AUTONOMOUS DRIVING

How the Driverless Revolution Will Change the World

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BY

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PREFACE

Writing a book about autonomous driving is quite a challenge, because new findings on the subject – often contradictory – are appearing every day. Ideas, concepts and technologies relating to self-driving vehicles are emerging all over the world and it is hardly possible to gain a detailed overview of them all. So this book cannot aim to be an entirely consistent description that is accurate in every detail, but is more like the collected journals of an expedition that is not yet completed. It was worthwhile setting out on this expedition, because there is probably no other technology that will so fundamentally transform our economic and social lives. The time has come to address the subject of autonomous mobility and to make it the subject of social discourse, thus contributing to changing our lives for the better.

Examining this subject was also quite an experience for the authors, because it's about software, sensors and algorithms only at first glance. The underlying narratives about new opportunities (and also risks) offered by autonomous driving are far more exciting. Rupert Stadler, as CEO of Audi, is faced with the challenge of guiding a globally leading automobile company into the digital age. This requires a gigantic transformation process, which will change the company's culture and organisation as well as its products. Andreas Herrmann, Professor of Marketing, has experienced in the slums of São Paulo how mobility is a precondition for work and prosperity. If we succeed in using autonomous driving to move people faster and further, they can find better work, escape poverty and take control of their lives. Walter Brenner, Professor of Information Management, is fascinated by the speed and intensity of automotive digitisation. In collaboration with colleagues in start-ups in Silicon Valley and at Stanford University, he has found out that information technology will no longer be added to the car, but that the car will be built around the information technology.

Many employees, colleagues, experts and outstanding personalities in the fields of politics, business and society have collaborated on this book.

We thank them all for contributing their knowledge and experience. The comments from our colleague Professor Hubert Österle and the wide-ranging research on pictures and texts by Nicola Schweitzer, Cynthia Sokoll, Barbara Rohner and Manuel Holler were particularly valuable. Finally, we appreciate the enthusiastic support of Pete Baker at Emerald and especially his patience, as we repeatedly had to tell him that it would take us a bit longer because new findings had become available.

We hope our work has resulted in a book that illuminates this very important subject from various perspectives and contributes towards an open, honest and broad-based discussion about the opportunities and risks of autonomous driving. We authors are euphoric and convinced of this technology's potential. But we have doubts and concerns as well, which are also expressed in this book.

Andreas Herrmann
Walter Brenner
Rupert Stadler

PART 1

EVOLUTIONS AND REVOLUTIONS IN MOBILITY

CHAPTER 1

AUTONOMOUS DRIVING IS A REALITY

FASCINATION

The automobile has fascinated people ever since its invention in 1886 by Carl Benz in Mannheim, Germany. A car can embody what is technically feasible, as well as what is socially desirable. The generations of automobiles over the years are evidence not only of technical progress, but also of aesthetic, social and cultural changes, as expressed in automotive design and the materials used. Cars can be viewed as a demonstration of human achievement over more than 100 years in the fields of electronics, informatics, mechanical engineering, art, design and many other disciplines (see Figure 1.1). In its essence, the automobile with its features and functions, its appeal and aesthetics, reflects how many of us imagine what a society is capable of producing with input from various sectors. However, the fascination of the automobile is a result of not only its visible qualities, but also of the possibilities and opportunities it offers. Mobility, freedom and independence, as well as social status are all advantages that many drivers associate with their cars [83].

Although the automobile gives people control and power over a machine – and the feeling of freedom, movement, pride and pleasure – the desire for autonomous vehicles is not something new [116]. Driverless cars have been described in some detail for several decades now: at first as science fiction and later in scientific publications. In some fictional cases, the authors' fantasies stretch to self-driving cars living lives of their own and taking on human traits by independently setting a route or even expressing emotions. No matter how we express our ideas of modern mobility, autonomous vehicles are

Figure 1.1. Milestones of Automotive Development.

Sources: Daimler AG (upper left), Wikipedia: Audi Typ A (1910–1912). Picture taken by Bildergalerie (upper right), Taina Sohlman/123RF.com (middle left), Wikipedia: 1950 Studebaker Champion 4-Door Sedan, Picture taken by GTHO (middle right), Wikipedia 1985 Toyota MR2, Picture taken by Riley from Christchurch, New Zealand (lower left), Audi AG (lower right).

the logical endpoint of a development that began with the crank handle in the motor car patented by Carl Benz, and has led to driver-assistance systems such as adaptive cruise control, forward collision warnings, lane departure warnings and blind-spot detection. The vision of motor vehicles no longer needing a driver has reached the research and development departments of many car manufacturers, but also of some technology companies (Nvidia, Qualcomm, Mobileye, NuTonomy, etc.), and seems likely to be implemented in the coming years. The idea of a vehicle not needing a driver is no longer a fiction, and the underlying technology is well on the way to changing the economy, society and our everyday lives [7].

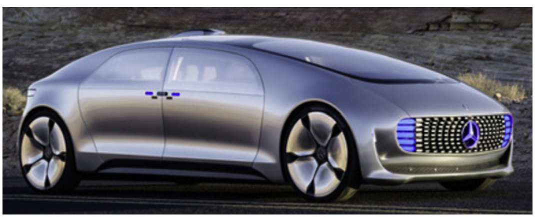
Some manufacturers' autonomous vehicles have already emerged from the concept phase and passed thorough tests to take their place on the roads. Currently, they operate in controlled environments but will be found soon within normal traffic. For example, an Audi car drove itself from San Francisco to Las Vegas, and another driverless Audi reached a maximum speed of 149.1 miles per hour (240 kilometres per hour) on a racetrack (see Figure 1.2). NioEV's new sports car Nio EP9 completed the circuit of the Americas Formula 1 racetrack in Austin in a spectacular 2:40.33 minutes.

Mercedes has presented its F015, which provides an impression of the autonomous mobility of the coming years with its futuristic design and many innovative features (see Figure 1.3). For several years, Google has been testing its well-known vehicles in California and other US states. Tesla has equipped some of its cars with software, cameras and radar, enabling them to drive autonomously in certain traffic situations. Volvo plans to put cars that can drive in autonomous mode on the beltway around Gothenburg,

Figure 1.2. Driverless Race Car of Audi.

Source: Audi AG.

Figure 1.3. Mercedes' Self-Driving F015.



Source: Daimler AG.

Sweden. Many other car manufacturers such as Ford, General Motors, BMW, Toyota, Kia, Nissan and Volkswagen are working on prototypes of self-driving cars or have already tested them in road traffic.

The CTOs of many car manufacturers and technology companies agree that achieving the first 90 per cent of autonomous driving is nothing special. It's the last 10 per cent – in the most challenging traffic situations and especially in urban areas – that makes the difference. That's why the vehicles have to be tested in as many traffic situations as possible so that experience is gained on their reactions. A similar argument is presented by Jen-Hsun Huang, CEO of Nvidia, who demands accuracy of 99.999999 per cent in the development of autonomous cars, whereby the last percentage point can only be achieved at very great expense. Toyota and Rand Corporation have published calculations of the number of miles self-driving cars have to be tested before they can be assessed as roadworthy because the algorithms required for driverless cars undergo self-learning in multiple road traffic situations. The more traffic situations these algorithms are exposed to, the better prepared they are to master a new situation. Designing this training process so that the accuracy demanded by Jen-Hsun Huang is obtained will be the crucial challenge in the development of autonomous vehicles.

When discussing what fault tolerance might be acceptable, it should be borne in mind that people are more likely to forgive mistakes made by other people than mistakes made by machines. This also applies to driving errors, which are more likely to be overlooked if they were committed by a driver and not by a machine. This means that autonomous vehicles will only be accepted if they cause significantly fewer errors than the drivers. For this reason alone, the precision demanded by Jen-Hsun Huang is indispensable.

The world's first self-driving taxi has been in use in Singapore's university district since August 2016. It can be booked via a smartphone app to drive to selected destinations. NuTonomy, which operates this taxi service, has already reported on enthusiastic passengers, and a whole fleet of these cars is due to be put into use by 2018 [124]. They won't be without competition; the Singapore transport authorities have also approved tests of five self-driving vehicles by Delphi Automotive Systems. The city-state is regarded as an ideal testing ground for autonomous cars, because the weather is always good, the infrastructure is excellent and drivers there actually comply with traffic regulations, unlike in other countries. Singapore also regards itself as a laboratory for testing new technologies and improving autonomous driving and the required infrastructure. The government is aware that this technology is a threat to the traditional automotive industry but that it might give birth to a new industry, thus initiating international competition [7].

Wanting to be at the forefront in the development of driverless cars, South Korea is building the world's biggest test arena near Hwaseong. K-City, as it is called, is the size of a small town and lets researchers simulate many different traffic situations, with narrow streets, lots of curves, traffic lights, roundabouts, parking spaces, bus lanes, a highway and, if requested, pedestrians and bicyclists crossing the streets. The 360,000 square metre (3,875,007 square feet) test ground is one way in which the South Korean government wants to help the country's automotive industry in its quest to launch self-driving cars. The artificial city will be open to South Korean carmakers like Kia and Hyundai and to technology firms like Samsung, SK Telecom and Naver. Furthermore, insurance providers and urban planners have been invited to collect data on mobility behaviour on the test ground. But K-City is not the only place where South Korean companies can test their self-driving vehicle technologies. The government has given Samsung permission to have its autonomous experimental cars drive on public roads. With this approval and the construction of K-City, South Korea want to reach its ambitious goal of putting large numbers of cars equipped with autonomous driving technology on public roads by 2020.

Many people are interested in the idea of autonomous driving, as shown by an analysis of more than 100,000 posts on various social networks. Since Google presented its driverless car in 2010, the number of posts on this subject has doubled from year to year. The analysis shows that people have twice as many positive emotions and opinions as negative ones in connection with autonomous driving. The positive associations include smart, intelligent, safe, modern, advanced and capable, while dangerous, expensive, disruptive, slow, complex and inevitable are among the more negative views. On the one hand, people are apparently curious and interested, and also hopeful that this technology will solve major traffic problems such as congestion, pollution and accidents. On the other hand, people are sceptical and doubtful as to whether it will actually work. People wonder whether autonomous vehicles will really be safe and affordable, or whether the technology will be manageable.

In addition to cars, there are other vehicles that already move autonomously, particularly within the military. These vehicles can also be found in agriculture: self-driving tractors, combine harvesters and other vehicles are used and communicate with each other to coordinate their movements. In the recent years, many driverless city vehicles and city buses have been put on the roads, especially in Europe and Asia; most of them support the public transportation systems on defined routes. Another application is freight transport, with autonomous trucks linking up into a platoon. At present, a truck with a driver takes the lead, while the other trucks link up electronically. At automated loading hubs, freight can be loaded from one truck to another without any personnel involved, and the trucks can reform into new platoons.

DEFINITION

A glance at the communications of many car manufacturers, suppliers and technology companies shows that they usually refer to 'automated driving', and only rarely to 'autonomous driving'. The former term is the umbrella term that includes several phases of automation beginning with driver-assistance systems. The latter describes the final stage of automation, the situation in which a system takes over all steering, accelerating and braking manoeuvres. In this phase, a person is out of the loop and the car is able to act totally alone at all times and in all traffic situations. Vehicles that have reached this stage can be described as autonomous, driverless or self-driving. In short, the term automation is used to express the self-acting aspect of a machine. Autonomy goes beyond that and means the self-governing ability of an entire system [110].

So far, we have only been talking about autonomous cars, the furthest and most advanced stage of vehicle automation in which the system is responsible for all driving tasks everywhere and at all times [3]. With this full automation, there is no driver anymore; all the occupants of a vehicle are just passengers. It will take quite a few years until a lot of these vehicles are seen on the roads, but some vehicles are equipped with considerable automation already today. Level 0 is the starting point – there is no automation and the driver steers, accelerates and chooses to apply the brakes on the vehicle without any system support. With Levels 1 and 2, the system takes over more and more of these driving tasks. However, the driver is obliged to permanently monitor the system, the traffic and the surroundings, and must be able to take over the driving function at any time. Level 3 means that the driver no longer has to continuously monitor the activity, because the system indicates to him or her when it is necessary to take control of the vehicle. With Level 4, the system masters all driving functions in normal operation and in defined surroundings, but the driver can overrule the system's decisions. The last stage is Level 5, which is the focus of this book.

For the sake of uniform terminology, two key terms will be used here. The term automated vehicles refers to Levels 1–4, while the terms autonomous, self-driving or driverless vehicles refer to Level 5.

TECHNOLOGY

The technologies upon which autonomous driving is based blur the boundaries between the automotive industry and the robotic, electronic and software industries [117]. Software with programming codes and algorithms, as well as cameras and sensors using radar, ultrasound and lasers, are all gaining importance. Meanwhile, the hardware of a vehicle – the chassis, suspension and other mechanical parts – are losing importance. So it's not surprising that technology companies such as Apple, Google, Nvidia, Mobileye, NuTonomy, Qualcomm and Microsoft are occupied with autonomous driving and have actually developed their own driverless vehicles. Even the traditional automotive suppliers such as Aisin, Delphi, Bosch, Denso, Continental, TRW, Schaeffler or Magna are either preparing their own prototypes of self-driving cars or working on key components for autonomous driving. The technology of autonomous driving will have a significant role to play in the success of electric mobility. As automation has a positive impact on energy efficiency, increasing vehicle automation will also significantly extend the range of electric vehicles [148].

The essence of autonomous driving is the development of vehicles into cyber-physical systems that comprise a combination of mechanical and electronic components. A vehicle's hardware and software exchange certain data about the infrastructure (the Internet of Things), and the vehicle is controlled or monitored by a processing unit. In the future, each vehicle will communicate with the infrastructure: parking garages, parking spaces, traffic lights, traffic signs and a traffic control centre (vehicle-to-infrastructure communication or V-to-I). Data on factors such as traffic flow, available parking spaces and traffic-light phases, will allow the processing unit in the vehicle to select the best route and decide on a suitable speed. With vehicle-to-vehicle communication (V-to-V), automobiles will be in contact with each other to exchange data. This will allow cars to coordinate their speed and manoeuvres and to warn each other of dangers (rain, ice, fog, potholes, etc.). It is already clear that information and communications technology within a car is gaining importance and will lead to a paradigm shift in the automotive industry. Conventional car manufacturing is being transformed into an industry that creates digitised products, requiring completely new skills. Car manufacturers will have to become more like technology companies in their culture, organisation and processes, and must absorb the spirit of this industry [147]. It is no coincidence that the traditional American car-plant sites in Michigan, Ohio and Indiana are in difficulty, while a completely new mobility industry arises in Silicon Valley.

APPLICATIONS

A crucial point for the further development of automated vehicles is that they are able to master a diverse range of traffic situations. These cars are robots, so the software can only master those situations that were previously programmed or learnt through machine-learning algorithms. Therefore, autonomous driving is likely to be applied first where traffic situations are straightforward and predictable [18]. A typical case is a stop-and-go situation in congested traffic, where cars alternate between standing and driving a few meters at very low speeds. Here, the traffic-jam assistants that are already available can further be developed to cope with increasing speeds and more complex traffic situations. Another example is driving on a highway, where the complexity of the traffic situation is relatively low despite the prevailing high speeds. In urban traffic, there would have to be separate lanes for autonomous vehicles because of the diffuse traffic situations with pedestrians, cyclists and repeated changes of direction. It is to be expected, however, that starting with these scenarios, the software will be further developed so that increasingly complex situations in road traffic can be recognised and processed.

Autonomous driving will not arrive overnight, and certainly not in all countries and regions at the same time. Starting with the driver-assistance systems that are already in use today (parking assistance or traffic-jam assistance), the processing unit will gradually be given more and more driving tasks. The speed of development mainly depends on progress within the software, including the recognition and identification of objects. It also depends on customers' willingness to use these systems and on regulatory and statutory conditions. Legislation must be updated in many countries, as it is essentially based on the Vienna Convention of 1968, and does not, for example, address liability issues relating to autonomous vehicles. For autonomous driving to become accepted, it is also important not to have too many accidents with self-driving cars in the coming years. Another spate of fatal accidents as occurred in 2016 could result in negative reactions among legislators and the general public, hindering or even preventing the further spread of this technology [116].

To arrive safely and speedily, every driver must always monitor the behaviour of the other road users and make decisions accordingly. Is the car behind me following too closely? Could this result in an accident? Am I keeping enough distance to the vehicle in front of me? Is the road free enough for me to overtake? Will the child cross the road or stay on the pavement?

In this way, the driver projects what the other traffic participants will do and what could happen depending on his own behaviour. Based on his experience and intuition, he actually develops a best guess and decides accordingly. Systems proceed in a similar way. They collect as much data as possible from the vehicle's environment, from which they derive numerous scenarios concerning the traffic situation. Each scenario is assigned a probability of occurrence, on the basis of which the best manoeuvre is initiated.

Two main components play a role in making the right decisions. Firstly, the computer model must collect accurate data, and secondly, the reasoning system must be able to draw the right conclusions. For this purpose, the vehicle sensors deliver a wide range of data about the vehicle's environment, the driving behaviour of the other vehicles and the weather. The reasoning system interprets these data and, e.g. comes to the conclusion that the driving behaviour of the trailing vehicle is dangerous or the car needs to slow down because of the heavy rain. To come to this conclusion, the system draws on past events in order to determine the probability of occurrence of a certain event. For example, the aggressive driving behaviour of the trailing vehicle provides the basis for calculating the probability of an accident.

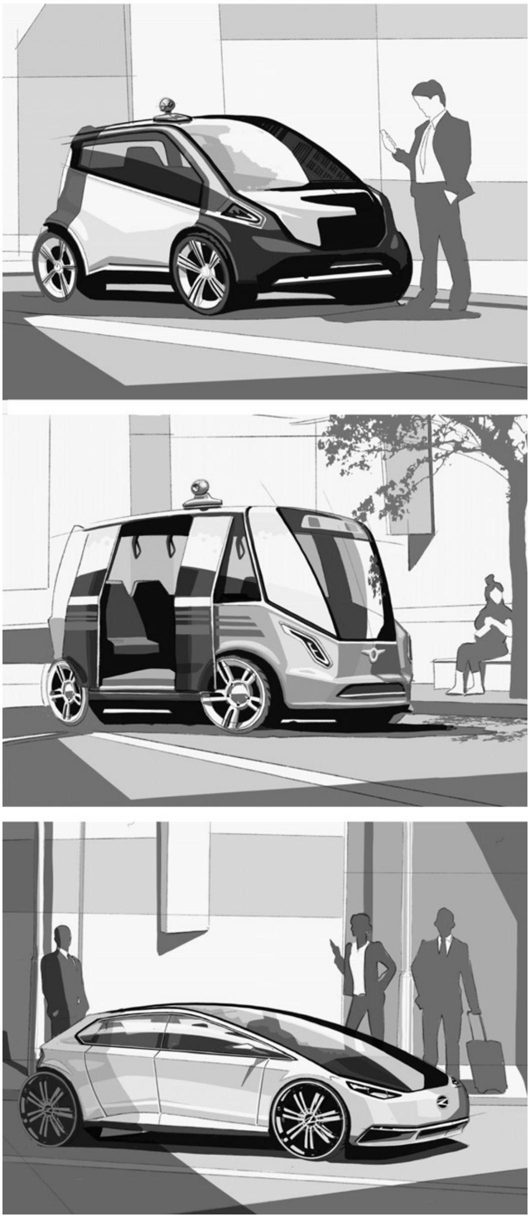
Depending on the calculated value, various driving manoeuvres can be initiated. As models improve, they collect more data and capture more variables relevant to making these decisions. However, the increasing amount of data and variables also makes it more difficult to make an optimum decision. Therefore, it is also necessary for the artificial intelligence in the vehicle to develop and be able to make the best decisions possible in real time. The model and the algorithm entirely depend on each other to produce the optimal decision. For example, if the model cannot see the rocks that fall on the road, even the best algorithm will not make the car swerve. On the other hand, if the model identifies the obstacle but the algorithm cannot process the amount of data, the car will not be able to circumvent the rocks.

VEHICLES

Within research and development departments, the technology of autonomous driving is developing in various directions. As vehicles will only have passengers and no drivers, novel interior layouts are being considered. Some concept cars are being developed that look like rolling lounges, bedrooms or offices, and are equipped with the best communications and entertainment technology. Others focus on urban use and the integration of autonomous cars with public transport. Autonomous mobility offers the opportunity to link up various modes of transportation intelligently (see Figure 1.4). One application of self-driving vehicles could be to transport travellers on the last mile from the train station to their homes, for example. It is to be expected, however, that not just one, but three types of autonomous vehicles will emerge in the coming years [24, 113, 115].

Robo-cars are revolutionary because they have been conceived as autonomous vehicles right from the start. These vehicles will operate in cities at low speeds, in exactly defined areas and on previously programmed routes. They will operate in fleets, managed by taxi companies, railroad companies or municipalities. This means that their users will not own them, but will pay either a use-related price or a flat rate. It will be possible to reserve or call up these taxis via an app, and they will be optimally navigated by a traffic management centre with due consideration of the current traffic situation. For this application, it would be possible to use robo-cars such as the prototype from Google because the design and functionality makes them ideal for fleet use.

Figure 1.4. Examples of Autonomous Robo-Cars, Buses and Multi-Purpose Vehicles.

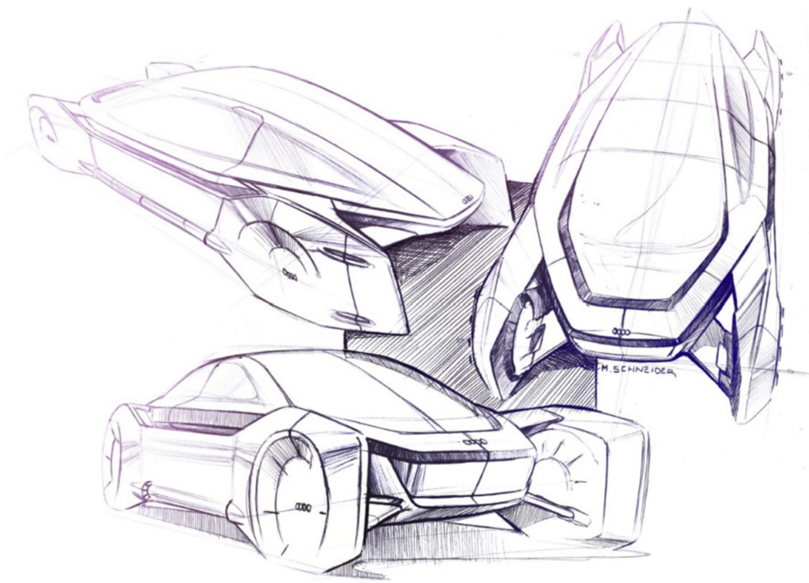


Source: The authors.

It is also to be assumed that more and more autonomous buses will be on the roads in the coming years. They won't be for long-distance use, however, but will be small city buses for 8–20 passengers. Some cities already have such bus services for transportation in inner cities, but only on exactly defined routes and with few bus stops. The best-known example is the CityMobil2, which is already in use in several urban environments across Europe. Such buses are suitable for shuttle services between various locations that are fairly close to each other – for a company, public authority, hospital or university, for example.

Multi-purpose vehicles are the result of an evolutionary process in which current vehicles are increasingly enhanced with automated functions. These cars still have a driver's seat and are laid out conventionally from the driver's perspective (see Figure 1.5). This concept has been adopted primarily by premium manufacturers, if only to transfer as much automotive expertise as possible into the new era of mobility. It is conceivable, however, that various types of vehicle will emerge for business, long-distance or family use, for example. These will each be quite different from vehicles now on the roads,

Figure 1.5. Example of the Exterior of a Multi-Purpose Autonomous Vehicle.



Source: Audi AG.

as they will have neither a steering wheel nor a central console. The exterior and interior will be newly designed and will reflect the specific application of each vehicles.

The business vehicle will be equipped with a full range of information and communications technology so that office work can be carried out while travelling (see Figure 1.6). For example, a lawyer who has to travel between an office and the law courts several times a day could prepare for the hearings in the car. The family car will offer lots of space, allow highly flexible seating arrangements, and have the latest audio and video systems. Time in the car can be used to play with children, talk to each other, listen to music

Figure 1.6. Example of the Interior of a Long-Distance Autonomous Vehicle.

Source: Audi AG.

or watch videos. In a long-distance vehicle, it will be possible to sleep, allowing overnight journeys to the mountains or seaside, for example. Upon arrival, the car will head for the manufacturer's lounge so that the occupants can shower and have breakfast before going skiing or sailing.

INDUSTRY

The convergence of industries means that players such as Mobileye, NuTonomy, Nvidia and LeEco have suddenly entered the automobile market without any previous experience of car manufacturing. These companies are not interested in taking the evolutionary path from assistance systems to autonomous driving. Their route is revolutionary; they are developing self-driving cars right from the start [47]. Because of these companies' core competencies, it is not a case of software being applied to cars, but of cars being built around the software. This disruption of the automotive industry appears to be putting pressure on the established car manufacturers. The revolutionary approach makes the existing players appear slow, sluggish and ponderous, although they are actually following the logic that has served their industry well for more than 100 years. This is a potentially explosive situation, which could turn an entire industry on its head, overthrow established market and industry structures, and open up a new era of mobility with completely new players (see Box 1.1).

Simply answering the question of which market is actually relevant reveals serious differences between the established manufacturers and the new entrants to mobility. The car manufacturers' basic assumption is a world market with a volume in 2015 of about 90 million vehicles and an average price of $23,000. This adds up to total revenue of $2.1 trillion, which serves as a reference for revenue planning for the coming years. The technology companies start their definition of the market with the observation that roughly 10 trillion miles (16 trillion kilometres) were driven in 2015. As the costs for a driven mile are about $1, this yields a potential revenue volume of $10 trillion. These differing views of the market result in differing strategies and tactics for the development of products and services to generate sales and revenue.

Autonomous mobility is also leading to completely new possibilities for intermodal transport, as mentioned above, especially involving rail and road

Box 1.1. Statement by Matthias Wissmann

Matthias Wissmann, President of the German Association of the Automotive Industry (VDA)

The German Association of the Automotive Industry (VDA) is working on the framework conditions so that automated driving will soon become possible in Germany and the European Union.

We can assume that automated driving functions will gradually be introduced and put into series production in the next 10 years. This technology will first be applied on highways, and then also on other roads. Many different and very complex traffic situations in the city present special challenges for automated driving. Urban traffic features pedestrians, baby carriages, cyclists, pedestrian crossings, bus stops, schools, kindergartens, roundabouts and so on. However, in the German automotive industry alone, about 20,000 development engineers are currently working on connected and automated driving. Manufacturers and suppliers will invest approximately €16 billion to €18 billion in this technology in the coming years. The VDA is working on the framework, together with the German government, the European Union and partners worldwide.

It is already clear that the new IT companies entering the car market and the traditional automobile manufacturers have differing concepts for autonomous driving. The former envisage an autonomous vehicle without a steering wheel, brake pedal and accelerator pedal. The occupants do not control the car; they are conveyed – there is no driver any more. The latter, however, are more evolutionary in their approach, starting by enhancing ‘conventional’ vehicles with automated functions where the occupant has the possibility at any time and in any driving situation to take over control of the car. Of course this does not exclude the development of new driverless vehicle concepts by the traditional automobile manufactures were the same technology as used in the conventional vehicles can be re-used. Autonomous driving is possible in special situations, automated driving offers greater flexibility and convenience.

From a global perspective, it is apparent that especially in the emerging markets, many people still have the goal of buying a car. In Germany, there are about 500–600 cars per 1,000 inhabitants depending on the region; in China, there are currently about 60–70. A mayor in China has reported that the commuters in his city spend an average of about 30 days a year in traffic jams. He sees it as beyond dispute that autonomous vehicles will help to significantly improve the traffic flow. But as soon as the traffic improves, many of those commuters will want to drive their cars themselves again.

The situation in Germany is not comparable with that in a Chinese city. The German cities have not grown at this speed and they have well-developed public transport and good roads. Nevertheless, for ecological and economic reasons, everything should be done to make traffic more fluid. Digitisation makes car driving more comfortable, it ensures more traffic safety and less congestion. This is why the German automotive industry is so heavily involved in this field of innovation.

transport. Robo-cars are the future of transporting passengers in the centres of smart cities. It will be possible to request such a car from the train using an app, and then to be picked up and driven home. The car will know the train timetable, the traveller's final destination, and will find the best, fastest or shortest route to that destination, taking traffic conditions into consideration. In the future, railroad companies may operate fleets of autonomous vehicles to supplement their existing services.

ECOSYSTEM

Autonomous driving not only involves technological challenges, but will also change the very essence of cars, which have been stand-alone products since they were invented [70]. Cars are now developing into ecosystems because they communicate with other cars, the traffic management centre and the infrastructure, and are integrated into a network of mobility services. In order to provide these services, it will be necessary to cooperate with suppliers, customers, technology companies and even competitors. Intercompany projects are increasingly gaining importance and are essential for launching products quickly and sustainably. This networking is usually temporary and project related, whereby the players take on changing roles within the mobility ecosystem. One example is the mobility platform Moovel, which finds the fastest or most convenient way of travelling from A to B for its customers, combining various modes of transport. This and other similar platforms are located in the ecosystem between mobility customers and suppliers, and are not focused on a vehicle or a manufacturer, but on optimising door-to-door connections. The vehicles themselves are equipped with various connected services, including not only all possible Internet services, but also specific remote services at home (closing the roller shutters as soon as the vehicle leaves the garage) or at the office (the light in the office is switched on as soon as the car approaches). In any case, the car is developing into a platform, perhaps even the control centre, for all kinds of communication between people and their surroundings [75].

So autonomous driving will mark not only a technical advancement, but also a cultural, social and economic phenomenon. It will change people's daily routines and working lives, the style and content of their communications, indeed, their entire mobility behaviour, and thus a number of established perspectives and certainties. The mobility revolution will change the rhythm of life for commuters, customers and consumers; it will certainly involve new risks, but will also open up new opportunities. The shift away from the product and towards mobility will have a significant impact on car manufacturers' organisation, culture and processes. A product that has been with us for over 100 years (the car) is now creating a service (mobility), which is integrated into an ecosystem. For many companies, this results in the need to answer the crucial question: What is our product?

If we look again at robo-cars, which might primarily be used on the last mile and in cities, public transport with train and bus operators will also play a major role for customers' mobility experience. Only fleets of cars in conjunction with trains will supply the mobility required by the market, which makes the product even more complex. This means that both companies and customers are required to re-examine the way they see mobility and related products and services in order to fully utilise the new possibilities of autonomous driving. In this book, we will therefore examine and discuss all (or as many as possible) of these developments.

How will autonomous driving change people's lives? What impact will it have on companies in the automotive and technology industry? Can environmental protection be improved? What will the economic consequences of this technology be? How will legal and regulatory conditions have to be changed? How can traffic be organised with this technology, especially in megacities? Can autonomous driving improve a nation's prosperity and competitiveness? These questions and others have to be answered so that autonomous mobility can be used for the benefit of people, companies, nations, cities and the environment. But before that, we need to look at some interesting facts about human driving, so that the significance of autonomous mobility and its social and economic consequences can be assessed.

Key Takeaways

Autonomous driving is no longer a fiction, it is reality. Many self-driving cars are already on the roads, most of them in controlled environments, but soon to be used in normal traffic.

For radical new ideas to become reality, all our previous perspectives, convictions, certainties and habits have to be discarded. The bastion of certain knowledge must be left behind in order to find a new perspective.

The essence of the driverless car consists of the processing unit and the technologies required to recognise and interpret the environment, such as cameras, lidar, radar and ultrasound. While in motion, the vehicle communicates with the infrastructure (V-to-I communication) and other vehicles (V-to-V communication).

The first autonomous taxis have been in use in the university district of Singapore since August 2016. An entire fleet of those vehicles is expected to be in operation by 2018.

In the coming years, three types of self-driving cars could emerge: robo-cars, buses and multi-purpose vehicles. The latter category could be subdivided into business, family and long-distance vehicles.

Autonomous vehicles will offer a wide variety of connected services and will feature an element of mobility solutions that will include other modes of transportation. This means that the existing stand-alone product will develop into an ecosystem.