.13.8 Nissan and autonomous technology

Nissan early began investigating autonomous technology. In 2009, the company created a concept vehicle called Eporo equipped with an anti-collision system. The Eporo concept was in fact a number of vehicles that mimicked the behavior of a fish shoal in the sense that the vehicles were able to drive close together and move like a school of fish. This was achieved by letting the vehicles share information about the surrounding environment among each other. The small robotic vehicles were only a concept but it showed that Nissan was taking autonomy seriously from the beginning.

At the Tokyo Motor Show in October 2015, Nissan showcased the IDS Concept which is a futuristic EV car featuring an autonomous driving mode. When the self-driving mode is engaged, the pedals retract, the steering wheel folds into the panel and a large display pops up instead. The chairs also rotate slightly inwards to facilitate easier conversation. The car leverages from a range of sensors including five radars, five lasers and twelve cameras. When the autonomous driving mode is disengaged, the car also helps the driver with a HUD that displays information on the windshield in front of the driver. An interesting feature with the concept car is a display in the bottom of the windshield that can indicate the car's intentions, for instance by flashing an "After you" message to a crossing pedestrian. The side body has a strip of LED lights that can show that the car is aware of pedestrians or cyclists by turning on a white light that follows the object's location along the side of the vehicle.

Figure 31. Nissan IDS Concept interior when in self-driving mode

Source: Nissan

The prototype for the Piloted Drive 1.0 was unveiled simultaneously with the IDS concept car in 2015. The prototype was essentially a modified Nissan LEAF which is now being tested on both highways and in an urban environment. The vehicle has been fitted with an array of sensors including five radar sensors, four lasers, twelve cameras and ultrasonic sensors which is more than most other similar initiatives have equipped their test cars with. This can be seen as a bit contrary to the goal of making the autonomous technology available in affordable models and the reason why other initiatives refrain from using an equally large amount of sensors is, in fact, precisely to avoid piling up unnecessary costs. On the other hand, Nissan has developed a miniature high-spec laser (essentially a lidar) as well as a 360-degree view camera system in-house which might make an extensive use of sensors feasible. At the Geneva Motor Show in March, 2016, Nissan revealed that it will offer Piloted Drive 1.0 on the new Qashqai model that will be available in 2017. It seems likely that the next generation of the LEAF model (not unlikely to debut in 2017) will get a similar or enhanced autonomous system.

Nissan has also equipped one of its test cars with a system for self-parking. The system is activated with a smartphone app and requires the user to keep a button depressed. This effectively makes the user responsible for incidents although the system should be capable of stopping for pedestrians. The feature is still in the development stage and has not gained much attention.

11.13.9 Renault and autonomous technology

Renault's development of autonomous car kicked off in 2014 when it brought forward the "Next Two" concept. The concept car was based on a Renault Zoe and featured two autonomous functions. The first was an autopilot for traffic jams on highways and would work in speeds below 30 km/h and without lane changing. The second feature was an automatic valet parking that would be possible to use in parking lots adapted to driverless vehicles. Compared with concept cars from the more luxury oriented automakers, both the traffic jam autopilot and the valet parking were relatively modest. However, the concept also put lot of attention to connectivity and how it can be an integral part of autonomous driving.

In 2014, the French government authorized testing of autonomous cars in real traffic. The decision was a part of the government's "Nouvelle France industrielle" program which aims at enhancing France's position in the digital industry. The program has the same goal as the Renault-Nissan alliance - to have autonomous cars on the market by 2020. The authorization has enabled Renault to perform real-world testing in its domestic market.

Renault has since the government's authorization allegedly been testing a fleet of autonomous Espace prototypes for several hundreds of hours on public roads including some outside France. The Espace prototypes have been equipped with six different types of sensors: more than 20 short range ultrasonic sensors, 4 short range cameras giving a 360 degree view, 4 medium range corner radars, 3 laser scanners with a wide field of view, a trifocal camera in the front, and a long range front radar. This is similar to Nissan in that it is a rather extensive use of sensors when compared to other automakers' research vehicles. However neither Nissan, nor Renault has any roof-mounted rotating lidar but instead relies on multiple laser scanners that together capture the entire field around the car.

11.13.10 Nissan-Renault's position in the autonomous car development

The Nissan-Renault alliance has an interesting position for a future with autonomous cars. The alliance is in terms of volume one of the largest automobile manufacturers globally which gives it strength to invest in development of the technologies necessary for autonomous driving. On the other hand, both brands mostly target the mass market with relatively inexpensive cars and are by all appearances not interested in changing this. It will likely be a challenge for the alliance to make autonomous technology available in the low- and mid-market segments due to the extensive sensor and development costs.

An interesting aspect is that Nissan and Renault have developed two of the world's most popular electric vehicles (the Nissan LEAF and the Renault Zoe) which gives them an edge in a future market where emission free cars seems to go hand in hand with self-driving capabilities. Furthermore, the fact that Nissan-Renault is an alliance and thus is used to collaborations might provide an additional advantage. This is a result of the high probability that the development of autonomous cars will require different players to work together. The Silicon Valley based research center's partnership with NASA and the alliance's collaborations with University of Tokyo, Stanford, MIT and Oxford are further examples that indicates Nissan-Renault's willingness to cooperate with others.

On the other hand, the alliance is not one of the top players pursuing the development of autonomous technology. Despite stating that it will have a car that can drive without human input in most situations by 2020, the alliance is taking a rather careful approach to get there. For instance, the Pilot Drive 1.0 system, supposed to debut in 2017, will only allow Level 2 autonomous driving in traffic jams on highways. This is a feature already available from some high-end car manufacturers and a few even have more sophisticated systems that enable automated highway driving in regular speeds.

Still, Nissan-Renault has proven that it can develop high-performing and affordable technology, as evident by the EVs, indicating that the alliance should not be underestimated. The fact that the alliance is taking an incremental approach is also well in line with the alliance's goal to offer autonomous technology to the affordable segment. It is probably not necessary for the alliance to be the first actor to develop a fully or even near-fully autonomous car since its target market is not made up of early adopters.

11.14 Fiat Chrysler Automobiles

It should be mentioned already from the beginning of this section that Fiat Chrysler Automobiles (FCA) is not one of the most active companies in developing autonomous technology. The group has been included here due to its large size and particularly because of its recent deal with Google to deliver a fleet of 100 minivans for Google's autonomous car program - more of that below.

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> Fiat Chrysler Automobiles was incorporated as a public limited liability company in April 2014 through the merger of Fiat and Chrysler Group. The two companies first entered into an alliance in 2009 and since then Fiat has gradually increased its ownership stake in Chrysler Group before completing the acquisition of the remaining shares in early 2014. The group markets passenger cars and light commercial vehicles under the Fiat, Alfa Romeo, Lancia, Abarth, Chrysler, Jeep, Dodge, Ram and Fiat Professional brands. Maserati is the group's main luxury brand. On 3 January this year, the spin-off of Ferrari from FCA was completed after the group's public offering of a portion of FCA's interest in Ferrari corresponding to 10 percent of the Ferrari shares while FCA's remaining interest in Ferrari was distributed to shareholders of FCA.
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> As part of its 2014–2018 business plan, FCA will make significant investments in expanding several brands into new markets. Sales of Jeep models will be expanded globally through localized production in Asia and Latin America. The Alfa Romeo brand will be reintroduced in North America and other markets worldwide along with an enlargement of the model range. The plan also includes a broader range of Maserati brand models to cover all segments of the luxury vehicle market.
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> FCA also operates in the automotive components sector through Magneti Marelli and Teksid, in the production systems sector through Comau and in after-sales services and products through Mopar. Excluding Ferrari, total FCA revenues increased 18 percent to € 110.6 billion in 2015 of which € 104.1 billion came from vehicle sales. Total sales of passenger cars and light commercial vehicles remained unchanged from the previous year at 4.6 million units.
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> FCA has about 234,600 employees, operates 164 manufacturing plants and has operations in 40 countries. The company sells passenger cars and light commercial vehicles in about 150 countries worldwide. North America is the largest market, accounting for nearly 56 percent of the group’s vehicle unit sales in 2015, followed by the EU28+EFTA area that accounted for over 27 percent of total unit sales and Latin America that accounted for over 12 percent of total group vehicle unit sales. The five largest individual countries in terms of unit sales were the US, Brazil, Italy, Canada and China that accounted for about 48 percent, 10 percent, 9 percent, 6 percent and 3 percent of total unit sales respectively.

11.14.1 Overview of Fiat Chrysler Automobiles passenger car models

The first Fiat car was produced in 1899. Since then the company has mainly focused on mass market compact cars for the Italian, European and Latin American markets. Today, Fiat cars are marketed in nearly 100 countries globally, including 32 European countries. The Fiat brand was re-launched in North America in 2011 after more than two decades of absence. Current Fiat models include the Fiat 500 and Panda A-segment compact cars, the Fiat Punto B-segment hatchback, the Fiat Bravo and Linea C-segment hatchback and sedans, the 500L mini MPV, 500X mini crossover SUV and the Fiat Freemont crossover MPV. Lancia, founded in 1906, has been part of the Fiat Group since 1969. Today, Lancia vehicles are mainly targeted towards the Italian market, focusing on elegance and personality in the small cars segment. Examples include the Lancia Ypsilon A-segment car, based on the Fiat 500 platform, and the Delta C-segment compact car based on the Fiat C-platform.

Alfa Romeo, founded in 1910, markets premium cars with a focus on design and driving performance. Alfa Romeo was acquired by Fiat in 1986. The current Alfa Romeo model range includes the MiTo B-segment and Giulietta C-segment compact cars and the 4C lightweight sports car. In early 2015, Alfa Romeo started to deliver the new Alfa Romeo Giulia D-segment sedan and estates as replacements for the Alfa Romeo 159 that was produced until 2011. Alfa Romeo cars are sold in about 50 countries worldwide, including 30 countries in Europe. Alfa Romeo cars were also re-introduced in North America in 2015, an important step as the brand aims to increase global sales to 400,000 units by 2018.

Maserati was founded in 1914 and became a part of Fiat in 1993. Maserati is FCA's main luxury brand focusing on high quality interior and exterior design, sports handling, performance and comfort. The Maserati brand was reintroduced in 2013 with the launch of the all-new Ghibli E-segment sedan and the new generation of the Quattroporte F-segment four door sports luxury saloon. Maserati also markets the GranTurismo coupe and convertible and in March, 2016, Maserati unveiled the Levante luxury SUV which is the brand's first endeavor into the SUV market.

The Chrysler brand is used for premium sedans, convertibles and minivans sold in about 150 markets globally. The Dodge brand is used for mass market cars, minivans, crossovers and SUVs. Ram now sells light and medium weight trucks and commercial vehicles in the Americas. Jeep manufactures off-road vehicles, SUVs and crossovers. Jeep set an all-time brand record in 2015 with over 1.2 million vehicles sold worldwide. Abarth is a relatively small brand producing racing cars like the Abarth 124 Spider roadster and city cars like the Abarth 500 3-door hatchback.

11.14.2 FCA and development of ADAS

Since the FCA group consists of a number of different brands it also follows that the group does not offer the same generic driver assistance features across the product range. In general, though, FCA has clearly not kept up with the top carmakers in terms of ADAS development. The core brand of Fiat and Chrysler as well as Jeep have started to offer some ADAS during the last couple of years. However, both Fiat and Jeep did not offer these systems until after several other carmakers had already made them available to the market. Chrysler is a notable exception since it had some features available on the market relatively early.

There are indications, though, on FCA catching up. A parking assist system available on both Jeep and Chrysler models lets the cars park themselves partly autonomously by taking control of the steering while letting the driver handle the pedals. The all new Dodge Durango and the recently revealed Alfa Romeo Giulia both offer extensive ADAS.

On the other hand, Maserati, supposedly an extravagant luxury brand, has up until recently not put any significant resources into ADAS which is notable since most other luxury carmakers, like BMW, Mercedes-Benz and Audi have invested extensively in these systems. However, even Maserati seems to be changing its attitude - the new Levante SUV will have adaptive cruise control and lane departure technology and the goal is to, in the future, equip the vehicle with a highway autopilot. Nevertheless, Maserati is late in the development of these systems since most other luxury brands have been investing in it for years. The remaining car brands in the FCA group (Lancia, Ram Trucks and Abarth) all lack extensive ADAS.

11.14.3 FCA and autonomous driving

The Fiat Chrysler Automobile group has been very reluctant to develop autonomous technology. A major reason to this can be found in the group's CEO, Sergio Marchionne who at the Geneva Motor Show in March 2015 declared that FCA will not get carried away in the development of self-driving cars. FCA has deemed it unnecessary to spend money on developing the technology in-house implying that it can be bought at a later stage. In fact, Marchionne has personally gained quite a reputation in the industry for being rather outspoken and has for instance said that he would rather be shot before manufacturing a self-driving Ferrari. Marchionne has used the same response when asked about developing a Ferrari SUV and he has also exclaimed his dislike for electric vehicles. Furthermore, FCA has so far announced no plans to pursue any car-sharing or ride-hailing program.

However, just because FCA does not want to lead the development of autonomous cars does not mean that it does not believe autonomy will play an important role in the future. The group has therefore taken a laid back position where it keeps track of the development without actively engaging in it. Alfa Romeo is the main brand used for semi-autonomous technology. FCA spend $ 1 billion on the Alfa Romeo Giulia new platform and aims to use this platform as a basis for testing increasingly autonomous systems. The roll-out of these systems, such as an highway autopilot will, however, be more cautious compared to most other carmakers.

In May this year FCA entered a deal with Google to deliver 100 units of the 2017 Chrysler Pacifica Hybrid. FCA and Google engineers will collaborate to make the cars suitable for autonomous driving. The deal might seem counter intuitive since FCA has not been developing autonomous technology but, in fact, that factor seems to be the very reason why both parties have been able to reach an agreement. Google has previously been in talks with GM but they were unable of reaching a decision as to which party would own the rights to the technology. Unlike GM, FCA is not developing any self-driving car and there is therefore no conflict of interests between the group and Google. How this collaboration will affect FCA is uncertain but at the very least it indicates that the group also has an interest in autonomous cars.

Figure 32. 2017 Chrysler Pacifica Hybrid

Source: Chrysler

11.15 Groupe PSA

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> Groupe PSA (previously called PSA Peugeot Citroën and commonly referred to as PSA), headquartered in France, is the second largest car manufacturer in Europe behind Volkswagen Group and the leading manufacturer of light commercial vehicles. The group was formed in 1976 when Peugeot acquired Citroën. Peugeot and Citroën launched their first cars in 1890 and 1919 respectively. Today, the PSA group develops and manufactures passenger cars, light commercial vehicles, engines, as well as mopeds and scooters under the Peugeot, Citroën and DS brands. The group also owns Banque PSA Finance, which provides financial services, and holds a majority stake in the automotive parts supplier Faurecia.
>
> At the end of 2015, PSA was present in 160 countries, employing over 184,000 people and operated 7 R&D centres as well as 11 vehicle production sites. PSA is also stepping up its presence in China (which now is the company’s largest market) by developing two joint ventures: Dongfeng Peugeot Citroën Automobile (DPCA) and Changan PSA Automobile (CAPSA). The aim is to gain a market share of 8 per cent in China by 2020. In 2015, total group revenues grew 3.0 per cent to almost € 54.7 billion, while automotive revenues grew 1.4 per cent to nearly € 37.5 billion. PSA sold a total of 2.97 million vehicles in 2015.
>
> PSA's strategic plan for the next few years involves a reduction in the model range, based on fewer global product platforms, to focus on profitable segments. Although Europe constitutes the group's main market it also focuses on future growth in markets outside Europe. Peugeot cars are now sold in 160 countries through more than 10,000 dealerships, while Citroën cars are sold in 90

countries. DS was established as a separate premium brand in 2014. DS cars are sold through Citroën dealerships as well as a growing number of independent DS stores in Europe and China.

Sales of Peugeot vehicles grew 4.6 per cent to 1.71 million units while sales of Citroën vehicles declined 2.0 per cent to 1.16 million units and sales of DS vehicles fell 13.6 per cent to 102,000 units in 2015. The European market accounted for 63 per cent of PSA's total vehicle units sales in 2015 while the China and Southeast Asia market accounted for 25 per cent and the Middle East and Africa region accounted for 6 per cent.

11.15.1 Overview of Peugeot and Citroën passenger car models

PSA markets about 20 Peugeot and a dozen Citroën models in the A-, B-, C-, D- and E-segments as well as MPVs and crossovers. Examples include the Peugeot 108, 208, 308, 508, 2008, 4008, 5008 and RCZ, as well as the Citroën C1, C3, C3 Picasso, C4, C4 Cactus, C4 Air-Cross and C-Elysée. The current DS range now comprises the DS 3, DS 3 Cabrio, DS 4, DS 5, DS 5LS and DS 6. The C-segment Peugeot 308 hatchback, sedan, estate and cabriolet models were most popular in 2015 with nearly 346,000 units sold globally. It was followed by the 208 B-segment hatchback that sold almost 317,000 units worldwide. The most popular Citroën model is the Citroën C4 C-segment hatchback with over 313,000 units sold in 2015, followed by the Citroën C3 B-segment hatchback with almost 213,000 units sold in 2015. The most popular DS model was the DS 3 A-segment hatchback with nearly 49,000 units sold globally in 2015.

11.15.2 PSA and ADAS development

The PSA group offers some ADAS across its three brands and various models. The more expensive models of Peugeot and DS include the most sophisticated systems. The systems are in general not among the more advanced on the market. However, the group plans to step-by-step introduce more sophisticated driver assistance systems over the next four years getting increasingly close to autonomous cars.

The latest version of the Peugeot 308 model has adaptive cruise control, a collision warning system and autonomous emergency braking. The AEB only reduces the speed with a maximum of 20 km/h when it detects a risk of collision so the driver needs to apply the brakes as well. Some models from the Peugeot 208 and the Citroën C4 also have a parking assist system that facilitates the steering while the driver has to control the throttle and brake pedals. The system works for both parallel and perpendicular parking.

As the luxury brand in the PSA group, the DS brand adopts some ADAS across its models but these are not in parity with those offered by other similar luxury brands in the car industry. Included ADAS are adaptive cruise control, autonomous emergency braking, lane departure warning, blind spot monitoring, hill assist system, a heads-up display and adaptive headlights. The DS 3 and the DS 3 Cabrio are the first models to integrate the new PSA technology dubbed Active City Brake which is an autonomous emergency braking system specifically designed for a city environment. The system is based on a short-range laser at the top of the windscreen that detects potential hazards and avoids collisions in speeds up to 30 mph.

11.15.3 PSA's approach to autonomous cars

PSA has showed a positive attitude towards development of autonomous cars. The group has started to see changes in customers' expectations of mobility. In response to these changes, the group has generated a road-map for its development of autonomous technology. The first step will be taken in 2018 when the group will offer what it calls Automated Driving which means systems that enable the driver to delegate the driving task to the car on motorways and dual carriageways although the driver has to remain vigilant and ready to respond to unexpected situations. These systems correspond to a Level 2 autonomy.

The second step after Automated Driving is the Traffic Jam Chauffeur which offers increased autonomy in that the driver actually can let go of supervision for periods of time. However the system will only work in traffic jams at speeds below 50-70 km/h and on specific road stretches. This system corresponds to Level 3 autonomy and is expected to be ready in 2020 technology-wise but PSA is uncertain if regulations will allow drivers to divert control already at this time.

Following the Traffic Jam Chauffeur is the Highway Chauffeur which in turn offers yet another degree of autonomy. This system features autonomous driving on dual carriageways regardless of whether there is a traffic jam or a deserted road. However the driver must be ready to take back control in an interval of some seconds of prior warning from the car. This system opens up more freedom to the driver for longer periods of time and in more situations compared to the Traffic Jam Chauffeur but still corresponds to an SAE Level 3 since the human driver constitutes the fallback also in this system. The Highway Chauffeur is planned to arrive after 2020.

As can be derived from PSA's road-map, its roll-out of self-driving cars follows a stepwise approach with increasingly sophisticated ADAS as building blocks. PSA has only painted the path until the Highway Chauffeur is released as the last step but the company has plans to deliver vehicles with full autonomy in the future as well. However, the CEO of PSA, Carlos Tavares, wants to be cautious in the beginning of the development since full autonomy requires a lot of advanced technology which is difficult for a volume player like PSA to introduce in its cars. In line with this is PSA's goal to make the autonomous systems available in affordable vehicle models.

On 5th of April this year, PSA announced a new corporate strategy for growth dubbed "Push to Pass". The strategy included the change of names from PSA Peugeot Citroën to Groupe PSA (or PSA Group) as well as a five year plan for PSA's intentions. One of those intentions is to increase technology quality and associated with that is the plan to launch seven new plug-in hybrid models and four electric vehicles. The plan acknowledges that people's mobility patterns are changing and aims at adopting to these changes. Included in this plan is also the implementation of a program of connected and autonomous vehicles.

11.15.4 PSA and autonomous technology

PSA's Automated Driving system scheduled for debut in 2018 will rely on a range of sensors including numerous cameras, long-range and short-range lasers and ultrasonic sensors. Incorporated will also be driver monitoring systems to ensure that the driver stays alert - a camera will monitor the driver's actions and capacitive sensors on the surface of the steering wheel will make sure that the driver grips it. PSA has also recognized that the vehicles will need an intuitive human machine interface to facilitate smooth transition of control between the vehicle and the driver with both visual and acoustic warnings. The group is currently testing five models equipped with prototypes of the Automated Driving system.

The second step to Level 3 autonomy with the Traffic Jam Chauffeur will need additional technology compared to the Automated Driving system. PSA aims to increase redundancy and add a lidar for detection of obstacles. Furthermore, PSA wants to enhance the human machine interface to enable situations where the driver can let go of supervision but be ready to regain it five to ten seconds after a warning is issued from the vehicle. The transition from autonomous mode to normal driving mode can occur for instance following a speed up of the traffic. A problem with this system is that current regulations under the Vienna convention do not allow drivers to be inattentive while driving. PSA is, however, lobbying to change this, just like other car manufacturers developing autonomous technology. PSA currently has one operational prototype ready but is still working on the technological architecture for the system.

The Highway Chauffeur is planned to be able to perform lane changing to overtake other cars as well as deciding to pull back. The system will create a real-time model of the car's environment based on input from several lasers, radars and cameras. It will also rely on ultrasonic sensors and GPS. A version of the Highway Chauffeur system in which the driver is required to maintain supervision of the driving at all times is scheduled to arrive in 2020 while the more autonomous version will take longer to introduce.

PSA is working on two separate parking assist systems. The first is an enhancement of the current Park Assist available in the Peugeot 208 and the Citroën C4 and upwards. It will be called City Park Full Automatic and will follow the same procedure as the current Park Assist but do it completely autonomously, although the driver should supervise the operation. This feature is planned to arrive to the market in 2017. The second parking assist system is dubbed City Park Remote and corresponds to a Level 2 system since it controls both speed and steering. This system lets the driver exit the vehicle before it autonomously enters a parking space. The driver must, however, maintain supervision of the operation which PSA plans to ensure by disabling the parking operation if the driver stands more than a few meters away from the vehicle. PSA sees the City Park Remote as a first step to a Level 5 Valet Park Assist that lets the car park itself without driver supervision.

PSA is recognizing the trend of increased connectivity and is therefore targeting development of devices to facilitate internet of things. From 2017 the group plans to release solutions that enable increased connectivity. Two years ago PSA revealed plans to integrate its cars with Technicolor's Qeo software platform starting on the Citroën C4 Picasso. Qeo is a communication gateway that has been specifically designed to enable connection between smart devices. Qeo could for instance allow the driver to remotely activate the TV set at home and record a program from the car or to activate the home security system automatically when driving out of the garage.

PSA is currently also developing a "Smart Antenna" that allocates all inbound communications from mobile networks, television, radio and navigation (3G, 4G, DTT, DTR, AM/FM and GPS). The Smart Antenna establishes a Wi-Fi to communicate with the passengers mobile terminals. Except for the increased functionality of such a system, since different users can access different information, the antenna also offers optimized reception for internet connection - ten times the power of mobile phones onboard the vehicle according to PSA. The Smart Antenna is scheduled to launch in 2019 on a production car model. PSA sees connectivity as an important aspect for future autonomous vehicles.

PSA believes that the roll-out of autonomous cars will occur gradually and has therefore identified augmented reality as an important system to enhance the human machine interface and the transition of control between the vehicle and the driver. When a Level 3 autonomous vehicle encounters a situation it does not understand and tells the driver to regain control of the vehicle, the driver could benefit from an augmented reality system that indicates what object or situational aspect the autonomous system fails to understand. The group already has heads-up display available in several models and is now looking into developing augmented reality to enhance this technique. PSA is also developing gesture control systems to further enhance the human machine interface. The group believes gesture control can make the interaction more intuitive as well as more efficient.

In the beginning of October, 2015, PSA made one of its four autonomous test vehicles drive the 580 km stretch from Paris to Bordeaux. The car arrived to participate at the Intelligent Transport Systems (ITS) World Congress held in Bordeaux to showcase PSA's progress in autonomous technology as well as in V2X communication. The journey between the French cities were made entirely autonomously including changing lanes to overtake slower vehicles, although a driver supervised the operation and were ready to regain control of the vehicle. The vehicle was also equipped with systems for V2X communication which provide safety features like warnings of pedestrians and other potential hazards transmitted from preceding vehicles and infrastructure.

The autonomous drive between Paris and Bordeaux happened just a few months after PSA in July, 2015, received approval to test its self-driving technology on public roads in France. PSA is the first carmaker to be granted such a permission in France. Since October, 2015, four Citroën C4 Picasso modified with self-driving technologies have so far travelled more than 20,000 km in autonomous mode in France. After the ITS World Congress, PSA also received permission to test its autonomous cars on authorized road stretches in Spain and has performed a test drive loop from Paris to Vigo and Madrid in Spain before returning to Paris via Perpignan, Marseilles and Lyon - a journey of over 3000 km.

In April this year, PSA did yet another test run with two Citroën C4 Picasso prototypes which drove autonomously (Level 3) from Paris to Amsterdam. The initiative occurred at the same time as the EU transport ministers and European car manufacturers attended an informal summit on autonomous driving in Amsterdam. The ministers got the opportunity to test drive both PSA's as well as other carmakers self-driving prototypes.

In 2015, PSA was the leading French patent filer for the ninth consecutive year. By then, PSA had filed more than 130 patents related to autonomous vehicles. The patents have been particularly focused on HMI, ADAS and adaptations for interior equipment.

11.15.5 PSA's position in the autonomous car development

PSA is not among the automakers that offer the most expansive semi-autonomous technology but it has nevertheless decided to target the development of autonomous cars. Although PSA is not leading the development, it is taking autonomous technology seriously as indicated by the road-map it has put together for the group's incremental approach to autonomous driving. PSA has showed that it anticipates changes in mobility patterns among people and is trying to respond to those changes as evident by the Push to Pass plan. The group is apparently taking an holistic approach to a future with autonomous vehicles by looking into trends as well as various technologies, including HMI, increased connectivity to mobile networks and V2X communication.

PSA's initiative in self-driving vehicles accelerated after receiving the permission for testing on French roads in July, 2015. Since then, the group has come relatively far in its testing of autonomous cars. However, the group is taking a somewhat cautious approach with the Highway Chauffer as the final scheduled step on its road-map to autonomous driving.

An interesting aspect of PSA is that current prototypes featuring Level 3 autonomy is based on the Citroën C4 Picasso model rather than any of the more luxurious DS models. This indicates that the group is serious with its plan to roll out autonomous technology in affordable models.

11.16 Google

In October 2015, Google created Alphabet as a parent brand over all its subsidiaries and operations. Alphabet is currently taking turns with Apple regarding ownership of the position as the most valuable public trading company in the world. Alphabet's revenues in 2015 amounted to almost US$ 75 billion which (as usual) primarily came from advertisement services offered by Google.

One of the reasons behind the restructuring along with the creation of the name Alphabet was to relieve the brand Google from associations with other business areas than internet service. As a result of that, the Google subsidiary behind the development of autonomous technology, Google X, also changed name and is now denoted with a simple X. A lot of the operations at X are undisclosed to the public but the company is known for various creative initiatives. The projects at the subsidy are at a research and development stage and include for instance Google Glass and Project Loon. In particular - at least for this report - the company has started an extensive project for development of autonomous vehicles.

For the sake of clarity, this report will refer to the research and development efforts being made in autonomous vehicles at "X "as being made at "Google". The reasons for this is that Google was part of the original name when the project started, the department is essentially the same except for the change of name and finally because Google is by far the name that is most associated with the company's advancements in driverless technology.

11.16.1 Google's approach to autonomous cars

In 2009, Google decided to start a project in driverless cars lead by Sebastian Thrun who had supervised the Stanford team that won the 2005 DARPA Grand Challenge. The company put together a specific team, including newly employed Chris Urmson who had also participated in the DARPA challenges for Carnegie Mellon University in 2004-2007. Chris Urmson lead and was the outside face for Google's autonomous car project until August 2016 when he left the company The team's vision was stated to be to improve people's lives by transforming mobility.

Google's self-driving car project can be divided into three phases. During the first two years from 2009-2011 the goal was to drive 100,000 miles on public roads as well as 1000 miles on interesting roads to understand the breadth of the challenge of creating a self-driving vehicle. In the second phase from 2011-2013 the team focused on mastering highway driving before it started to target surface street driving in the third phase in 2013 which is still ongoing.

Once the team had realized that the development of autonomous cars actually is feasible, it started to consider how such a product should function and what level of autonomy it should have. The team developed a highway autopilot that made the car do most of the driving but relied on the driver to take over control when the system failed to understand a situation. The team then picked about 140 employees at Google to test the system. Although this test indicated to the team that people, or at least Google employees, are interested in autonomous cars it also highlighted a problem. Despite the team's effort to tell the test drivers that its highway autopilot system was just a prototype and that it sometimes fails, the test subjects still behaved in an irresponsible way. The drivers got so used to the system working smoothly that they stopped staying alert to hazards. Some drivers for instance reclined their seats far back when the highway autopilot was engaged. A particular driver removed attention from the road for several seconds while searching for a laptop and a charging cable in the back seat to charge the phone with. After these problems had surfaced, Google made the decision to start targeting highly autonomous vehicles without any intermediary steps (corresponding to an SAE Level 4). This aim is quite unique for Google since most automakers are pursuing an incremental approach by continuously developing upgrades to their ADAS packages for each new car model or by sending out software updates over-the-air.

By targeting the development of fully autonomous cars, Google wants to transform mobility and is putting much attention to the safety benefits of self-driving vehicles. During Google's test drives, its cars have captured a lot of irresponsible behavior among other drivers in its camera and lidar data. This includes vehicles driving against the direction of traffic, cars parked in the middle of the road and vehicles running against red light. Chris Urmson has said that after having witnessed all these dangerous situations, he thinks self-driving cars cannot hit the market soon enough.

Another reason behind Google's determination to develop fully autonomous cars is to improve mobility among people who are not able to drive, including elderly or disabled people. In 2012, Google's self-driving car project received a lot of attention through a video commercial that featured a man whose vision was 95 percent gone and hence lacked the ability and freedom of driving by himself. The man got to ride in one of Google's Prius test vehicles while it cruised along in autonomous mode and he expressed the significant impact such technology would have on his everyday life.

Chris Urmson has publicly stated that Google is not interested in building cars on its own. Instead, the company seeks partnerships with automotive manufacturers and has, already collaborated with first tier suppliers to build its prototype vehicle.

In May, 2016, Google announced a partnership with FCA although the collaboration seems to be more of a vehicle order than an actual partnership. Google has bought 100 units of the 2017 Chrysler Pacifica Hybrid along with the automaker's expertise in vehicle engineering to adapt the cars to autonomous driving. Google has previously been in talks with GM but they were unable to agree on which party would own the rights to the technology and a partnership therefore failed to materialize.

11.16.2 Google and autonomous technology

Google has been testing technology for autonomous driving for the past six years. At first the company only used modified cars, especially the Toyota Prius but also the Lexus RX450h SUV and Audi TT, as test vehicles. However, in 2014 Google developed an electric prototype car in collaboration with Roush and some other established automotive partners and first tier suppliers (including: Bosch, Continental, FRIMO, LG Electronics, Prefix, RCO and ZF Lenksysteme). The prototype has been specifically built for autonomous driving and has since its construction been tested on streets around Google's headquarters in Mountainview, California, and in Austin, Texas.

Figure 33. Google autonomous prototype

Source: Alphabet Inc.

Google is currently testing 34 prototype vehicles and 24 modified Lexus RX450h SUVs in Mountainview in California, Austin in Texas, Phoenix in Arizona and Kirkland in Washington. The basic principles in terms of sensors and software logic behind the modified vehicles and the prototypes are the same although the prototype is built with the single purpose of autonomous driving which enables some advantages in performance. The prototype has for instance a rounder shape to increase sensor views of the environment and redundant safety systems for steering and braking as well as a custom built computer.

Perhaps the prototype's most conspicuous feature is the lack of steering wheel as well as throttle and brake pedals. It simply has a two-passenger compartment with one start and one stop button and a screen that shows the route. However, current regulation prohibits Google from testing self-driving vehicles in a public environment without a human who is able to take control of the vehicle in an emergency. All test cars have therefore been equipped with modularized manual controls (i.e. pedals and a steering wheel) that can be removed for nonpublic testing. For testing on public roads, Google has specifically educated safety drivers who can take over control of the vehicle if necessary and are responsible for incidents. Even if a safety driver deems it necessary to regain control of the car, the data from the situation is registered and can be used as input in a test where the car's behavior can be simulated showing what would have happened if the driver did not take over control.

The system for controlling both the modified vehicles and the prototypes relies on radars, ultrasonic sensors, cameras, GPS, digital maps and a Velodyne HDL-64E lidar mounted on a spinning axis on top of the vehicle. The positioning of the lidar has made Google's test cars rather eye-catching and added to the project's publicity. The sensors on the prototype can detect objects up to 200 yards (180 meters) away. Furthermore, the test cars have a speed limit of 25 mph and include safety features such as waiting an additional 1.5 seconds after a traffic light has turned green since a lot of accidents take place in that time frame. To enhance its prototypes' cooperation with pedestrians and cyclists, Google has recently equipped the vehicles with a sound system that imitates the sounds of a combustion engine revving up or slowing down. Google has also equipped the prototypes with a horn capable of signaling two different sounds - a loud and strong signal for emergencies and a rapid signal sounding twice to obtain other drivers' attention.

As of May 31, 2016, the fleet of Google's test cars has driven more than 1.6 million miles in autonomous mode and over 1.1 million miles in manual mode. The cars have logged data from those test drives in order to learn from the experience and improve the technology performance.

Up until 14 February, 2016, Google's test cars had not been involved in any accident that had been caused by the autonomous technology. However, on Valentine's Day this year, one of Google's test cars bumped into a bus while attempting to change lanes. The incident happened while the prototype car had a speed of about 2 mph and there were no injuries on any person involved. The prototype car had come to a standstill in the rightmost lane because of two sand bags blocking the right part of it. The vehicle realized that it had to change lanes to get around the sandbags and waited for the right moment to do so. When the vehicle saw the bus approaching from behind in the adjacent lane it figured that the bus driver was going to stop because there was very little room for the bus to fit beside the Google car. The bus driver on the other hand saw the gap between the test car and the vehicles on the left and thought it would make it through and kept driving (subsequent analysis made by Google shows that there was about a foot of space so the bus would probably have made it although it had been tight). Due to the test vehicle's erroneous assumption, it attempted to change lanes and scraped into the side of the bus. After the incident Google used data of the situation to train the software not to do the same type of mistake again.

Despite the minor severity of the accident it showed that Google's self-driving vehicles are still prone to errors. It also highlighted the complexity in driving since assumptions of other vehicles’ behavior are not always correct. Furthermore there are numerous occasions when the test vehicles would likely have inflicted accidents if the test drivers had not intervened. Google's self-driving cars are thus not ready for commercialization yet.

So far Google's fleet of autonomous test vehicles has mostly been tested in relatively undemanding weather conditions. However, that is about to change as Google earlier this year added Kirkland, Washington, to its test locations because of the city's wet climate and hilly terrain. Google has also started test drives in Phoenix, Arizona, to see how the cars' sensors handle large amounts of dust in the air and hot temperatures. Google has also decided to establish a technology development center for autonomous driving in Novi, Michigan, not far from Detroit. A reason behind the location for the center is its proximity to several of Google's current collaboration partners.

As a result of the Google Maps division, the company already has an advantage in available mapping technology as well as a bank of mapping data to use with the autonomous vehicles. Google Maps was in 2015 the sixth most popular app for smartphones in the US with almost 88 million average unique users each month.

Google has also developed Android Auto which is a smartphone projection standard to connect with regular cars' infotainment systems. The built-in display shows applicable apps and leverage on the smartphone's connectivity to enable features like navigation through Google Maps as well as phone calls and music streaming.

11.16.3 Google Chauffer software

The software Google uses for its autonomous vehicles is called Google Chauffer. This software is constantly updated with data from the road stretches covered by the test vehicles, which amounts to about 10,000 miles per week. In addition to this, Google also performs simulation of roughly 3 million miles every day. There are also employees at Google whose work it is to come up with unusual traffic situations to test how the vehicles respond to them. However, despite these efforts, there are still an infinite amount of situations that can occur and it is therefore impossible to train the software for every scenario it can encounter. To deal with this, the Google Chauffer has a system called anomaly detection which recognizes the novelty of an unusual situation and takes extra precaution by coming to a halt and let whatever is going on play out before the car continues driving. The anomaly detection system has for instance had to dealt with the encounter of a woman in a wheelchair chasing a duck in the middle of the road with a broom.

The logging of data and the simulation do not only serve to enhance the software but also to quantify how well the cars are performing in specific circumstances, such as driving in good or bad weather, on freeways or in residential areas. This can be useful to determine when the cars are safe enough to be used on the roads without a supervising human. Chris Urmson recently described Google's test vehicles as a bit too paranoid. They tend to be overly cautious when approaching objects difficult to identify, like debris or shadows. He said that his team is currently working on making the cars drive more smoothly while maintaining a reasonable amount of paranoia for safety.

The self-driving cars' software follows some norms for dealing with the problem of choosing which object to hit in a scenario where only bad outcomes are possible. The software is programmed to first and foremost avoid hitting vulnerable road users such as pedestrians or cyclists. Secondly it tries hard to avoid hitting moving objects on the road and lastly it avoids static objects such as a car parked next to the curb. For instance, the cars follow the rule that it is five times worse to hit a pedestrian than to hit an oncoming vehicle straight on. These norms do not cover all possible situations since the software is not yet sufficiently sophisticated to correctly identify all the objects the sensors detect. An additional way in which Google tackles the problem of choosing between only bad choices is to make sure the vehicles end up in such situations as seldom as possible. That is also why the cars have safety features such as waiting an additional 1.5 seconds after a traffic light has turned green before accelerating.

11.16.4 Google's position in the autonomous car development

Google is the actor that has pursued the most ambitious initiative in autonomous car development so far. It has done more testing than any other actor and is also taking a different approach than incumbent automakers by targeting fully autonomous cars instead of developing increasingly sophisticated ADAS.

A problem for Google is the current US regulations that restrict the use of fully autonomous vehicles on public roads. However, there are indications on that this situation is about to change. In February, 2016, NHTSA explained in a letter to Google that the organization is going to change its view on what party can be seen as the driver of Google's test cars. Google had requested that the software that controls the cars, the AI, by interpretations of the provisions in the Federal Motor Vehicle Safety Standard (FMVSS) should be seen as the actual driver of the car. In the letter, NHTSA approved several of Google's requests for interpretation. However, some of the paragraphs could not be interpreted in Google's favor and thus will require changing of rulemaking or, to speed up the process, be resolved through the means of exemption petitions which Google was encouraged to file. The FMVSS indicates the need for steering wheel and brake and throttle pedals as well as other controls in a car which prohibits Google from publicly testing a car without such features. The letter from NTHSA does not solve all the issues and does not change any rulemaking, it only provides guidelines. Nevertheless, it is a step in the right direction for Google and any other actor that wants to make a Level 4 autonomous car in the USA.

A factor that speaks in favor of Google is its significant expertise in software. Since software development, and particularly development of AI, is one of the major issues to overcome to create autonomous cars, Google's large investment in its self-driving car project makes sense. Furthermore, the company's extensive testing has given it an edge to other actors pursuing a development of autonomous cars.

11.17 Apple Inc.

Apple was founded in 1976 by Steve Jobs and Steve Wozniak who had the vision to make ordinary people use computers which was not uncontroversial by that time. Since then, Apple has not been afraid to take risks and enter new markets with a consistent focus on the user-friendly aspect as well as elegant design. The company' story has not always been one of success, though, especially not in the early nineties. However the turnaround marked by the introduction of the iPod in 2001 and the subsequent iPhone (Apple's bestselling product) allowed the company to attain the position as the world's most valuable public trading company in terms of market capitalization. Apple reported revenues of nearly $ 234 billion for its fiscal year ended September 26, 2015 (an increase of 28 percent from the preceding year).

11.17.1 Apple's vehicle project

Apple is pursuing a very secretive electric car project that allegedly started in late 2014 and goes by the codename "Titan". Apple has released few clues to any details about the project but it can be stated beyond all doubt that the company is doing some kind of vehicle project and that it very likely is an electric vehicle Apple is working on. The best indication to Apple's Titan project is the large number of people involved in the automotive industry that have been hired by Apple over the last two years - including people from Tesla, Ford, GM, Fiat Chrysler Automobiles and Autoliv.

There is information that suggests Apple has been in talks with charging station companies which indicates that it is indeed working on an electric vehicle. There are also rumors about Apple working on autonomous technology for its vehicle project, although recent information suggests that the vehicle initially will not feature such technology. Apple is said to have contacted the GoMentum Station proving ground for autonomous and connected vehicles in California. Apple allegedly wanted a secure facility to test its vehicles. Regardless of whether an autonomous car is targeted at Apple or not, it is safe to assume that the company is investigating and investing in the technology.

It is estimated that Apple has as much as about 1800 people working on the project. The target date for launch of the product is according to various sources sometime in 2019 or 2020 although there are indications on this timing being too optimistic.

The contract manufacturer of automobiles Magna Steyr has allegedly been in talks with Apple on assisting in building its vehicles. Some sources also suggest that Apple has been in talks with Daimler and BMW but that it has not ended in any partnerships so far, possibly due to disagreements as to which party will have ownership over data.

In May this year, Apple invested $ 1 billion in the Chinese ride-hailing company Didi Chuxing. Didi Chuxing offers vehicles and taxis for hire through a smartphone based platform in China where it has more than 80 percent of the market share.

Something that speaks in favor of the success of Apple's potential development of an autonomous vehicle is the fact that the company has previously been successful in entering new markets as evident by the iPod, the iPhone and the Apple Watch and to some extent also the Apple TV. A car is arguably more different from computers than the above mentioned products but on the other hand, for self-driving cars to work they need very sophisticated software which is something Apple is good at developing. Another interesting aspect is that one of Apple's main selling points has always been ease of use and the company has been a pioneer in developing intuitive interfaces between user and technology. Apple thus might have the right know-how to develop HMI for future autonomous vehicles. The company has already developed CarPlay, available on selected cars, which allows the car's infotainment system to connect with and utilize a passenger's iPhone. The phone apps are shown on the on-board screen which makes it easier for the driver to access them. Apple also has an extensive mapping business that could be an important advantage for the development of an autonomous vehicle.

11.18 Uber Technologies

Uber Technologies was launched in 2009. Its business model is based on ride-hailing and leverages on the fact that some car-owners can use their spare-time to transport people who do not want to or are unable to drive. Just like other sharing economies, Uber lets supply that otherwise would go unused meet demand for the service in an effective way by the use of a smartphone based platform. In this case, it results in relatively inexpensive fares compared to other alternatives for private transportation. Uber does not hire its drivers, nor does it own the fleet of vehicles used to transport people. Instead Uber simply provides a platform in the form of an app where a rider can order a car to pick them up. The app also facilitates the payment from the rider, part of which the driver receives and part of which goes to Uber. Uber's drivers are seen as independent contractors which means that Uber does not have to pay any part of their drivers' taxes; neither does it have to offer benefits to the drivers unlike regular taxi service companies. By the end of 2015, Uber's service covered 75 percent of the US population, had 1.1 million drivers and was active in more than 360 cities worldwide.

11.18.1 Uber's approach to autonomous cars

Already in 2014, Uber CEO and co-founder Travis Kalanick said that Uber will eventually replace all its drivers with self-driving cars. The statement is not very surprising since autonomous cars could potentially disrupt Uber's entire business if the company does not respond to the development. Uber's business model is unique compared to traditional ride-hailing services like taxi since it does not employ its drivers or invest in cars and thus saves a lot of money. Nevertheless, autonomous cars can have a just as disruptive power on Uber as on the taxi-industry since both parties rely on human drivers. The implication is that Uber faces serious threat from any actor interested in developing a self-driving vehicle and offer it to customers as a car-sharing or ride-hailing service. Kalanick has said that Uber has to work on self-driving cars or it will end up like the slow-moving taxi industry which it is currently disrupting.

The baseline for Uber's investment in autonomous cars is to ensure its survival but the company likewise also sees a large opportunity in this market. Kalanick has said he believes car ownership can become rare once Uber's service become truly inexpensive. Uber drivers currently get more than 75 percent of each fare. If the driver is no longer a part of the variable costs, it allows significantly lower fares for the service, possibly to a level that renders car ownership economically questionable.

Uber wants to leverage on its platform for mobility service that is already well established among the American people and in several other countries as well. The service offered can essentially be the same, just without drivers present in the cars. Uber believes autonomous technology will result in more affordable and accessible transportation in addition to the usually advocated benefits of increased safety and less congestion.

To summarize, Uber's peril is that its entire business can become obsolete when drivers are no longer needed unless the company attains its own fleet of self-driving cars. On the other hand, since at least 75 percent of Uber's income from fares goes directly to the drivers, there is a substantial amount of money Uber can save by having self-driving cars instead of human drivers. In other words, Uber has a lot to win by launching autonomous vehicles but it also has a lot to lose if it falls behind its competitors.

11.18.2 Uber and autonomous technology

Uber has not been very open with its progress in autonomous technology. Neither has it been pursuing development of autonomous cars for very long - after all, it is a young company that was founded the same year Google started its self-driving car project.

In February, 2015, Uber announced that it would enter a strategic partnership with Carnegie Mellon University (CMU) with the ambition to create autonomous technologies. However, the partnership was more of a large-scale hiring for Uber which quickly employed 40 researchers and engineers from Carnegie Mellon's National Robotics Engineering Center (NREC) including its director, Tony Stentz. This was a move that had a rather severe impact on the university but was very important for Uber since it prior to the hiring had virtually no expertise in autonomous technology at all. Simultaneous with the start of the hiring process, Uber established a research site called Uber Advanced Technologies Center located close to the CMU campus in Pittsburgh. The center targets its research towards development of the three overlapping areas of mapping, safety and autonomy.

Uber has not only hired people from CMU but also targeted Google employees, especially from its mapping division. Uber believes high-definition maps will be key to develop driverless vehicles and is therefore enhancing its mapping department alongside the self-driving car division. Uber has also initiated a partnership with the University of Arizona that will put particular focus on enhancing mapping and optic technologies to aid the development of an autonomous car.

The first tangible indication of Uber's progress regarding self-driving cars came in May 2015 when a research vehicle with a top-mounted rotating lidar was spotted and photographed in Pittsburgh. According to Uber, the vehicle was part of its Advanced Technology Center but Uber was reluctant to acknowledge it as a self-driving vehicle.

It was not until May 19, 2016, that Uber revealed the first official photo of its research vehicle for autonomous driving. The vehicle was a modified Ford Fusion driving around in Pittsburgh where Uber has received permission to test self-driving cars publicly. The research vehicle collected mapping data while also testing its autonomous driving systems with a test driver at the wheel to ensure safety. The car had a range of sensors including radars, lidars and high-resolution cameras. The prototype is able to accelerate, brake, steer and perform other simple functions autonomously. If it encounters a problem, the system switches off and hands back control to the test driver with a loud beep. Uber has said that real-world testing is crucial to its development of self-driving cars and that Pittsburgh is a suitable yet challenging place for testing. The city features various difficult environments for an autonomous car to handle including aging infrastructure, disorganized parking, hilly roads and rainy and snowy weather. In the beginning of 2016, Uber announced that it will open a new research facility in Pittsburgh to enable further testing of autonomous technology. The research facility will contain temporary roads as well as housing and parking spaces to simulate a real driving environment.

In March, 2016, a rumor surfaced about Uber shopping around for cars and particularly that it had placed an order for 100,000 Mercedes-Benz S-Class sedans. Both parties have declined to publicly comment on the rumor. In July, 2016, Uber acquired the startup Otto which works with autonomous systems for highway driving with heavy trucks.

In August 2016, Uber announced a partnership with Volvo Cars. Uber has so far acquired a few Volvo XC90s which will be equipped with a system for autonomous driving and deployed in Pittsburgh by the end of the month. Customers in Pittsburgh will be able to summon the self-driving vehicles through a smartphone app and use them for ride-hailing. Safety drivers will, however, be ready to cease control of the vehicles in case of failures. By the end of the year, Uber will have acquired and launched 100 XC90s on the streets of Pittsburgh. The SUVs will be equipped with an array of sensors including: cameras, lasers, radar, and GPS.

Figure 34. Volvo Cars XC90 equipped for Uber's autonomous ride-hailing program

Source: Uber Technologies

11.18.3 Uber's position in the autonomous car development

Since Uber has been rather quiet with its progress in developing an autonomous car it is hard to determine its position for the future. What can be said, though, is that autonomous cars could have a tremendous impact on Uber's business - an impact that the company has acknowledged and is clearly trying to shape in its favor. Overall it seems like Uber has responded well to the trend of self-driving cars and states that it sees it as a large opportunity for the company although admitting that it also constitutes a large threat.

It is somewhat ironic that a start-up tech company like Uber - that is heavily associated with a controversial business which has attracted the dislike and even open protest among the taxi industry - is now facing a similar threat from even more sophisticated technology. On the other hand, Uber has been careful not to be negative towards or try to slow down the development of self-driving cars. Travis Kalanick has said that Uber is a tech company that won't resist the future like the taxi industry but instead aims to be a part of it. The partnership with Volvo Cars indicates that Uber is indeed making a serious bet on autonomous cars.

Since mobility as a service is widely believed to be one of the major applications of self-driving cars, Uber has an interesting potential to benefit from this. Uber's main strength lies in its renowned brand. Uber already has the software platform and the customer base for autonomous ride-hailing, all it needs is the driverless vehicles. Uber is also used to fight against restrictive regulations and knows how to deal with licensing and security which gives the company and edge towards other actors interested in launching a ride-hailing fleet of driverless cars. This indicates that Uber does not have to develop the cars by itself to be able to benefit from the arrival of autonomous cars. However, how such a collaboration would be constructed and which part would reap most benefits from it is uncertain.

11.19 Baidu Inc.

Baidu Inc. is a Chinese web service company with a distinct focus on the domestic market and most known for its Chinese search engine. Baidu was incorporated in 2000 and today offers many services in addition to the search engine, including Baidu Maps which features digital maps over China, Baidu Baike which is an online lexicon similar to Wikipedia but censored by the Chinese government, a music stream service called Baidu Music, and Baidu Cloud which offers users 2 Tb of free cloud storage. In general, much of Baidu's activities mirror those of Google, including the current investment in autonomous cars.

Baidu gets its revenues essentially from online marketing on a pay-per-click basis. By August 2014, Baidu's search engine made for a 56 percent market share in China. As of January 2016 there are 686 million internet users in China which constitutes the largest internet user population in the world. Baidu also sees opportunity in markets outside China, especially in economies with a growing middle-class like Brazil, Indonesia, Egypt and Thailand but also in Japan. Baidu employs over 46,000 people and in 2015, Baidu's revenues amounted to € 8.96 billion, an increase of over 35 percent from the year prior.

11.19.1 Baidu's approach to autonomous cars

Baidu's interest in autonomous cars took off in 2014 when it announced that it will use its knowledge in artificial intelligence, big data and deep learning to create self-driving vehicles. The company's initiative is thus similar to Google's which also focuses on the business knowledge in software to deliver the breakthroughs necessary for full autonomy. However, Baidu is not targeting the kind of wheel-less prototype vehicle Google has developed. Baidu wants to allow people to drive by themselves if they so desire.

Baidu has said that it will not make self-driving cars commercially available for private consumers but instead cooperate with authorities to provide a fleet of driverless vehicles to be used on a service-basis. The plan is to initially operate the vehicles on fixed routes or in specific urban areas to minimize the amount of difficult situations the vehicles encounter. China's urban traffic condition is among the most congested and has among the highest accident rates in the world. Both Baidu and the Chinese government see driverless cars as a way to improve this situation. Baidu's goal is not to become a car manufacturer but to develop the software necessary for making a car drive on its own.

In June this year, Baidu's president, Zhang Yaqin, announced that Baidu will mass produce electric and autonomous cars within five years. The actual production will be outsourced to a Chinese automaker, yet to be decided. In general, Baidu seems to be open to partnerships with other companies as evident by its collaboration with BMW and that the company has invested in Uber Inc. and Uber China.

11.19.2 Baidu and autonomous technology

For its first test vehicles, Baidu launched a partnership with BMW which delivered two 3 Series Gran Turismo models in 2014. The cars were equipped with self-driving sensors like cameras with varying range and lidar. The software used in the cars relied on Baidu's deep learning algorithms together with its highly detailed digital maps and is called AutoBrain. The cars were for instance tested on Beijing's fifth ring road and other motorways in the city's northern outskirts. The partnership with BMW is indicative of Baidu's goal not to produce the actual vehicles itself but to leverage from the automotive industry's expertise in this area.

Figure 35. Baidu's autonomous BMW Gran Turismo test vehicle

Source: Wall Street Journal

Baidu's main research in autonomous cars is focused on artificial intelligence, deep learning, big data and mapping. The company has three labs under the umbrella brand of Baidu Research, namely: the Silicon Valley Artificial Intelligence Lab, the Beijing Deep Learning Lab and the Beijing Big Data Lab. The research facility in Silicon Valley was opened in May, 2014, and the Big Data Lab two months later while the Deep Learning Lab was established early in 2013. Some of the areas Baidu Research is investigating include image and speech recognition, natural language processing, robotics and big data - all relevant to the development of autonomous cars. To further enable autonomous cars, Baidu has also invested in high definition mapping as well as environment perception and sensor fusion technologies.

In April 22 this year, Baidu announced that it had formed a self-driving car team in Silicon Valley that by the end of 2016 is targeted to reach a total of 100 employees. The team will be a part of Baidu's broader Autonomous Driving Unit and has the goal to research, develop and test autonomous cars. Baidu is looking to employ hardware and software engineers working with various technological areas like machine learning and computer vision as well as robotics and sensors.

In May 2016, Baidu held a press conference with the Chinese city of Wuhu in the Anhui province where they revealed the city's plan to set up a special zone for testing of autonomous cars in which driving of regular vehicles will be prohibited. Baidu's co-founder and CEO, Robin Li, said that he believes China will be home to the world's first city with only self-driving cars. For the next five years, Baidu's autonomous vehicles in the shape of cars, vans and buses will incrementally be adopted on specific roads and in selected zones of the city. However, during the first three years, the vehicles will only be used for testing and not carry public passengers. Eventually the vehicles will be allowed to use the public highways across the city. Baidu has also tested its autonomous cars in a closed research area in Shanghai and has been in discussion with another Chinese city, Guiyang, about adopting driverless vehicles.

As mentioned above, Baidu plans to mass produce autonomous and electric vehicles in five years from now. The company has created a plan for the realization of this goal which includes testing of the cars in ten cities around China with diverse road and traffic conditions as well as various weather. In 2018, Baidu aims to launch its first commercially available autonomous vehicle. It will come in the shape of a shuttle bus that will transport people around a pre-determined route.

11.19.3 Baidu's position in the autonomous car development

Baidu is another actor that is somewhat reluctant to reveal much details of its progress in autonomous vehicles. Despite this, it is safe to say that Baidu is making a significant effort in self-driving vehicles and that it has reached far in a fairly short time. The company has performed testing in various environments and has struck deals with several other actors to accelerate its progress.

Although the technological advancements in China overall lags some year behind the progress in the western world, Baidu is trying to keep up the pace - for instance by taking short-cuts like leveraging on BMW's cars rather than developing own prototypes. Baidu could potentially also invest in technology companies in Europe or the US. Nevertheless, with the possible exception of the Chinese region of Baidu Maps (which has a quality fully comparable or even better than Google Maps), Baidu has no significant advantages from core technologies compared to its international competitors.

Despite the lack of technological advantages, Baidu has a strength in its close relationship to the Chinese government as well as its strong brand among the Chinese population. Since the government as well as the population is interested in autonomous cars to get rid of its pollution, congestion and accident problems, the Chinese market for the technology is believed to be of major importance in the future. This indicates that Baidu's advantages for the Chinese market can be tremendously valuable.

11.20 Supplier and technology company initiatives

An interesting aspect is that most of the automakers get their sensors, computers and other technologies for autonomous features from the same few suppliers. The carmakers then refine the systems to fit their vehicles. Although the same basic technologies are used it does not mean that the semi-autonomous systems in use today act in the same way or have equal performance. For instance, Tesla's highway autopilot is widely believed to be the highest performing on the market even though similar Level 2 autonomous functions can be found in other brands.

The first tier suppliers have traditionally been the companies that provide the automakers with their systems for driver assistance. However, along with ADAS getting increasingly autonomous and thereby more sophisticated, a need for more diverse sourcing has become apparent. Especially when the systems begin requiring some kind of intelligence, the automakers have seen it fit to establish deals with other suppliers. Software developers and semiconductor vendors are now being approached directly by automakers which have lead some companies to realize the car industry as a new potential market.

11.20.1 Autoliv

In 1997 Swedish company Autoliv AB merged with the American supplier Morton Automotive Safety Products Inc. to form the current Autoliv. The company has head-offices in Stockholm and Auburn Hills, Michigan. Autoliv has a main focus on automotive safety and is the world's leading supplier of seat belts and air bags which it delivers to essentially all major car manufacturers. Passive safety has traditionally been Autoliv's strength but the company also offers active safety systems and with the advent of increasingly autonomous cars the company is investing more in this area.

Autoliv is one of the most recent actors to join the race for developing autonomous technologies. The company has started to acquire companies relevant for active safety as well as commencing strategic partnerships or collaborations. Autoliv is for instance working closely with Volvo Cars and the City of Gothenburg in the Drive Me project. Autoliv has developed a new stereo camera and a radar to be used in collision-avoidance systems. The company has now also started to develop the software for object recognition with obstacle detection as a particularly important aspect for future self-driving cars.

11.20.2 Robert Bosch GmbH

The German electronics and engineering Robert Bosch GmbH (commonly referred to as Bosch) is the world's largest supplier of components to the automotive industry measured by 2015 sales. In addition to mobility solutions, which in 2015 constituted 59 percent of revenues, Bosch produces industrial technology, consumer goods, and energy and building technology. Bosch manufactures a range of different automotive components including simple products like spark plugs and wiper blades as well as more advanced systems like brakes, generators, electrical drives, fuel pumps and steering systems. The company has also acquired a strong position in the manufacturing of anti-lock braking systems, traction control systems and electronic stability programs. Bosch also develops ADAS like lane keeping assist, autonomous emergency braking, adaptive cruise control, traffic jam assist and systems for pedestrian detection.

Bosch provides both BMW and Google with ultrasonic and radar sensors and has also initiated self-driving car projects on its own. Back in 2013, a Bosch-owned BMW 325d equipped with a range of sensors was spotted on the roads of Palo Alto in California. Since then, Bosch has been testing autonomous cars in Germany, the US and Japan. By 2020 Bosch wants to launch a highway autopilot that will allow cars to drive autonomously on freeways and similar roads. Bosch has also developed a parking assist that allows the driver to exit the vehicle before parking. The driver has to keep a button on the Bosch smartphone app pressed and stand in proximity to the car, though.

11.20.3 Continental AG

Continental is another leading German automotive supplier. Continental manufactures a range of different components for the automotive industry but has a particular focus on tires, brake systems, powertrains, chassis, vehicle electronics, instrumentation and infotainment as well as networked vehicle communication. Continental's interest in autonomous driving started already in 2007 and the company has since then pursued several research initiatives in this field. In 2012, Continental tested highly automated driving in Nevada for a total of 24,000 km on public roads. The company has subsequently tested its technology in Japan for an additional 5,000 km.

In 2013, Continental announced that autonomous driving will be a core part of its strategy for the future. According to Dr. Elmar Degenhart, Chairman of the company's Executive Board, Continental's engineers are working on six different fields to facilitate autonomous driving, including: sensor technology, cluster connectivity, HMI, system architecture, reliability, and acceptance among consumers. The company aims to enable fully autonomous driving in 2025 through stepwise progress like developing V2X capabilities, developing a traffic jam assist and a system for autonomous parking. Similar to Bosch, Continental wants to develop a highway autopilot corresponding to an SAE Level 3 by 2020.

11.20.4 Delphi Automotive PLC

Delphi is headquarted in Kent, UK, and is one of the largest first tier suppliers of the automotive industry. It has divided its operations into four main business segments under the following titles: Electrical & Electronic Architecture, Electronics & Safety, Powertrain Systems, and Product & Service Solutions. Delphi also manufactures systems for driver assistance and pioneered automotive radar systems as well as integrated navigation systems.

Delphi manufactures many of the computer units utilized in semi-autonomous systems. The company has played a part in the development of a gesture control system for BMW and in V2V communication technology for Cadillac. Delphi's approach to autonomous technology is to make it affordable by reducing the required systems' complexity for instance by integrating many ECUs into one multi-purpose controller.

In 2015, a Delphi research vehicle equipped with radars, lidars, cameras, GPS, intelligent software and several ADAS drove large part of the 5,500 km stretch between San Francisco and New York in autonomous mode. Delphi is also putting a large focus on HMI by creating graphics that indicates to the driver what the car is seeing, doing and planning while in autonomous mode.

11.20.5 ZF TRW Automotive Holdings Corp.

In May 2015, ZF Friedrichshafen AG acquired TRW Automotive to create one of the world's largest tier one suppliers of the automotive industry. ZF TRW is a major provider of both active and passive safety systems to virtually all large vehicle manufacturers worldwide. It has developed a range of ADAS including adaptive cruise control, lane keeping assist, lane change assist, blind spot monitor and autonomous emergency braking to mention some of the more important.

ZF TRW believes the merging of active and passive safety systems will provide the foundation for autonomous cars and believes highly automated vehicles will emerge on the roads in 2020 to 2022. ZF TRW believes it can leverage from its already existing array of sensors, processors and actuators along with its progress in software capacity and HMI devices in the development of autonomous vehicles. The company has for instance developed a highway autopilot corresponding to an SAE Level 2.

11.20.6 Mobileye

Mobileye, launched in Israel in 1999, is a technology company that is active in the development of ADAS which rely on computer vision and system on a chip (SoC) technology. Mobileye has developed a processor chip called EyeQ which is specifically adapted to handle image processing that enables collision mitigation and other safety systems in vehicles. Mobileye's software is for instance able to detect other vehicles, cyclists, pedestrians, animals and debris. It can also understand traffic signs, traffic lights and identify lane markings. One of the key aspects of Mobileye's system is that all the capacity is enabled by a monocular camera which translates to a low cost.

One of Mobileye's most notable customer is Tesla which integrated the EyeQ chip in its Model S to enable the Autopilot. However, Tesla and Mobileye ended their collaboration in August 2016. Mobileye recently established a partnership with BMW and Intel to jointly develop a standard platform for autonomous driving which BMW will use to accordingly create a fleet of fully autonomous cars by 2021.

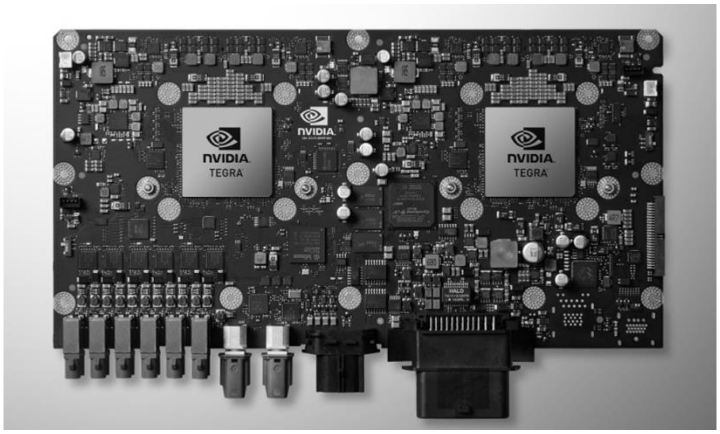
Mobileye is in collaboration with STMicroelectronics currently developing a fifth generation of its processor chip, called EyeQ5, which will serve as a central computing platform for sensor fusion. The EyeQ5 will have a capacity of 12 trillion floating-point operations per second (Tflops), is targeted to fully autonomous cars and is planned to be released to the market in 2020.

11.20.7 Nvidia Corporation

The American technology company Nvidia is not a traditional supplier of the car industry but has nevertheless emerged as an important player in the development of autonomous vehicles. Nvidia was founded in 1993 and originally focused on designing graphics processing units (GPUs) for the gaming market. The company still gets most of its revenues from the gaming industry but has in recent years seen an increased interest from the automotive industry. Initially this interest led the company to develop infotainment system components to several automobile manufacturers like BMW, Honda and Bentley. Later this evolved into a business focusing on the development of technology and software for ADAS. The automotive sector is currently the fastest growing revenue stream for Nvidia.

During the 2015 CES in Las Vegas, Nvidia revealed a new computer called Drive PX aimed at providing ADAS and autonomous driving by deep learning. The computer had a capacity of 2.3 Tflops and was welcomed by the automotive industry. However, the carmakers requested even higher capacity which led Nvidia to start development of an enhanced version called Drive PX 2. The upgraded version, which will have a computing performance of 23 Tflops, was revealed during the 2016 CES and will be launched to the market in the fall of 2016. The reason behind the strong performance is that Nvidia's system relies on GPUs instead of conventional CPUs.

Figure 36. Nvidia Drive PX 2



Source: Nvidia

Up until now, self-driving vehicle prototypes have filled the trunk with several computers to handle the large computing power necessary to deal with the vast amount of data collected by the sensors. Drive PX 2 allows the same computing power in a small box. Volvo Cars was the first company to place an order on Nvidia's computer. Drive PX 2 will be integrated in the Volvo XC90s that will be used for the Drive Me project in Gothenburg starting in 2017.

Nvidia is also targeting deep learning and has developed a sort of standard package that the automakers then can enhance and adopt to their vehicles. The company believes that its systems can become significantly better than humans at perceiving the environment but is reluctant to state when this transition will occur. Nvidia believes autonomous cars will be an important part of the future automotive industry.

11.20.8 Velodyne LiDAR

Velodyne LiDAR is a part of Velodyne Inc. that was founded in 1983 and initially only focused on audio technology. The silicon-valley based company began investigating laser technology in 2005 when it participated in the DARPA Grand Challenge. The company developed a laser system called HDL-64E LiDAR for distance-measuring that subsequently was used by all of the top teams in the 2007 DARPA Urban Challenge as a primary mean for perceiving the environment. The company's lidar technology has since then been integrated in most advanced test vehicles for autonomous driving. Google's self-driving car project was one of the first adopters of the technology. The technique also enables precise 3D mobile mapping and has been used for such applications by HERE, Baidu and TomTom among other companies. Earlier this year, Ford announced that it will use Velodyne's Solid State Hybrid LiDAR Pucks in its expanding fleet of autonomous research vehicles.

The Velodyne HDL 64E remains the company's highest performing product with 64 laser channels that cover 26.8° of vertical field of view and 360° of horizontal field of view thanks to its spinning axis. The lasers fire about 4000 times per revolution meaning that the horizontal resolution is much higher than the vertical. Furthermore, the lidar spins at between 300-900 rpm (5-15Hz) and gives a refreshed depiction of the environment for each turn.

Figure 37. Velodyne HDL-64E LiDAR

Source: Velodyne

11.21 Other actors

The field of autonomous cars constitutes a very large area that spans over many different types of research. It follows that there is a vast amount of actors relevant in the field. The players with what appear to be the most important and interesting activities can be found above but in addition to them, some additional actors deserve to be mentioned. This includes smaller actors in the automotive industry, mobile network providers, mapping and GNSS providers and other tech companies.

11.21.1 Automotive industry

Subaru has showed some interest in the development of autonomous cars. In 2017, the company will launch a new traffic jam assist system that will aid the driver in congested traffic in speeds below 40 mph (64 km/h). The system will start and stop automatically as opposed to the currently available system that requires the driver to accelerate the car after it has come to a stop. The new system will also feature steering around curves which is not available today. By 2020, Subaru has said that it will introduce a highway autopilot with automatic steering and lane changing. These systems will leverage on Subaru's current camera-based Eyesight system for safety together with radars and GPS.

Mitsubishi Motors Corporation is another relatively large manufacturer of automobiles that has showed a positive attitude to the development of autonomous cars. At the Geneva International Motor Show in 2016, Mitsubishi debuted its eX concept vehicle which is an electric compact SUV. The concept vehicle features semi-autonomous driving on expressways with automatic control of the car's speed and is capable of maintaining as well as changing lane. The concept car also envisions an autonomous valet parking assist system that relies on connectivity to public parking lot's online systems to find the location of an empty space.

Other automotive manufacturers that have shown interest in autonomous cars include Aston Martin, McLaren, BYD Company, SAIC Motor Corporation, Dongfeng Motor Corporation, Geely, Tata Motors and Koenigsegg.

In addition to the incumbent automobile manufacturers there are some startups that also are pursuing interesting projects with autonomous vehicles. One of the best known examples is the startup called comma.ai which is led by entrepreneur George Hotz (who is known for hacking an iPhone) and aims to develop self-driving car technology base on deep neural networks. Zoox is another startup business that aims to build a fully autonomous taxi car using an acquired research concept vehicle from Swedish university KTH. A spun-out of MIT called nuTonomy is aiming at developing another fully autonomous taxi. nuTonomy uses Mitsubishi iMiev electric cars and market available sensors and focuses its in-house activity on developing the software intelligence required to make the car autonomous.

Worth mentioning is also Denso which as one of the largest first tier suppliers provides the automotive industry with ADAS and other safety systems. Denso has a close relationship to Toyota which owns about 25 percent of the supplier. Denso is not dismissing the autonomous trend but is not pursuing development of automated systems as heavily as some of its competitors. The supplier believes highly autonomous cars will not be established before 2030 and is thus taking a more cautious approach than other more optimistic suppliers. In addition to Denso, there are several large automotive tier one suppliers that have not been included in this report. The underlying reason is that they have a somewhat hesitant interest in autonomous driving. Nevertheless, these suppliers are likely to be affected and can possibly also play a role in an autonomous future.

11.21.2 Technology companies

Tech companies relevant for the development of autonomous cars can be divided into three main groups including: providers of connectivity and communication, semiconductor developers and mapping companies.

An especially relevant actor in the field of connectivity and communication is Ublox that is a major designer of GNSS receivers with advanced dead reckoning. Ublox is also active in the field of V2X through development of chips and modules for wireless communication based on short range or cellular networks. Another important actor in V2X communication is Cohda Wireless which has become a market leader provider to the first tier suppliers as well as to OEMs directly with high quality V2X technology and in particular devices for dedicated short range communication. Cohda Wireless has done over 18,000 km of V2X trials and now offers complete solutions for the technique with both road side and on board connectivity hardware as well as software for both access and applications. A third company active in the same field as Cohda Wireless and Ublox is Israeli Autotalks which, however, is more dedicated to V2V communication in particular. WirelessCar is yet another interesting developer of telematics solutions to the automotive industry.

Autonomous and connected cars also demand an increased internet coverage which is why networking equipment providers like Swedish Ericsson, Finnish Nokia Networks, American Cisco and Chinese Huawei can play important roles in an autonomous future.

NXP is one of the leading developers of semiconductors used in the automotive industry. In 2016, NXP revealed a computing platform for autonomous cars called BlueBox. The platform is designed to facilitate the sensor fusion of camera, radar, lidar and ultrasonic data input. BlueBox has already been shipped to at least four automakers for testing of autonomous cars. Another large developer of semiconductors is Intel which recently teamed up with BMW and Mobileye to jointly develop a platform for autonomous driving where Intel will supply the processing power in the form of chips. Intel has also made strategic acquisitions to better position itself in the IoT market- in 2015 it bought the semiconductor company Lantiq and in 2016 it bought Yogitech (which specializes in functional safety of semiconductors) and the computer vision startup Itseez.

In the third category adjacent to autonomous technology, mapping, there are a few major active players. HERE is one of the largest providers of digital maps. It was previously owned by Nokia but has now been acquired by a German consortium consisting of Daimler, Audi and BMW (see the final paragraph under Mercedes-Benz and autonomous technology above for more information). TomTom, AutoNav and NavInfo together with Google and Apple are other large players in this field.

11.22 Car manufacturers that avoid autonomous cars

Suzuki has revealed no plans to invest in autonomous cars - in fact the company seems to, at least publicly, disregard the autonomous trend. More notable is perhaps that Mazda as the world's seventeenth largest passenger car manufacturer officially has stated that it will not pursue development of autonomous cars. The two brands are the only of the top 20 passenger car manufacturers that are not investing in the new technology. Daihatsu does not seem to be doing much either but it is on the other hand a majority-owned subsidiary of Toyota which in turn targets autonomous technology through other brands. A similar situation characterizes Volkswagen's subsidy Porsche which has publicly stated that it has no interest in self-driving cars in a near future. Ferrari has also been very negative towards integrating autonomous technology in its cars.

12 Regions for development of autonomous cars

There are several regions where autonomous cars are being developed. The regions are strongly connected to the automotive industry clusters around the world, with the major automobile manufacturers' locations as bases for the development. However, due to the high-tech nature of autonomous cars, a lot of research is also performed outside the typical automotive clusters and instead appears in technological research centers.

12.1.1 USA

The USA is currently the region with most research initiatives in autonomous car technology. Especially California has grown to become a hub for the development of highly or fully autonomous cars. The underlying reason for this is that Silicon Valley is the world's leading region for computer technology and software development. This is also the primary location for startup firms trying to develop autonomous technology as well as artificial intelligence in general. Since AI development is at the fundamental core of autonomous cars, many automakers have decided to locate their research facilities in Silicon Valley in the hope that they will be able to pick up on the latest breakthroughs. California also has generous environmental conditions with little precipitation and temperatures above freezing, suitable for early initial testing of self-driving cars.

The US government has also shown a positive attitude to the development of autonomous cars. The DARPA Grand Challenges, for instance, were authorized to award cash prizes by the Congress. More recently, the Obama administration proposed in the beginning of 2016 to allocate $ 3.9 billion over the next ten years to speed the acceptance and adoption of autonomous vehicles. The aim with the proposal is to let federal regulators jointly with automakers and other stakeholders establish policies and regulations for autonomous vehicles. The plan is also to launch pilot programs with connected vehicles. The US government sees autonomous vehicles as a way to reduce the significant amount of traffic fatalities in the nation as well as a way to reduce impact on the environment and make transportation more efficient.

The automakers have called for nation-wide standards and policies in the US. It would be problematic for car manufacturers and for the customers to have different regulations in different states in terms of what features the autonomous cars must have. It is disadvantageous if for instance California allows operation of cars with no steering wheel as long as other states do not.

The USA did not sign the 1968 Vienna convention on road traffic that explicitly states that a human driver must be in control of a vehicle operating on public roads. The USA did however sign the 1949 Geneva convention on road traffic but regulations relating to the driver's responsibilities are less stringent compared to the Vienna treaty and more open for interpretation. Regulation in the US does not necessarily prohibit autonomous cars mostly because state vehicle codes were not written with driverless vehicles in mind. Currently there are seven states that have enacted regulations allowing testing of autonomous cars including: Nevada, California, Florida, Michigan, Hawaii, Washington, Tennessee along with the District of Columbia. However, in March 2016, 23 states had a total of 53 pieces of legislation relating to autonomous vehicles, some of which contradicted each other. Google has called for the US Transport Secretary to be given more authority to decide on nationwide regulations as the current approach with individual states enacting new policies risks creating a patchwork of different legislation across the states.

Los Angeles is one of the pioneers in terms of adapting its infrastructure to fit a future with self-driving and connected vehicles. It has established a Coalition of Transportation Technology that will lay down plans for how the Los Angeles region can become more ready to adopt autonomous and connected vehicles. However, a study made in 2015 revealed that US cities in general are not prepared for the emergence of autonomous cars despite several states passing legislation that allows for testing of autonomous vehicles. For instance, only six percent of the large cities included in the study talked about autonomous vehicles in their long-term plans for transportation.

The US has several renowned universities that pursue research in relevant technologies for autonomous cars. For instance, Stanford, Carnegie Mellon and MIT have all competed in the Grand Challenges. These universities also have collaborations with several automakers with the aim to develop autonomous technology. Moreover, the University of Michigan has created a 32-acre mock city, called Mobility Transformation Center (or informally Mcity), in Ann Arbor specifically for testing of connected and autonomous vehicles. The GoMentum station in Concord, California is an even more ambitious test facility spanning 5000 acres of a former navy weapons station with 20 miles of paved roads. Contra Costa Transportation Authority (CCTA) manages the test ground with numerous automakers, first tier suppliers, technology companies, academia, public agencies and other actors performing research and testing of connected and autonomous vehicles there.

12.1.2 EU

EU has initiated several research projects related to autonomous vehicles investigating platooning, HMI and ADAS technology as well as how urban environments and infrastructure will be impacted by self-driving vehicles. EU is in general positive to autonomous vehicles and discussions to establish amendments to the 1968 Vienna convention on road traffic - which currently states that a human must control the vehicle - are ongoing. A problem for EU is that individual states might want to speed the development of their own projects and be the first to launch a self-driving vehicle which might hinder collaboration across borders.

EU has voted in favor to make the roadside emergency assistance telematics function eCall, which automatically alerts EU's emergency number 112 in the event of an accident, mandatory in all new cars starting in 2018. This indicates that EU is prepared to regulate on factors increasing traffic safety. On the other hand, the eCall initiative was first mentioned already in 1999 - in other words, it has taken more than 15 years to eventually reach a final approval of it.

The transport ministers of EU28 have all signed a document called "Declaration of Amsterdam on cooperation in the field of connected and automated driving" which lays down agreements for the steps necessary to take to enable development of autonomous cars in the EU. This includes amending rules and regulations to fit testing and commercialization of autonomous cars as well as supporting specific initiatives.

In addition to Germany, UK and Sweden which are further discussed below, France, Italy, Spain and the Netherlands are also European nations where autonomous technology is developed and tested.

12.1.3 Germany

Germany is the country of origin for the invention of the first motorcar by Karl Benz in 1885 and Germany has since then been considered the center for R&D and new car innovations in general. The German car industry is renowned for its high-performing quality vehicles. As one of the largest hubs of the automotive industry and the home for the world's top three luxury car manufacturers - BMW, Mercedes-Benz and Audi - Germany is an important region for the development of autonomous cars. Germany is Europe's largest manufacturer of passenger cars as well as the country with highest annual new registrations accounting for about 30 percent of the production and 20 percent of the sales in Europe. When it comes to the premium segment, Germany accounts for 41 percent of worldwide sales. The entire automotive value chain is integrated in the German industry and the country is home to 21 of the 100 largest automotive suppliers in the world including Bosch and Continental.

Following the automakers' and the suppliers' perceived threat of competition from new entrants such as Google, they have started to campaign for a quick evolution of policies in Germany regarding autonomous vehicles to enable the industry to stay ahead in the roll out of such technology.

The German Chancellor Angela Merkel has said that the government will work together with the industry to remove the legal barriers for autonomous cars. The government has also started to discuss ways to boost the demand of electric cars in the country.

The German transport minister has proposed new legislation on requirements for automakers that want to launch autonomous vehicles. This includes for instance the suggestion that drivers can divert attention from driving but must remain seated in front of the steering wheel to be able to regain control in the event of an emergency. Another proposal is to require German automakers to equip their cars with a black box as a way of determining responsibility after an accident. The transport minister has created a committee that includes various people from the automobile industry and researchers as well as politicians with the aim to establish legal frameworks for autonomous vehicles.

In the beginning of 2015, the transport minister announced that a stretch of the Autobahn 9 between Munich and Berlin will be equipped with technology for autonomous and connected vehicles to allow testing of V2X communication in addition to the self-driving features.

The German Ministry for Education and Research has funded project AutoNOMOS which is an initiative lead by the Artificial Intelligence group of the Informatics Institute at the Freie Universität Berlin. It started in 2009 and has developed an autonomous research car dubbed MadeInGermany. AutoNOMOS' aim is to develop autonomous technology and ADAS to prevent future road collisions.

Despite the recent positive attitude to autonomous cars, new legislation has still not been enacted and Germany has in that perspective fallen behind the US and in particular California. While entire states in the US have opened for testing on public roads, Germany only discuss allowing it on specific stretches such as the Autobahn 9.

12.1.4 UK

UK has a strong tradition as an automobile manufacturer and as an innovator in the automotive industry. It is the third largest European car producer after Germany and Spain (although the latter's large size is due to other European brands than Spanish car manufacturers locating their production there). The UK government has declared that it wants UK to take a leading role in the development of autonomous vehicles. The government has already spent £ 19 million (€ 22 million) in funding to four different autonomous vehicle projects around Britain but is planning to invest an additional £ 100 million (€ 116 million) and is challenging the industry to match the investment.

UK's transport minister has stated that UK will adapt regulations to make it easy to test and develop autonomous vehicles. He has made the comparison to the so called "red flag laws" which limited vehicle speeds and required a person with a red pennant to walk in front of the vehicles and thus slowed Britain's automobile development in the late 19th century. He stated that such a mistake will not be made again

In 2013 the UK government enacted legislation that permits testing of autonomous cars on public roads. Trials can take place without any specific permission and on all public roads but requires coverage by an extensive insurance bond. Up until the new regulation, testing had been done on closed-off private facilities. The UK has an advantage to other European countries since it never signed the Vienna convention on road traffic. To allow for public testing has therefore been easier in the UK.

UK has launched test projects in the four cities Greenwich, Milton Keyes, Coventry and Bristol backed by the £ 19 million fund from the government. In February 2015, the first project was initiated in Milton Keyes with the deployment of three driverless pods in the city center to assess if it is feasible to operate such vehicles in pedestrian areas both from a technological and a societal perspective. The pods are called LUTZ Pathfinder and have been built by the automotive innovation firm RDM in collaboration with the Mobile Robotics Group from University of Oxford. The project is planned to be expanded with a larger fleet of 40 pods along with regular cars and will involve Coventry in the project.

Registration for testing of the self-driving vehicles in Greenwich opened for members of the public in May, 2016. The project's purposes are to trial and validate different use cases of self-driving vehicles including driverless shuttles. The fourth city, Bristol has recently seen the start of project VENTURER which will create a test facility for connected and autonomous vehicles. This project will focus on the behaviors that will drive adoption as well as legislation and insurance adaptations that will be necessary for autonomous cars to emerge.

In addition to the strong automotive industry, UK has universities, like Oxford and Cambridge, which conduct autonomous vehicle research. UK might have an advantage in the future thanks to the tough test conditions the London traffic offers. The Department for Transport has said that if an actor is successful at putting a self-driving car in London with its utterly complex structure and traffic, the autonomous cars can be implemented anywhere.

UK has a rather good position to become an important region for development of self-driving vehicles in the future, mainly because of the strong presence of the automotive industry and the advantageous legal framework. However UK manufacturers do not currently lead the development of autonomous cars. Other nations have acted faster than UK and the Britons will have to work hard to catch up with the development in the US and Germany.

12.1.5 Sweden

The Swedish government has launched Drive Sweden - a strategic innovation program with autonomous transport systems and mobility as its core focus. The program was launched in 2015 and will continue until 2027 with the overall purpose to improve sustainability and Swedish transport industry. Drive Sweden aims to gather experts in the area to develop and especially coordinate joint projects in digitized vehicles and in new mobility solutions. Drive Sweden has a budget of a relatively modest SEK 20 million (€ 2.1 million) per year to sponsor research and related projects. On the other hand, Drive Sweden's role is foremost to act as a coordinator and not a funder. The program will back individual projects of smaller scale and rely on the automotive industry value chain to have sufficient capital to perform the volume development. Drive Sweden is for instance involved in Volvo Cars' Drive Me project which will see the roll-out of 100 test cars to the public in Gothenburg in 2017.

Sweden has a large automotive cluster centered around Gothenburg and the Swedish west coast where Volvo Cars is developing autonomous technology. The truck manufacturers, Volvo Group and Scania are two other players that also have showed interest in autonomous driving and have performed testing with platooning trucks. The Swedish automotive industry is world leading in terms of safety and Sweden is also at the frontend of information technology which is believed to be of increased importance in cars in the future.

Sweden is only the twelfth largest producer of passenger cars in Europe but Volvo Cars, on the other hand, has a large amount of overseas production and Volvo Cars is in fact the fifth largest luxury car brand in terms of unit sales worldwide. Moreover, Sweden has a well-functioning collaboration between government, industry and academia - a so called triple helix - and this could prove to be an important benefit for the development of self-driving technology.

As for legislation, Sweden is bound by both the Geneva and the Vienna conventions on road traffic. However a proposal for new legislation in April, 2015, suggested that the conventions do not restrict self-driving vehicle trials on public roads since the conventions were made to facilitate international road traffic and improve safety. While the proposal suggests that trials on public roads should be allowed in Sweden it has also received significant criticism from the Swedish Data Protection Authority as it believes that self-driving cars in accordance with the proposal does not respect the data security aspects related to gathering and handling of information about people. Autonomous cars rely on sensors and will have to gather all kinds of surrounding information which can be a violation of people's integrity and result in potential security problems if the data is not handled safely.

12.1.6 China

As both the world's largest producer of passenger cars and the largest market for them, China is undoubtedly an important region for the automotive industry in general. The luxury car industry is experiencing strong growth in China as luxury cars are seen as an important status symbol for executives. China does not lead the technological development of autonomous cars, although Baidu and some other companies have launched interesting projects, but China is likely to be an important market for self-driving cars.

China is not bound by either of the international conventions on road traffic. In fact the regulatory structure in China enables quick adoption of autonomous cars. Furthermore, the Chinese people seem to be more willing to actually ride in self-driving cars compared to people in both Europe and the US. Surveys have indicated that as much as 75 percent of the Chinese people would be likely to ride in a self-driving car while, for the US, the same measure is closer to 50 percent. Chinese companies have performed some testing of autonomous technology and the city of Wuhu in Anhui has plans to put up a special zone where self-driving cars can be tested and regular driving will be forbidden.

Beijing is trying to shift the economy from the current heavy-industry and low-end production to an economy more oriented towards consumer markets with high-tech products. Autonomous cars are well in line with that transition. Adoption of autonomous cars could also lower the significant number of the

200,000 fatalities that occur in the Chinese road traffic each year. Moreover, China has tremendous problems with air pollution and congestion and the government sees self-driving vehicles as a way to reduce these problems.

A committee backed by the Chinese Ministry of Industry and Information Technology has started drafting a roadmap for China's development of autonomous cars. The draft will be unveiled later in 2016 and is likely to include pathway to develop highway capable self-driving cars within 3-5 years and cars with urban autonomous driving capacity in 2025. In particular, the draft will focus on regulation and technical standards for V2X communication and other aspects that need to be agreed upon across the industry.

12.1.7 Japan

The Japanese automakers have been somewhat hesitant to initiate projects in self-driving technology although Nissan has taken a leading position in the country with Toyota and Honda more recently putting in efforts. The first test on public roads was performed in November, 2013, with a Nissan Leaf that drove autonomously on a highway and was able to overtake other vehicles, stop at red lights and exit the highway by itself.

The Japanese Ministry of Economy, Trade and Industry put together an overview of the current state of autonomous vehicles in a paper published in 2014. The document included a four-level scale of autonomy. In 2016, the Japanese National Police Agency established several policies regarding testing of autonomous cars on public roads. The policies state that testing of driverless cars, i.e. without any person ready at the wheel, is prohibited. Testing of self-driving cars on public roads will need a test driver that is ready to take over control. Additionally, the policies require all autonomous vehicles to be equipped with a black box to help determine the factors causing an accident in the event of such. The agency will also establish a team that will analyze current legislation and determine whether it has to be adapted or not to realize the new policies regarding self-driving vehicles. Liability, cyber security and adaptations of the driver's license regulations are some of the topics that will be discussed.

Japan has begun a more offensive bet on autonomous cars in the last year. When Tokyo hosts the summer Olympics in 2020 the ambition is to have some kind of self-driving cars as means of transportation for the athletes. It would definitely be very beneficial from a branding perspective to make autonomous cars an integral part of one of the most extensively broadcasted global events. Undoubtedly, authorities in Japan have identified this possibility as a great chance to show the rest of the world the high-tech capabilities of Japan.

Another reason why Japan is interested in autonomous cars is that it has an aging population. A study by the Japanese government has showed that people older than 65 at the end of 2014 made up more than 25 percent of the Japanese population which is more than any other nation in the world. The same study estimates that the number will climb to 40 percent by 2060. Since old people often find it difficult to handle driving, self-driving cars could help them and increase their mobility.

12.1.8 South Korea

South Korea is the fifth largest producer of motor vehicles in the world with Hyundai and its affiliate, Kia as the nation's leading car brands. Furthermore, South Korea has an important IT industry with Samsung as one of the world's largest players. Since the automotive and the IT industry are converging in autonomous cars, it gives South Korea an advantageous position. Both these industries also make up a large part of the South Korean GDP and are therefore important for the South Korean population.

The South Korean government has a strong relationship to the large domestic conglomerates, including Hyundai and Samsung which is beneficial since collaborations between industry and authorities are important to establish the right standards and regulations. On the other hand, Hyundai and other actors in South Korea have not taken a pioneering role in the development of autonomous technology. Then again, to be a fast follower has traditionally been an important an successful strategy in South Korea.

The South Korean government is positive to self-driving cars and has actually stated that the nation will have Level 3 autonomous cars on the roads by 2020. This prediction is in parity with most active automakers' targets and rather bullish as other governments refrain from suggesting when autonomous cars will emerge. Similar to Japan, South Korea also has an aging population.

South Korea is not bound by the Vienna convention on road traffic but by the Geneva convention. In March, 2016, the Ministry of Land, Infrastructure and Transport issued South Korea's first license for testing of autonomous cars on public roads applied for by Hyundai. The ministry has revised the Automobile Management Act to enable testing of self-driving vehicles. However the permit acquired by Hyundai only covers a Genesis sedan which may only drive on two designated stretches of expressways and four sections of roads with slower speed limits. Furthermore, the car needs to have two test drivers and is required to have a sign that informs other people that it is an autonomous test car.

The ministry has already received inquiries from some small tech companies and from universities regarding autonomous vehicle test licenses. With this first license to Hyundai, the ministry hopes that additional actors in South Korea will follow with more applications for testing of self-driving vehicles. The government's attitude to testing of self-driving vehicles is that it should be allowed as long as it does not pose any threat to other people on the roads. Along this line, the government has plans to establish a mock city as a test area for autonomous vehicles. The government has said that it will improve regulations and help the launch of a local autonomous vehicle industry by supporting local small and medium sized firms that develop autonomous technology.

12.1.9 Singapore

Despite the lack of large automakers, Singapore has turned into an important early market for autonomous cars. Singapore has a very strong economy and the authorities have a keen eye towards high-tech innovations. The government has also indicated that it is supportive of autonomous vehicles. In 2014, the government formed an Autonomous Vehicle Initiative as a coordinator for research. In August 2016, Singapore announced the upcoming launch of a test center for self-driving vehicles in a business center nearby the Nanyang Technological University in 2017. The test center will cover 4.4 acres with paved roads and different traffic conditions such as roundabouts and slopes.

Singapore has well-maintained roads, the country is small, the land is flat and the weather is warm. These factors make Singapore a suitable place for testing and commercialization of urban autonomous cars. Furthermore, the government is supportive of autonomous technology and has donated extensive amounts of money to various startup initiatives related to autonomous driving. Since the nation is so small it is much easier for the Singaporean government to make adaptations and determine on new regulations compared to, for instance, the US which has to make the system work across all the states. Singapore is also not bound by the Vienna convention on road traffic but by the Geneva convention.

A further reason why Singapore might be an early adopter of the technology has to do with the fact that only about 15 percent of the people in Singapore own a car as a result of high taxes and fees associated with car ownership. The Singaporean people rely on public transportation and are used to the concept of mobility as a service. The population could benefit significantly from a fleet of driverless vehicles that can solve the first- and last-mile problem in public transportation and make mobility much cheaper.

The first tier supplier Delphi Automotive announced in August 2016 that it will test a taxi fleet consisting of six autonomous cars in Singapore in 2017. At the beginning, the cars will have a safety driver ready to cease control and they will only drive on specific routes in a specific district. By 2019, the goal is to have the test fleet expanded to 50 cars that are completely autonomous and have no drivers and by 2022 the company aims to start commercial production of the cars.

The MIT spinoff nuTonomy that develops software for autonomous cars is also targeting Singapore as a launch-pad for their autonomous technology. Similar to Delphi, nuTonomoy wants to build a fleet of self-driving vehicles in the next one to two years. The initial goal is to make driverless shuttles transporting people from outskirt neighborhoods to train stops as taxi drivers tend to avoid these areas. In the long run, the startup wants to create a complete taxi service spanning the entire city with driverless cars.

13 Analysis

This chapter will first analyze and propose the main factors that affect emergence and adoption of autonomous cars respectively. Then follows a general forecast for the different levels of autonomy before the actual scenarios are analyzed. There are three scenarios, a baseline, a pessimistic and an optimistic.

13.1 Factors that influence emergence

The empirical evidence leads to the conclusion that there are indeed some aspects that will have a particular important influence on the emergence of autonomous cars. That there is a substantial base level of demand for autonomous cars can easily be established when considering the potential benefits of these cars on both a macro and a micro level. Furthermore, there is certainly not a lack of interest from the producers' side to this development as indicated by the large number of automakers, suppliers as well as new entrants that are investing heavily in autonomous cars technology. The question is how fast these actors will be able to develop an autonomous car. As previously argued, this question is to a large extent dependent on what we define as autonomous. Level 1 has already been around for many years and Level 2 emerged, in 2015, with an estimated 194,000 cars.

Thus this section will focus on the emergence of Level 3, non-driverless Level 4 and driverless Level 4. The reason why Level 4 is split into two categories is because there are two parallel paths that different actors are pursuing to reach Level 4 capability. One targets cars with self-driving features in some situations that will require the driver to handle driving in other circumstances while the other approach targets driverless cars that only will be used in confined areas. Level 4 is a rather broad category in itself and includes cars with highly varied capabilities.

The following three factors have been identified as especially important for the emergence of autonomous cars:

1. Technology reliability
    - artificial intelligence
    - computer vision
2. Regulations
3. Collaborations

The emergence of autonomous cars is first and foremost dependent on the technological development of such cars. This is certainly not a novel identification - undoubtedly it is safe to assume that for all technologies to emerge they need first to be developed. However, in the case of autonomous cars, the aspect of technology development is unusually challenging. All the technology in terms of hardware to build an autonomous car already exists today. The problem is to make these cars sufficiently reliable through the software that controls the cars. The technology reliability is affected by all the various technologies that an autonomous car is made of. However, the main areas that need further development are the closely related areas of artificial intelligence and computer vision. So far, self-driving prototype cars are prone to errors due to lack of sufficient artificial intelligence or since they are unable to correctly identify surrounding objects. Thus it follows that the emergence of autonomous cars relies on the technology reliability with AI and computer vision as particularly important fields.

Since current regulations do not allow autonomous cars in virtually all countries around the world, at least some region will need to alter its regulations to allow for the emergence of autonomous cars. Depending on the timing of changes to legislation and development of the technology, the regulation factor will have a direct hindering or allowing effect on the emergence of autonomous cars.

Another important factor that influences the development of the actual technology as well as the regulatory environment is collaborations among different actors. This is one the factors that was most emphasized by several of the interview objects. They said that this factor is vital and that cooperation among different actors, involved in the development of autonomous technology today, could be better. The underlying reason behind this factor's importance is a result of the tremendous amount of technologies that have to come together. For instance, this includes camera, radar and lidar sensors as well as telematics, software for driving logic and human machine interfaces to mention some of the most important technologies. Furthermore, most of these various technologies must be at their respective fields' forefront of innovation to enable self-driving functions. Since high-tech industries in general, and the automotive industry in particular, tend to be fragmented with companies specializing in different areas, it follows that the speed of the development and emergence of autonomous cars are affected by collaborations. An important part of this is the establishment of standards, for instance for V2X communication and similar issues. Moreover, collaborations between authorities and industry will affect the rate of legislative changes to adapt to a future automotive industry with autonomous cars.

13.2 Factors that influence adoption

The empirical study reveals that there are several factors that can influence adoption of autonomous cars. The adoption of autonomous cars will not be heavily affected by the technological development since this aspect either lets autonomous cars emerge or not rather than impacting the subsequent adoption numbers.

Change of regulations will be important not only to allow autonomous cars to emerge but also to enable wide-spread adoption. Regulations around the world vary but in general there is no established legislation for autonomous cars. Laws about the automobile industry are made from the assumption that a driver is supposed to control the car and is responsible for the control of the vehicle. In fact, a driver is not allowed to remove attention from driving. This must change in order for autonomous cars to be adopted across the globe.

Related to authorities’ attitude and willingness to amend regulations are the overall public acceptance of or interest in autonomous cars. Undoubtedly, this factor will have a tremendous impact on the adoption of autonomous cars. An important aspect here is the rate of accidents in today's Level 2 cars and in current self-driving prototypes. So far, there have been two incidents of importance - one with a Tesla Model S that resulted in the death of the driver and one with Google's autonomous prototype which hit a bus in slow speed. Both these incidents got widespread attention and have most certainly had a negative impact on people's acceptance of autonomous cars despite both actors' well motivated responses to the allegations. If several more such incidents occur it might have an impact on authorities' attitude to autonomous technology as well as public acceptance. The public acceptance will further be influenced by several other aspects such as the technologies' reliability and safety as well as how the technology is marketed.

Another factor that will influence people's willingness to adopt the technology revolves around the liability concern. It is yet unclear which party will assume liability in the event of an accident with an autonomous car, i.e. whether it is the driver or the automaker or some other party like the government. How this factor unfolds will affect people's adoption of autonomous cars.

In a long perspective, the cost of autonomous cars will have a large impact on the technology adoption. This is particularly important for this technology since a new car is already from the beginning a rather expensive investment. However, in a short perspective the cost (as long as it stays within reasonable limits) will not affect the sales as much as might be expected. This is because the first autonomous car features will roll-out in the luxury car segment which has a large basis of affluent buyers who are less price sensitive than the average buyer. There is a reason why every of today's available Level 2 cars are found in the luxury segment. Nevertheless, in a long perspective, the cost of autonomous cars and especially the rate with which costs decrease will be a vital factor for the large-scale adoption of autonomous cars.

To summarize, the most important influential factors are these four:

- Regulations (enabling adoption)
- Public acceptance (attitude perspective)
- Tort Liability (attitude and economic perspective)
- Cost (economic perspective)

13.3 General analysis of emergence and adoption

It typically takes three decades for features that are offered in luxury cars to become adopted by the entire vehicle fleet. At a first glance, this indicates that the diffusion of autonomous features will occur painfully slowly. In 2010 forward collision warning systems were approximately standard on 1 percent and optional on 11 percent of new vehicles. If this type of systems continue their current rate of adoption it would take close to fifty years before 95 percent of the market is reached. However, such estimates give a false view of the diffusion of autonomous cars since the adoption of such cars are likely to be accelerated by economic pressures. Consumers' request for flexible mobility is today met with privately owned cars. However, currently available cars are, as indicated above, capital-intensive and very expensive in relation to their grade of utilization. Autonomous cars can significantly transform this and that fact will play an important accelerating role in the diffusion process. In fact, it is difficult to find a reasonable analogy to Autonomous cars in the automotive industry. One could look at the diffusion of electric vehicles and reach the conclusion that autonomous car will diffuse slowly. However, electric vehicles do not provide the same benefits as autonomous cars since electric vehicles still have low net benefits economically speaking and the impact of autonomous cars have the potential to be significantly stronger.

The cost of the technology should be compared to the benefits it brings. This factor is dependent on the use cases that become available with autonomous cars and thus dependent on the Level of autonomy that is reached. In general some use cases are more important than others - for instance, driverless fleets of vehicles are more important to the macro economy than autonomous traffic jam assist.

A forecast of when autonomous cars will emerge on the market is heavily dependent on the definition of autonomous. A reasonable way to deal with this problem is to look at forecasts for the various levels of autonomy. At least half of all cars sold in 2015 had Level 1 autonomy and this number is expected to approach close to 100 percent already by 2022 and a more thorough forecast for Level 1 sales is therefore not included in this report. Level 2 has also arrived but still only in relatively small scale and is expected to grow strongly in the next ten years.

After Level 2 the diffusion of autonomous cars become much more uncertain. The diffusion can come through two different types of ways, the evolutionary and the revolutionary. It seems likely that Level 3 cars will be first to emerge through the evolutionary approach. After further updates of the systems, the cars are expected to reach some Level 4 capabilities. The revolutionary approach on the other hand wants to skip the third level entirely and go directly to Level 4. Since the technological hurdles for Level 4 is larger than those for Level 3 it is likely that the evolutionary pathway indeed will lead the development initially and offer Level 3 cars before the actors pursuing the revolutionary path is able to offer Level 4 cars. However, actors taking the revolutionary approach will likely be able to offer some Level 4 autonomous capabilities around the same time as the evolutionary. However, the use cases for these systems will likely revolve around low-speed city-driving and thus be different from the ones offered by the evolutionary developers. These use cases are arguably more difficult to achieve compared to an autonomous highway autopilot, since the cars will have to deal with more types of situations but on the other hand, the revolutionary approach is likely to develop at quicker pace resulting in both kinds of features emerging at around the same time. However, this is dependent on the development of cars' artificial intelligence. If this development is slow, the introduction of the more advanced Level 4 capabilities is likely to be more affected than the less complex evolutionary features.

13.3.1 Level 1

The first applications of Level 1 autonomy were introduced a long time ago with cruise control systems that today have become standard in premium cars. Level 1 provides driver aid through automatic functions that are reactive rather than proactive and are thus not autonomous in the sense the term is defined in this report. At least half of all cars sold in 2015 had some Level 1 feature although specific systems have lower penetration than this. Examples are adaptive cruise control and autonomous emergency braking (AEB) which are available in most new luxury cars but not yet offered as standard to the broad market. These more sophisticated Level 1 features are expected to increase in market penetration and be available in affordable car models as well.

Today, only Volvo Cars offers AEB as standard but at least 20 of the world's largest automakers (including for instance the top four; Toyota, VW, GM and Ford) have committed to the US Department of Transportation's request to make AEB systems standard on all models in 2022. This is expected to have a significant impact on reducing traffic fatalities and injuries. It also implies that Level 1 will approach close to full coverage by 2022 with cruise control or automatic emergency braking being included in virtually all new cars. 100 percent coverage will never be reached since there will be exceptions like sports cars that will offer no Level 1 features.

13.3.2 Level 2

Level 2 autonomy is already available on the market since 2015 through highway autopilot systems that take over both steering and speed control on highways but require the driver to maintain attention at all times. Models that have this capability are Tesla Model S and Model X, BMW 7 series, Mercedes-Bens S-Class, Infiniti Q50 and Volvo XC90 although the XC90 system only works in speeds below 50 km/h. Performance and applicable situations vary among the marques but in general Tesla's highway autopilot is considered the most capable and highest performing. An estimated 194,000 Level 2 capable cars were sold in 2015.

Just like ADAS in general, Level 2 capability is expected to increase significantly in the next few years. Many automakers have plans to increase the applications of their semi-autonomous features to cover more driving situations and to make them available in more models. Examples of this development are next year's Audi A8 and Volvo S90 and V90 as well as the upcoming Mercedes-Benz E-Class models which all will have highway autopilot systems with Level 2 capability.

The diffusion of Level 2 is expected to be limited to luxury cars for some time before premium and mid-range vehicles will start to enable some Level 2 features. The diffusion of Level 2 vehicles will continue as the ADAS technology drizzle down to less expensive models following diminishing costs. This will also lead to additional brands offering Level 2 systems, including volume makers like Toyota, Volkswagen, GM, Renault-Nissan, Hyundai, Honda and PSA.

There are some inherent problems with Level 2 autonomy that could have a braking impact on the adoption of cars with such capability. Critics advocate that it is unreasonable to expect people to stay alert at all times when the car does all of the driving by itself, especially when they know that the car has autonomous emergency braking. The fatal incident in Florida in 2016 with a Tesla Model S which had the autopilot engaged has evoked further debate about this. However, since the responsibility constantly lies with the driver, who at any time can take back control of the vehicle, it seems unlikely that authorities would be able to significantly slow down the adoption of Level 2 vehicles. It is more likely that people's acceptance of the technology might slow the adoption. Incidents like the fatal crash with the Tesla Model S in autopilot mode could make the public less enthusiastic of Level 2 cars. On the other hand, Tesla had allegedly logged a total of 130 million miles with the autopilot engaged before the incident occurred - significantly more than the average 90 million miles that is driven between each fatal accident in the US. The key point for automakers is to make people realize that Level 2 cars typically are safer than the average vehicle, which should become apparent in statistics after some years of diffusion.

13.3.3 Level 3

There is an important transition between Level 2 and Level 3 that is worth highlighting. Level 3 is the first level where we can actually speak about autonomous driving whereas Level 2 only provides driver assistance. At Level 3, the driver can take his or her eyes off the road for periods of time. However, this requires new regulations in virtually all markets since current conventions prohibit drivers from discontinuing driving awareness. The difference between Level 2 and Level 3 is thus much larger compared to the transition from Level 1 to Level 2. Regulations can be expected to play a more important role for the adoption of Level 3 vehicles compared to Level 2.

Level 3 autonomy is likely to be reached through incremental enhancements and extensions to currently available ADAS. Tesla, BMW, Mercedes-Benz, and other luxury brands all need to enhance their Level 2 system performance significantly before a driver can safely relinquish control and attention of the driving for periods of time. Moreover, if an actor reaches a level 3 application relatively soon it will likely take additional time before regulations will allow the use of it.

The first Level 3 applications are likely to be in the shape of traffic jam assist or parking assist. The next feature to emerge is probably a highway autopilot which can handle typical high-speed driving on its own on motorways and highways but will require the driver to regain control when exiting the motorway or at intersections. In this case, the car will know through the use of digital maps when it will encounter an intersection or an exit ramp and can warn the driver well in advance to take over control.

The third level of autonomy has in a similar way to the second level some inherent problems stemming from the fact that it relies on human machine interaction. It is difficult for a person to suddenly regain control after a warning. Moreover, it is unrealistic to assume that these warnings in all instances can come much sooner than a few seconds prior to a situation while studies have shown that a safe hand-over of control requires at least ten seconds. The fact that the driver is the fallback system in case of strange situations makes the autonomous mode potentially dangerous. The magnitude of this problem is to a large extent dependent on the amount of unusual situations the car is able to handle on its own.

13.3.4 Level 4

Level 4 autonomy offers completely self-driving capability in specific modes. This level of autonomy does not rely on the driver as a fallback system when it encounters something it does not understand which is the main difference compared to Level 3. Level 3 is also not expected to be able to operate in complex driving conditions since it would require too much driver intervention. A natural development along with the transition to Level 4 is thus to make more complex driving situations available. However, these situations are expected to be realized several years after the first Level 4 use case is introduced.

It should be noted that Level 4 is a very broad categorization that covers initial use cases like fully autonomous highway autopilot and fully autonomous parking assist as well as immensely more advanced vehicles capable of fully autonomous driving except for in severe weather conditions or not able to adapt to driving on unmapped roads for instance. Level 4 thus also incorporates driverless vehicles without driving controls adapted to a human driver. The adoption of Level 4 will therefore not see the adoption of one single innovation but many.

Some actors believe the incremental enhancements of ADAS technology - which today enable Level 2 autonomy and in some years Level 3 - is an unsafe approach. These actors therefore target a revolutionary approach to autonomous cars and aim directly for Level 4 autonomy. Ford and Volvo Cars are two automotive manufacturers that officially have said that they will skip Level 3 and directly develop Level 4 capability. However, the most notable actor in this field is Google which self-driving car project evolved from an initially evolutionary path to become a revolutionary approach after the program executives noticed the irresponsible behavior of test subjects who got to try the semi-autonomous cars. Google is now aiming for Level 4 low-speed city-driving as evident by the prototypes it has constructed which come with detachable steering wheels, pedals and other driving controls. However it is not unreasonable to assume that Google will develop simpler Level 4 features and offer this to the market before regulations approve of cars with no driving controls.

The initial use case for the first cars with Level 4 ability will likely be a highway self-driving mode. It will essentially be an extension of the similar Level 3 feature but will not rely on a human driver as a fallback system. The capacity will then be extended to cover some arterial roads as well. At first, this capability will only be available in specific regions with well-mapped roads, suitable for autonomous driving and where regulation allows it. Around the same time it is also likely to emerge autonomous shuttle service pods that can transfer people at low speeds in certain geo-fenced areas such as a city-center shopping area, a company campus or a college campus. These vehicles might even be completely without driver controls, not unlike Google's prototypes.

13.3.5 Level 5

Level 5 is the highest level of autonomy possible. It means that the car will be able to completely autonomously drive in all environmental conditions a human can handle from an arbitrary point A to point B and can thus be truly driverless. These type of cars will have to be able to handle precisely any situation which is tremendously more challenging than specific use cases like Level 3 and Level 4. Most probably, Level 5 cars will be reached by refinement of Level 4 cars until they reach sufficient reliability, especially in terms of computer vision, to handle all kinds of driving conditions.

Level 5 is thus essentially an end game and it is likely to emerge several Level 4 vehicles with close-to full automation before Level 5 arrives. Furthermore, the usability of Level 5 cars might not be much higher compared to very capable Level 4 cars. For instance, imagine that all major cities have driverless fleets of Level 4 vehicles and that intercity high-speed shuttles have been deployed. In such an environment, the need for a fully autonomous Level 5 vehicle is not very high which indicates that the economic pressures for Level 5 cars to emerge are not as large as for Level 4. Because of these reasons, cars with Level 5 capability are expected to emerge much later than Level 4.

13.4 Base line scenario

This scenario is based on an extrapolation of the current trends in the field of autonomous cars. This base line scenario is thus the author's view one the most likely development. The assumptions for this development and what numbers they should result in are presented below.

13.4.1 Base line emergence

Based on the current development and heavy investment into autonomous technology it seems likely that the technology development will continue in a fast pace. Furthermore, the amount of collaborations seems to be increasing. However, there are still standards that might need to be established before autonomous cars can emerge. According to several actors, autonomous cars will emerge already in 2018-2020, though it varies what these actors mean by autonomous – often they seem to be meaning Level 3 features or some of the more simple Level 4 features. Moreover, authorities of today are in general positive to autonomous cars and have begun initiatives to alter current legislation that hinders the emergence of autonomous cars. These assumptions lead to the following times of emergence for the various Levels of autonomy:

Level 3 cars emerge in 2020

Level 4 cars emerge in 2022

Level 4 driverless cars emerge in 2023

As AI and computer vision is expected to be developed relatively fast in this scenario, the revolutionary approach catch up relatively quickly with the evolutionary. Driverless cars adapted for use in specific geo-fenced areas thus become available a mere year after autonomous traffic jam assist and autonomous highway autopilot have emerged on the market.

13.4.2 Base line Level 3 adoption

Level 3 cars are expected to debut with about 200,000 units in 2020 and grow at a compound annual growth rate of 55 percent. In 2025 it is expected that almost 3 million Level 3 cars will be sold globally. As a majority of the luxury car market adopts Level 3 capability around 2027, the diffusion of Level 3 cars will decrease its growth pace although the technology slowly starts entering the premium and the middle segment. This is also a result of emerging Level 4 cars which cannibalize on the Level 3 sales. In 2030 an estimated 16.5 million Level 3 cars are sold globally, which is roughly the same size as the luxury car market. This corresponds to a compound annual growth rate of 55 percent. In 2030, the active installed base of Level 3 cars is expected to have reached over 57 million vehicles worldwide.

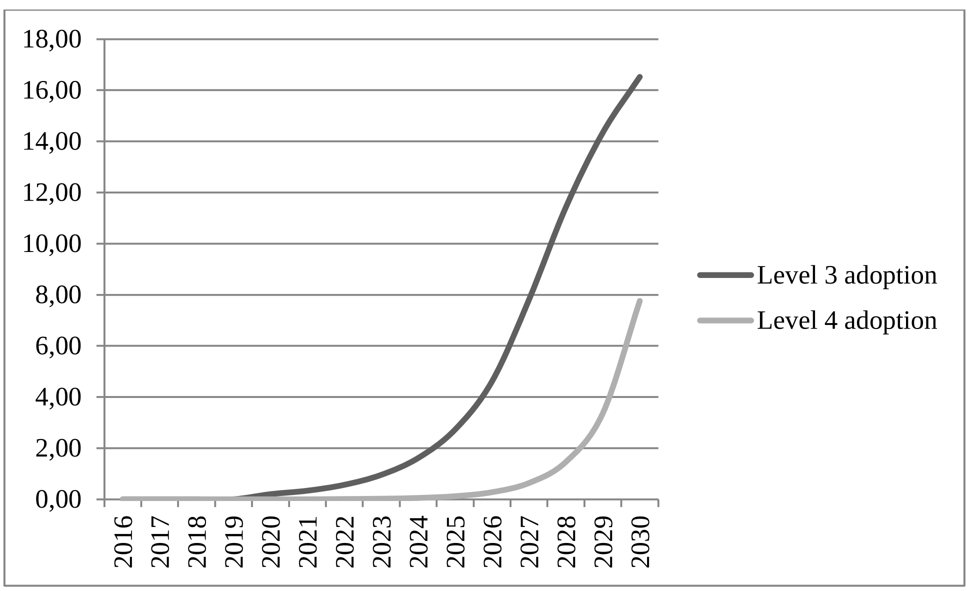
13.4.3 Base line Level 4 adoption

This scenario predicts that the first cars with Level 4 capabilities will debut in 2022. The initial use case will likely be a highway self-driving mode. It will essentially be an extension of the similar Level 3 feature but will not rely on a human driver as a fallback system. The capacity will then be extended to cover some arterial roads as well. At first, this capability will only be available in specific regions where regulations allow it.

In 2022, there will also emerge autonomous shuttle service pods that can transfer people at low speeds in certain areas such as a city-center shopping area, a company campus or a college campus. These vehicles might even be completely without driver controls. However, the number of vehicles adopted will initially be rather small since they will only work in some specific confined places. Moreover, these cars will probably not be sold directly to the end consumers but rather to companies and subsequently cities. The implication is that it will take time before the adoption of this type of revolutionary cars become wide-spread which is why the evolutionary path is expected to lead sales of cars with Level 4 capabilities even for a few years after 2022. Sometime in between 2025-2030 it is possible that the first city-based driverless fleets of autonomous cars start to emerge in some specific cities which will make the revolutionary approach begin to catch up with the evolutionary in terms of unit sales. These cars will have to blend with regular cars and be able to handle an immense number of situations which is why there will take some additional years of development to roll-out these cars compared to the first Level 4 modes. This diffusion will also be step-wise, beginning in specific city districts before incrementally starting to span entire cities. Google's technology is likely to continue the lead in the development of city-based Level 4 vehicles and will a have a strong position when they emerge on the market.

The diffusion of Level 4 vehicles is not expected to follow and be bound by the luxury car market to the same extent as Level 3 cars, although the first Level 4 cars are likely to be luxury cars that through incremental steps reach Level 4 capability. The adoption of Level 4 cars are expected to have more constraints (both regulatory and technological) than Level 3 and therefore launch with and initially increase with fewer vehicles each year. In 2022, the introduction of Level 4 cars will be a modest 10,000 units. However, this will subsequently grow at a compound annual rate of as much as 130 percent to reach around 7.8 million new annual registrations in 2030. In the same year, the active installed base of cars with Level 4 capabilities are expected to reach over 13 million vehicles.

Figure 38. Sales in million units



13.5 Pessimistic scenario

This scenario is a negative extrapolation of the base line scenario presented later on. In this pessimistic scenario, several factors combine to give a late emergence and a slow adoption of autonomous cars.

13.5.1 Pessimistic emergence

This scenario is based from the assumption that either the AI development or the development of computer vision is slow together with little collaboration in the environment. The result is that the emergence of autonomous features is slower than what most companies, active in this field, estimate.

For the first Level 3 cars, the slow development of software will not have as large impact as it will on Level 4. This is because Level 3 features can always opt the driver to take back control of the vehicle when it does not understand a situation. Arguably, this feature could be introduced in the current Tesla models as well as the other luxury cars that feature some kind of highway autopilot. However, since these systems still have a lot of issues it would result in an unreasonable amount of switchbacks to the driver for Level 3 to be launched today. Based on this argument, it will take some years before Level 3 cars emerge although it is not per definition impossible to introduce it already today. Another major reason why the introduction of Level 3 will not arrive quickly stems from slow changes of regulation making an early emergence of these cars impossible. Based on these assumptions, the emergence of the different Levels will be slow in the pessimistic scenario.

Level 3 cars emerge 2025

Level 4 cars emerge 2030

Level 4 driverless cars emerge 2035

Although there is a significant difference between Level 4 and Level 3 the difference between Level 3 and Level 2 is even larger. This indicates that once Level 3 is reached it should not take very much longer to reach Level 4. It might seem like the step from non-driverless Level 4 to driverless Level 4 is relatively small. However since AI development or computer vision development are slow in this scenario it results in the high requirements for driverless Level 4 taking an additional five years to reach compared to the initial introduction of the first Level 4 cars.

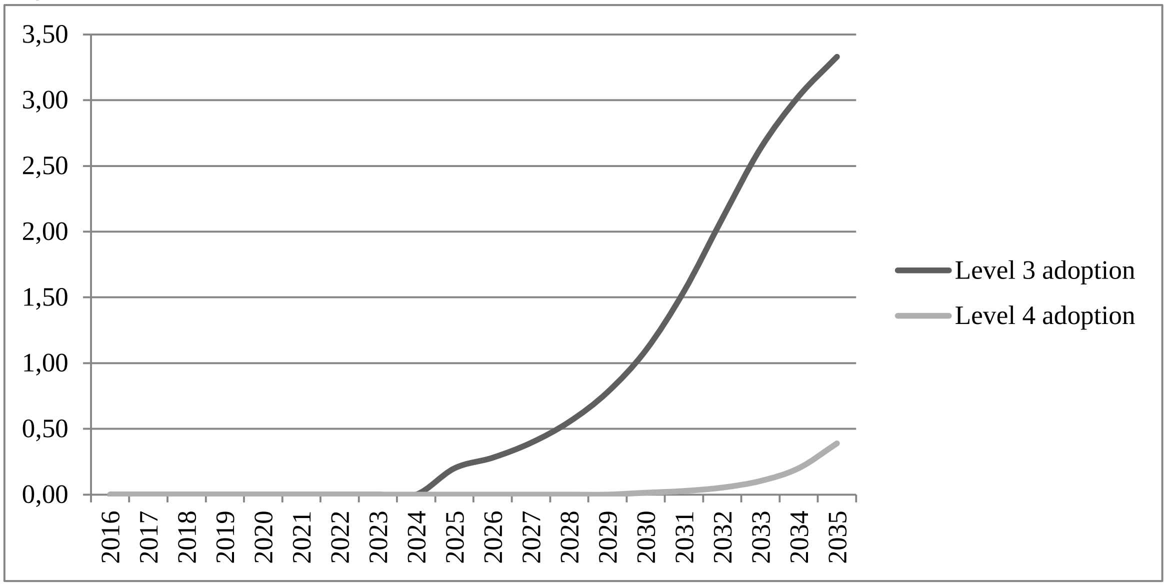
13.5.2 Pessimistic adoption

This scenario is based on pessimistic assumptions about the various factors' progress. Regulations in different countries are slowly changed to allow autonomous cars on the roads and at first only in specific areas. This might be a result of governments wanting to take a careful approach with the aim of ensuring people's safety by not allowing the usage of autonomous cars until they have been extensively tested. Furthermore, a high number of accidents or general distrust decreases the public acceptance and demand of the autonomous cars. The liability issue takes time to solve and the autonomous cars prove to be highly costly due to the advanced technology used in them and actors' attempts to cover their large R&D costs.

The implication of the slow development in all these factors result in a low adoption of autonomous cars. However, since autonomous cars will result in substantial benefits they could still be adopted surprisingly quickly, especially by the luxury segment. The same argument holds for the regulatory environment in different regions - authorities will, despite being careful, also be inclined to further or later allow the technology. Level 4 cars are thus expected to grow with a rather strong annual growth rate of 108% from

10,000 units in 2030 to roughly 390,000 cars in 2035. After emerging with an estimated 200,000 Level 3 cars in 2025, annual sales grow to 3.3 million Level 3 vehicles in 2035. That corresponds to an annual growth rate of 32 percent. The table below shows estimates of annual global sales for the different Levels, 10 years from their respective emergence.

Figure 39. Sales in million units



13.6 Optimistic scenario

This scenario is based on a more optimistic view on the development compared to the base line scenario. Optimistic in this case means a rapid development leading to both an early emergence of autonomous cars and a quick adoption of them.

13.6.1 Optimistic emergence

This scenario assumes that technology development occurs fast since breakthroughs in both AI and computer vision come quickly. Furthermore, standardization about common factors is reached early and the actors indulge in significant collaborations resulting in fast development of the technology.

Level 3 cars emerge in 2018

Level 4 cars emerge in 2020

Level 4 driverless cars emerge in 2020

Since the software development is rapid it enables a quick roll-out of driverless Level 4 cars which is why this happens simultaneously with the roll-out of the driver dependent but fully autonomous highway autopilots and traffic jam assist in 2020. If technology development is this fast it is reasonable to assume that regulatory changes will lag behind as this often is the case with new and potentially dangerous technology. Thus even if technology might be ready even before 2020, regulations will probably not allow Level 4 autonomous cars to emerge prior to this year.

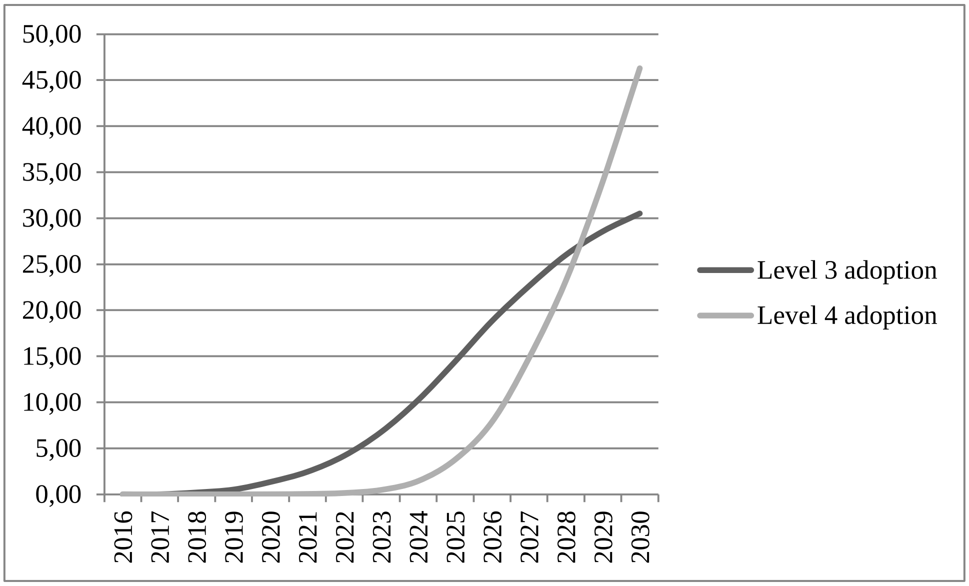
13.6.2 Optimistic adoption

Assuming that all of the four factors *of regulations*, *public acceptance*, *liability* and *cost decline*, progress quickly, the adoption of autonomous cars will be tremendously fast. This scenario might sound improbable – however it is not unrealistic. A quick emergence of autonomous cars would mean that the technological hurdles in building these cars have already been overcome. Due to the large benefits with autonomous cars, regulators would be inclined to quickly allow the driving of such cars. A similar argument holds for the manufacturers of autonomous cars who after seeing a large demand would be able to reduce costs due to large-volume production. The manufacturers of self-driving vehicles might also be sufficiently confident in their technology to enable them to assume some liability. Public acceptance might also develop faster than what is expected in the base line scenario assuming the technology is safe and stable. There is a risk that media might distort people´s view on autonomous cars by focusing on the few accidents that undoubtedly will occur. However, by comparing the number of accidents with self-driving cars and cars of today, people could be demonstrated the advantages with the new technology.

In this scenario Level 3 cars emerge with 200,000 units in 2018 and grow with a compound annual growth rate of 52 percent to reach 30.5 million units in 2030. It should be noted that this rate of growth is a bit smaller over the time period than in the base line scenario. However, this comes from the assumption that Level 4 vehicles will significantly cannibalize on the sales of Level 3 vehicles. In fact, the growth rate for Level 3 in this optimistic scenario is initially much higher than in the base line scenario.

The adoption of Level 4 cars will see an even stronger growth rate than in the base line scenario, reaching 23.2 million units of annual sales 8 years after introduction. The corresponding sales figure is 7.8 million in the base line scenario. Ten years after introduction, yearly Level 4 sales reach 46.3 million units in this optimistic scenario. At this time it is not unlikely that the fast adoption of driverless Level 4 cars might result in the global car market sales declining. This follows as a result of more effective use of cars when many people can share the same vehicle in public fleets

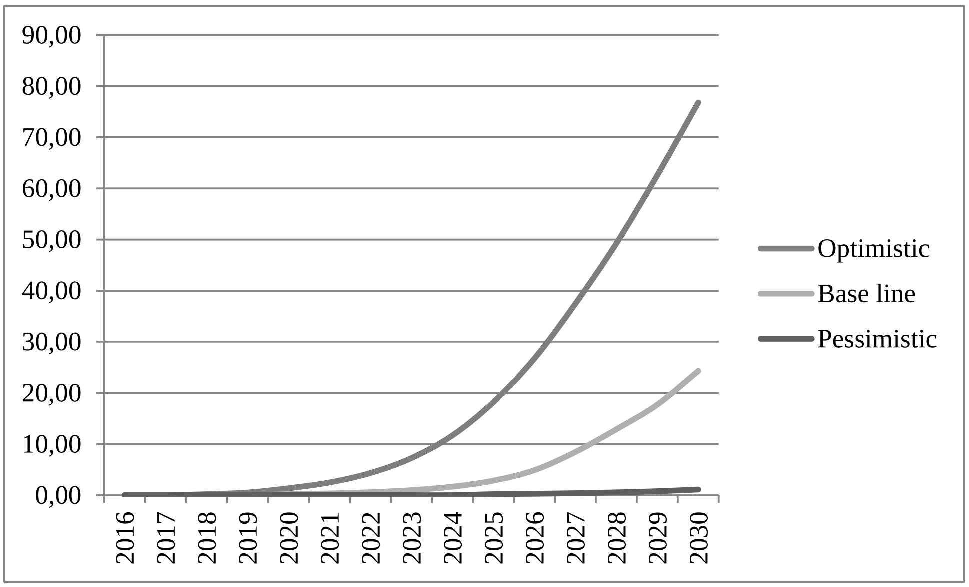
Figure 40. Sales in million units



13.7 The Scenarios combined

When combining the adoption curves for the different scenarios, it become obvious that the uncertainty is high. At 2030, the optimistic adoption of Level 3 autonomy or higher is at 77 million units while the pessimistic scenario forecasts only 1 million. The base-line scenario forecasts 24 million units sold in 2030.

Figure 41 Scenarios combined



13.8 Forecast beyond 2030

Estimates become very difficult beyond 2030 since it is uncertain how far the Level 4 autonomous use cases have reached and what impact Level 5 vehicles might have on the market as well as how several other aspects will influence the progress. The following section provides some thoughts on possible developments.

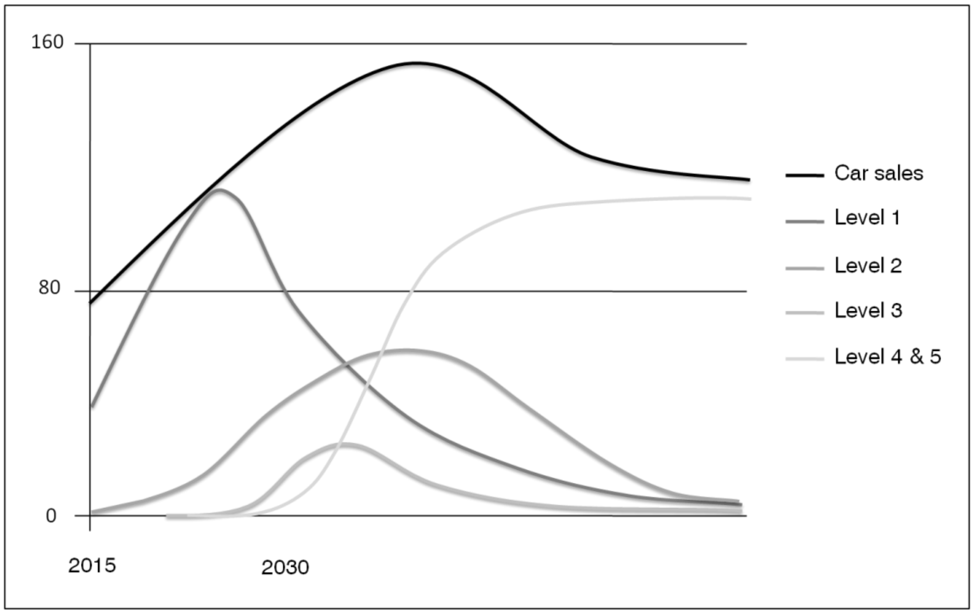
If the growth of Level 4 cars continues in a similar fashion as estimated from 2022-2030 according to the base line scenario, it will reach almost 15 million unit sales globally in 2035, accounting for about eleven percent of the total passenger car market. Subsequently it is not unlikely that Level 3 sales will go down as Level 4 takes over more and more of the market. Since Level 4 should not be much more expensive than Level 3 - it is essentially an enhanced and safer version of Level 3 which relies on the same kind of sensors - it is reasonable to assume that Level 4 will cannibalize significantly on Level 3 sales

A potential development is that low-income markets can leapfrog pass Level 3 to immediately obtain Level 4 cars. The emergence of mobile networks in some developing countries have for instance skipped earlier standards held by the developed countries since they have been succeeded by more efficient technology. The possibility for a similar development in autonomous cars becomes more probable the lower the economic step is between Level 3 and Level 4. A factor that speaks in favor of leapfrogging is the fact that Level 4 vehicles enable new business models like autonomous taxi fleets without drivers. Even though the people in an underdeveloped region might not have the economy to buy self-driving cars it is not impossible that governments can have the financial capacity to attain this technology. On the other hand, these types of regions have roads with bad infrastructure and the traffic is congested and unstructured. Furthermore, cars in general are expensive and autonomous cars will be one of the most technologically advanced innovations that have ever been created by mankind. It will take a long time before low-income markets can attain either Level 3 or Level 4 technology, probably decades.

According to the base line development, after 2030, most early adopters of Level 3 and Level 4 should have been reached and the technology should begin to diffuse to an early majority segment. Since the industry now approaches less curious and more reluctant buyers, the questions of public acceptance might become a reignited problem. In several surveys people have showed unwillingness towards riding in a self-driving car. On the other hand, people are, evidently, inclined to write and send text messages and perform other ill-advised activities while driving which indicates that people in fact do not want to drive at all times. It is important to remember that there is a difference in asking a person whether he or she would trust riding in a self-driving vehicle and letting the same person see an actual proof of the concept. People are in general suspicious to change, especially when they do not have sufficient information, but more willing to adopt something they see working. This indicates that acceptance is likely to be a surmountable problem also when it comes to the early and late majority segments.

An interesting aspect is that further in the process it is likely that the worldwide vehicle sales start declining due to the high adoption of mobility as a service in cities along with the potential emergence of inter-city high-speed shuttle services. It might well become economically unfeasible to own a private car and driving might be permitted only in geo-fenced areas and seen as a hobby or a sport.

Figure 42. Long term outlook on passenger and autonomous car sales (millions by year)



14 Conclusions

As indicated by the scenarios analyzed, autonomous cars will come. The question is not if but rather when and to what extent. This study has attempted to answer these questions of emergence and adoption by looking at different potential scenarios of development. Below follows some conclusions that can be drawn from the scenario analysis.

14.1 Conclusion on emergence and adoption

The scenarios above have been established based on the assumption that the factors that influence emergence and adoption all will evolve in either a positive or negative way simultaneously. That assumption might seem strange but is not invalid since the key factors are closely related to each other - for instance is development of technology reliability sure to influence regulations and public acceptance. Nevertheless, it is not unlikely that these factors evolve in different speeds which could have a considerable impact on both emergence and subsequent adoption of autonomous cars. It is thus difficult to predict which scenario will be most accurate with any certainty. Arguably the base line scenario should be closest to the actual development but the uncertainties in the forecasts render any definitive conclusions difficult. However, the scenarios provide a frame in which the time of emergence and rate of adoption is highly likely to occur.

According to the scenario analysis the emergence of autonomous cars will most likely occur in between 2018 to 2025. This is not an indisputable truth although it seems unlikely that the first Level 3 feature will emerge later than 2025 since this type of system could be introduced already today if it were not for the fact that the constant handing back of control to the driver would be unreasonably annoying. It also seems unlikely that Level 3 cars will emerge earlier than 2018, in particular since current legislation does not allow drivers to remove attention from driving.

Even more unpredictable than the emergence of autonomous cars is their rate of adoption. This study predicts that in 2030 the sales of autonomous cars will be somewhere between 1 million to 77 million units and according to the base line scenario it should be at about 24 million units.

14.2 Impact on society

The advent of autonomous cars marks the beginning of the largest transformation the automotive industry has ever seen. Releasing the driver from the actual driving is expected to have dramatic implications. The potential benefits can be read about in further detail in chapter 8. The potential benefits described in chapter 8 are also expected to happen but many of them will take a long time to realize and the benefits will also see large differences among different regions.

The benefits of convenience and safety are believed to have the first significant impact as they are greatly influence already by Level 2 capabilities. Since the large externalities induced by private drivers are mostly a result of the high rate and high costs of accidents, the extent of the impact on safety will also be significant. Subsequently we will start to see an impact on traffic efficiency as an increased amount of vehicles become connected and autonomous. It will probably take a long time before mobility and city infrastructure are influenced. The roll-out of autonomous cars is also likely to see a relatively slow and stepwise impact on sustainability since it will take a relatively long time to reach a majority of the market.

Autonomous cars have very few disadvantages but a tremendous amount of benefits. Critics of autonomous cars do not advocate that they will have a negative impact on society. Instead they argue that it will be very difficult to make them work reliably. However, when we compare human driving performance to machine driving performance, the fact that humans still are more proficient than machines is not the single conclusive factor. What is vital to note is that humans have an upper limit. There is a limit to how much we can see, how much we can comprehend as well as to how long time we can manage to stay attentive. Computers do not have this kind of limits, technology is only bound to how far we have managed to develop it. Current initiatives in autonomous driving has yet to build a sufficiently reliable computer to manage fully autonomous driving and it is definitely not easy but that does not mean that a human will always be better than a computer at driving a car.

As for the negative aspects of autonomous cars, such as that it will remove the fun in driving, it is important to remember that autonomous cars will not render sports cars obsolete. First of all, it will take a long time before human driving becomes illegal, even in specific regions. Secondly, even in a distant future where autonomous cars perform all transports, high-performing cars will still be available as a hobby or sport. As a comparison, there are still lots of horses and horse riders today despite the emergence of automobiles over 100 years ago, we just do not use them for transportation anymore.

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