Chapter 2: Background

2.1 Chapter Objectives

In this chapter, the technological context of the present research, namely Advanced Driver-Assistance Systems, will be described in more detail. Since this thesis will not focus on the technological aspects of ADAS, only a brief introduction on available systems and functionalities will be given. Potential advantages of ADAS will be discussed in more detail, together with potential risks of employing this technology. Next, an overview of the current market situation for driver-assistance systems in Europe is provided which shows the current state of diffusion of this technology. Finally, the chapter will close with a brief insight into the German car industry, explaining the relative importance of ADAS technology for this industry sector.

2.2 ADAS Technology

What is now called ADAS (Advanced Driver-Assistance Systems) can be considered as the collection of systems and subsystems on the way to fully autonomous driving. Industry experts agree that the rapid development of recent years will inevitably lead towards "intelligent" cars, detecting dangerous situations and acting autonomously to avoid accidents (European Commission for Information Society and Media, 2007). Already available ADAS concepts include among others Adaptive Cruise Control, Blind Spot Monitoring, Lane Departure Warning and Lane Change Assistance (Brookhuis, de Waard and Janssen, 2001, p.247). The basic aim of these assistance systems is "to help prevent driver errors, give warnings and provide support in performance of driving tasks" (Smith et al., 2008, p.341). Statistically, more than ninety percent of all road accidents are caused by human error, while an examination of accidents' most prevailing factors shows, perhaps not surprisingly, that the two most common reasons for accidents are loss of control over the vehicle and failing to avoid a vehicle (vehicle collision) (Bekiaris and Stevens, 2005, p.283; Brookhuis, de Waard and Janssen, 2001, p.245). Next to increased safety, most of these systems also offer a comfort benefit for the driver by taking over driving tasks and thereby reducing the driving strain. Traditionally, Advanced Driver-Assistance Systems are often categorized into safety systems, aimed at preventing accidents, and comfort systems, aimed at reducing the driving strain. This categori-

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sation is, however, rather artificial since most systems on the market provide both effects to some extent (Happe and Lütz, 2008, p.18). From a technical point of view, systems associated with ADAS can generally be allocated to three major categories: Longitudinal Support Systems, Lateral Support Systems and Assessment of Driver Vigilance System. Chart 1 provides a closer look at these categories and the major systems currently available in the respective categories.

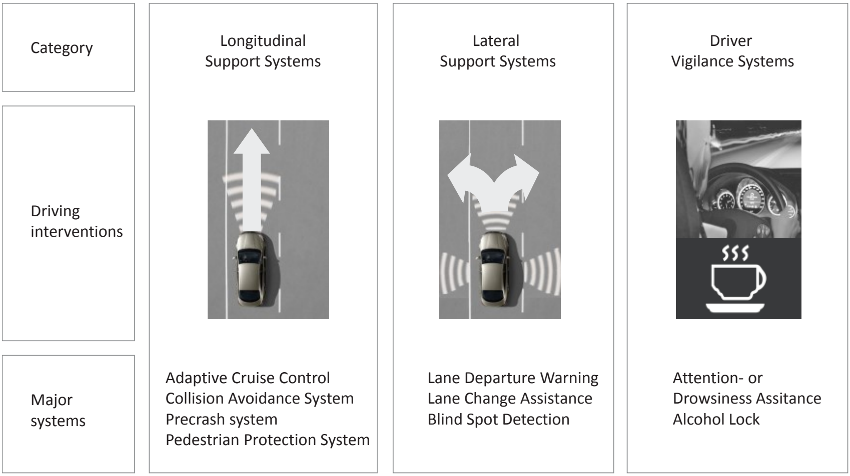

Chart 1: Overview of Advanced Driver-Assistance Systems, Source: Own drawing based on Papadakis (2007, pp.15–16)

Longitudinal support systems were the first available Advanced Driver-Assistance Systems on the market. As early as 1995, Mitsubishi introduced the Preview Distance Control, which can be considered the first Adaptive Cruise Control System (Mitsubishi Motors, 2008, p.1). Other car makers followed soon, making Adaptive Cruise Control (ACC) the most widespread available ADAS on the market today. ACC can be seen as an extension of conventional cruise control systems. In contrast to conventional cruise control systems, ACC, however, not only maintains the driver-set vehicle speed, but also adjusts the vehicle's speed to that of a preceding vehicle, thus keeping the exact distance to the car in front (Bekiaris, 2011, p.60).
Collision Avoidance Systems (CAS) use a similar technology to that applied by ACC in order to monitor the roadway in front of a vehicle and warn the driver when a potential collision risk to an object ahead of the vehicle exists. Active Collision Avoidance Systems additionally initiate an emergency breaking pro-

cess if a collision is judged as unavoidable (Krems, Risser and Barnard, 2011, p.16). A further extension of the forward road monitoring technology is the protection of so called *vulnerable road users*. Usually, these systems are aimed at protecting pedestrians from being involved in a car collision. Unlike the radar based ACC and CAS systems, Pedestrian Protection Systems (PPS) generally need a forward looking camera to identify potential vulnerable subjects in the vehicles pathway (Bekiaris, 2011, p.76).

Lateral support systems made their way into the car market considerably later than longitudinal systems, with the first lane-keeping support offered by Nissan in 2001 (Society of Automotive Engineers of Japan, 2011, p.1). Lane-keeping and warning systems are aimed to support the driver's lane keeping task. When a significant deviation from the expected vehicle trajectory is detected, these systems either warn the driver or steer the vehicle automatically back into the lane (Krems, Risser and Barnard, 2011, p.12). Other lateral support systems are designed to support the driver's abilities to change lanes. Blind Spot Monitoring Systems and Lane Change Assistance use various technologies to detect vehicles and objects in adjacent lanes, such as a fast approaching and potentially overtaking vehicle in the next lane. These systems either warn the driver that an intended lane change is unsafe or actively prevent the vehicle from changing lanes (Bekiaris, 2011, p.54).

Driver vigilance monitoring, finally, is aimed at detecting situations in which the driver's alertness is diminished, as a consequence of stress, fatigue or alcohol abuse. Most of the currently available systems in this field, such as the drowsiness alert offered by Mercedes-Benz, use already available information by several sensors (steering wheel positions, maintained speed, overall driving time, day time or daylight) in order to detect the driver's alertness. When a complex algorithm detects driver impairment, an alarm is given (Krems, Risser and Barnard, 2011, p.19). In order to detect alcohol abuse, Volvo was first to introduce a breathalyzer-based system which is connected to the vehicle's ignition. The system is aimed at preventing drunk drivers to start their vehicle when a critical alcohol level is exceeded (The American Beverage Institute, 2011, p.3).

2.3 Advantages of ADAS Technology

Providing support in critical driving situations, ADAS technology promises a significant decrease in road accidents. Due to the marginal market share of ADAS today, its potential future impacts can only be estimated. A study funded by the European Commission recently reported that the three percent of vehicles currently equipped with Longitudinal Support Systems prevent up to 4,000 accidents each year, while the 0.6% of cars equipped with Lateral Support Systems prevent about 1,500 accidents a year (European Commission for Information Society and Media, 2007, p.6).
German traffic researcher Johann Gwehenberger (2010, p.1) predicts that given a 100% equipment rate of ADAS in Europe, more than half of all serious accidents could be prevented. Considering that every year more than 40,000 lives are lost in European traffic, creating a direct and indirect economic loss of 180 billion EUR (Evgueni Pogorelov, 2007), it is not particularly surprising that the EU strongly supports the diffusion of ADAS technology. Next to the prevailing safety benefits and the increase in driving comfort, these systems could also provide cleaner and more efficient transport in the near future. Currently, researchers integrate the existing systems with online information and GPS signals, thus being able to judge the most efficient driving route and driving speed. Such systems could, for instance, identify a red traffic sign well before the driver is able to see it and reduce speed accordingly. Thinking this idea further, traffic signs might one day no longer be necessary, eliminating delays and waste of resources (European Commission for Information Society and Media, 2007, p.6).

2.4 Risks Associated with ADAS Technology

Even though there is clear evidence that ADAS technology provides major social and economic benefits, it must be acknowledged that these systems also entail some risks (European Commission for Information Society and Media, 2007, p.4).

ADAS can fail and, in general, there are two types of fault: random and systematic. Examples of random faults include communications interference and unexpected component failures, while systematic faults are related to software failures or overall failures in the design of the system (Bekiaris and Stevens, 2005, p.283). Moreover, it has been discovered that, whilst driver assistance

systems are aimed at reducing driving strain, they can also create stress by requiring performance of new tasks, for example, programming the navigation system or learning how to use the Adaptive Cruise Control (Smith et al., 2008, p.341). This touches another critical aspect regarding the ADAS technology: The lack of user-knowledge. Drivers usually receive little or no training about how to use a new system compared with, for example, personnel within a company. In most cases the maximum training consists of a user manual, which is often completely ignored (Bekiaris and Stevens, 2005, p.284). While the cognitive expenses necessary to learn how to operate the new systems are usually significant, the lack of training increases the risks of faulty operation, which might lead to ineffectiveness or even to serious traffic incidents.
Moreover, several studies have found evidence that excessive reliance on automated systems such as ADAS could deteriorate the driving performance. One important argument for supporting this claim is that while more and more normal driving operations are performed automatically, abnormal conditions have to be dealt with manually. Unfortunately, as a result of automation, experiences with these situations are limited and thus reactions could be sub-optimal. Increasing automation also has the effect that driver attention is shifted away from the driving task to a monitoring task. In general, studies have shown that prolonged periods of passive monitoring induce high levels of workload, despite the fact that information-processing requirements for these tasks are rather low in themselves. This shift also increases the danger of complacency, which is known to have a negative effect on alertness and reaction time (Brookhuis, de Waard and Janssen, 2001, pp.247–251; Papadakis, 2007, pp.21–22).

Shifting responsibility from humans to machines also raises ethical and legal implications. The question of technology paternalism in modern traffic was discussed as early as 1968 within the Vienna Convention on Road Traffic. In chapter
II, Article 13, the protocol expressly states that: *Every driver of a vehicle shall in all circumstances have his vehicle under control so as to be at all times in a position to perform all manoeuvres required of him* (United Nations Conference on Road Traffic, 1968, p.15). Whether or not future driver-assistance systems directed at partly autonomous driving are in compliance with this regulation is widely discussed by industry experts (ADAC, 2010, p.1; Berz, 2002, p.3; Etzold, 2002, p.1).The general notion, however, is that as long as the responsi-

bility is not completely shifted to the system and as long as the driver has the continuing ability to shut down or override the driving manoeuvre, driver assistance systems are in full accordance with this convention.

In sum, it has to be acknowledged that there are serious risks involved in ADAS technology. Even though most scientific studies in the field report that the advantages of ADAS far outweigh the disadvantages, there is still some uncertainty involved. This insight is a necessary condition for avoiding an uncritical "pro-innovation bias". According to Rogers (2003, p.106) "the pro-innovations-bias is the implication in diffusion research that an innovation should be diffused and adopted by all members of a social system, that it should be diffused more rapidly, and that the innovation should be neither reinvented nor rejected." Consequently, it is important to be aware that for many individuals, it might be perfectly reasonable not to adopt ADAS.

2.5 Market Situation of ADAS in Europe

In the next step, the current level of ADAS market penetration will be discussed with a focus on the relevant target group of the present study, the German automobile market. Despite their potential, most intelligent driver-assistance systems have not yet reached the market – neither in Germany nor elsewhere.
A recent study of the German Road Safety Council (DVR) revealed that only between 12 and 35 percent of car drivers in Germany are aware of certain Advanced Driver-Assistance Systems. In terms of equipment rates, however, the result is even more worrying. Only between 1 and 3 percent of cars are currently equipped with any of these innovations (German Road Safety Council e.V., 2010, p.1). Chart 2 gives an overview of the results from this study.

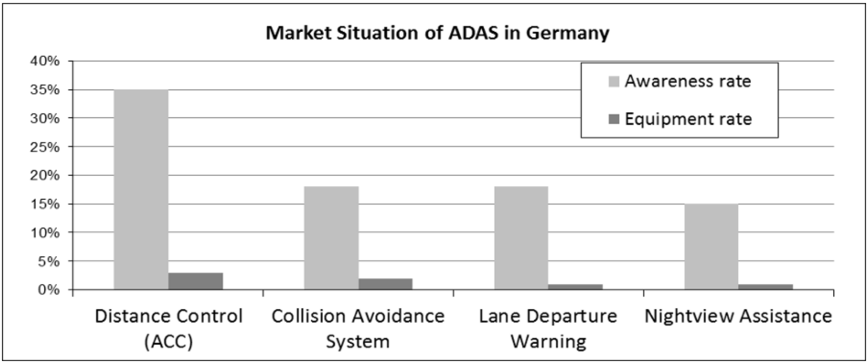

Chart 2: Market situation of ADAS in Germany, Source: Own drawing based on German Road Safety Council e.V. (DVR) (2010)

Equipment rates for other European countries are not available to date, but are expected to be on the same level or below. Due to the absence of definite numbers, the European Commission Working Group for the Implementation of ADAS estimated the penetration rates of ADAS innovations in Europe in a recent publication to be below 5 percent (European Union eSafety Forum, 2010, p.19). The study, however, remarked that penetration rates vary markedly between car categories. Safety innovations tend to start from the top end of the market, in luxury cars, and take a long time to 'trickle down' to the mass market. Currently most of these innovative systems are only available in the top-end luxury automobiles, which is a major barrier to further market penetration (European Commission for Information Society and Media, 2007, p.6). This development is comparable to the introduction of ABS and ESP technology, which were initially also restricted to luxury class vehicles. In terms of increasing acceptance rates, however, the comparison to the early assistance systems, ABS and ESP, shows a significant difference. While ABS and ESP have achieved s-shaped acceptance rates towards full acceptance (as predicted by current diffusion literature: see Rogers, 2003), ADAS still lacks the initial breakthrough that marks the start point of the increasing adoption curve (see Chart 3).

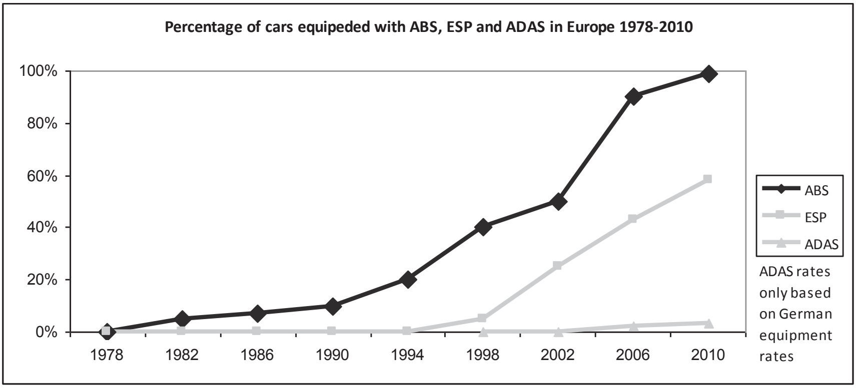

Chart 3: Equipment rates of ABS, ESP and ADAS, Source: German Road Safety Council e.V. (2005); Gottschalk and Kalmbach (2008); Happe and Lütz (2009); Kraus and Stephan (2010)

From the current perspective, it is thus questionable whether or not the Advanced Driving Assistance Systems will have the same market success as their preceding car innovation systems, ABS and ESP. According to Rogers (2003), perfect s-shaped acceptance rates that lead towards full acceptance (as in the case of ABS and ESP) are rather rare, and especially in the field of high-tech innovations, many innovations never actually gain any relevant market share. It is worth noticing that ABS became mandatory in Europe by 2004, while ESP will be mandatory from 2012 onwards (European Commission, 2007). Legislation thus stepped in when the adoption curve was already approaching full adoption in the European market. The question of whether or not Advanced Driver-Assistance Systems will one day be mandatory in Europe thus largely depends on how the adoption curve for ADAS will develop in future. Legislation can foster the development of technological diffusion but it cannot prescribe a certain development on its own. If ADAS is not accepted by the market, it is rather unlikely that legislation will be able to oblige its population to use this technology. The European Commission Working Group for the Implementation of Safety Systems in Cars developed two different scenarios for the future development of ADAS: First, the *Business as Usual Scenario*, with unchanged conditions, and second, the *Implementation Support Scenario*, which presumes legislative action in the form of financial or fiscal incentives and additional national support programs to increase the public awareness of ADAS. Table 3 shows the expected market development figures of both scenarios.

Table 3: ADAS market development scenarios, Source: European Union eSafety Forum, 2010, p.19

Business as Usual Scenario	**% new cars equipped**		
	2010	**2015**	**2020**
Obstacle & collision warning	< 5%	5% - 20%	20% - 50%
Emergency braking	< 5%	5% - 20%	20% - 50%
Blind spot monitoring	< 5%	5% - 20%	5% - 20%
Adaptive headlights	5% - 20%	20% - 50%	20% - 50%
Lane departure warning	< 5%	5% - 20%	20% - 50%

Implementation Support Scenario	**% new cars equipped**		
	2010	**2015**	**2020**
Obstacle & collision warning	< 5%	20% - 50%	50% - 80%
Emergency braking	< 5%	20% - 50%	50% - 80%
Blind spot monitoring	< 5%	5% - 20%	20% - 50%
Adaptive headlights	5% - 20%	20% - 50%	50% - 80%
Lane departure warning	< 5%	20% - 50%	80% - 100%

In conclusion, the current market for ADAS technology is still at a very early phase with a supply that is limited to a small model range (mainly luxury cars), a significant lack of customer awareness and a marginal market spread. Whether the rather optimistic market scenarios of the European Commission working group will come into reality will mainly depend on the acceptance of this technology by end-users in the respective markets.

2.6 The Importance of ADAS for the German Automobile Industry

This final part of the background chapter will focus on the special role of product innovations in the German car industry and will explain why driver-assistance technologies are of particular relevance to this industry sector. In the first step, an overview of the German automobile industry will be provided by identifying the key players and their current position on the world automobile market.

The German Automobile Industry

In terms of domestic car production Germany ranks third in the world, following the United States and China, with a total annual car production of almost six million cars. More than twice this number, almost 13 million cars are produced by German automobile companies worldwide (VDA, 2012). This makes the automotive industry the largest industry sector in Germany and with more than 700.000 direct employees one of the country's biggest employers (Germany Trade and Invest, 2010, p.3). Chart 4 shows the domestic production of the world's biggest car producing countries.

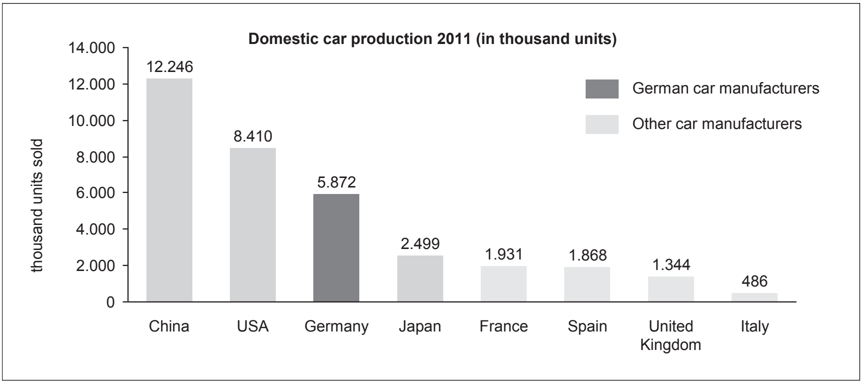

Chart 4: Domestic car production 2011, Source: VDA (2012)

Generally, Germany is renowned for its production of top-range luxury vehicles, but looking at the domestic car production reveals that, in terms of car categories produced, luxury cars represent less than five percent of the overall production volume. Most cars of the domestic production are in the medium and compact segment, with a considerable volume of off-road and upper medium vehicles. Chart 5 shows the segmentation of the German car production by car category.

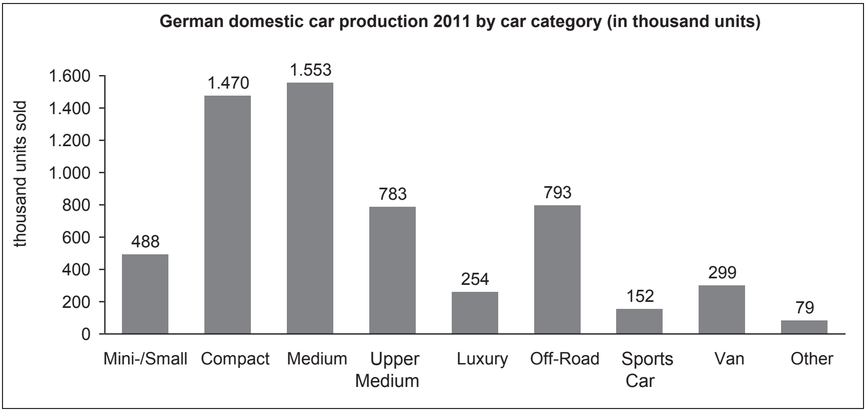

Chart 5: German domestic car production by car category, Source: VDA (2012)

As a result of an increasing market consolidation over the last decades, only three major German car manufacturers remained as independent corporations:

- Volkswagen (compromising the brands VW, Audi, Seat, Skoda, Bentley, Bugatti, Lamborghini and recently Porsche)
- Daimler (compromising the brands Mercedes-Benz and Smart)
- BMW (compromising the brands BMW, Mini and Rolls Royce).

It should be noted that the brand Opel/ Vauxhall, even though generally regarded as a German car brand, is actually part of the General Motors (GM) group and is consequently not considered as a German car manufacturer. In terms of production volume only Volkswagen ranks among the world's largest car manufacturers. Daimler and BMW have a considerably lower overall production volume, mainly due to their specific focus on premium brands (Center of Automotive Management, 2012b, p.22). Chart 6 shows the number of automobiles sold worldwide per car manufacturer in 2011.

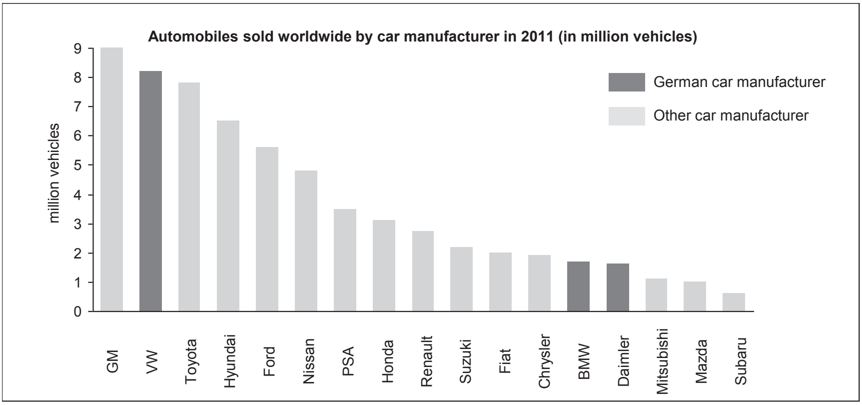

Chart 6: Automobiles sold per manufacturer, Source: Center of Automotive Management (2012b, p.22)

The Role of Innovations in the German Automobile Industry

Germany's automotive sector is the country's most innovative industry sector and accounts for more than one third of the total R&D expenditures within the German industry (Germany Trade and Invest, 2010, p.3). As a result of this, German car manufacturers also rank relatively high in the worldwide comparison of R&D spending per car manufacturer. Regarding individual companies, VW has had the highest R&D spending among all car makers with a total expenditure in excess of seven billion Euros in 2011. Daimler and BMW also invest heavily into the development of new technologies with an R&D spending of about four billion Euros each in 2011. When considering the relatively low rank in overall production volume of these two companies (see Chart 6), these figures are even more striking (Center of Automotive Management 2012b, pp.47). Chart 7 shows the Research & Development spending per car manufacturer in the year 2011.

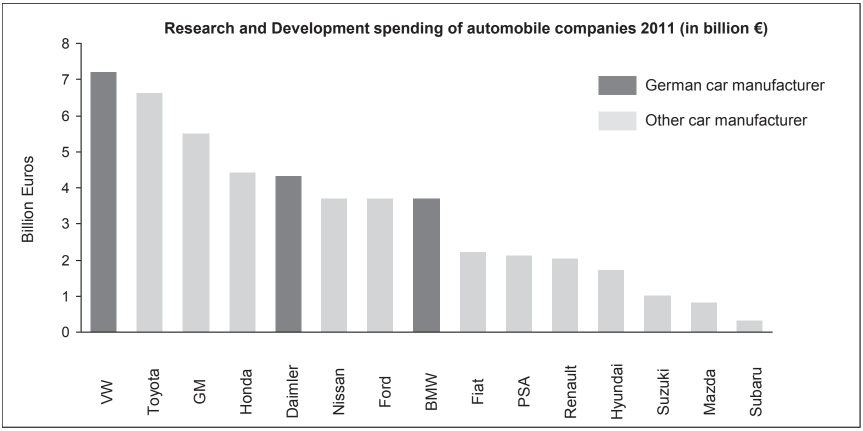

Chart 7: R&D spending per car manufacturer in 2011, Source: Center of Automotive Management (2012b, pp.47)

In the next step, the innovation output of car companies will be compared in order to determine whether the high R&D spending of German car manufacturers also translate into tangible product innovations. In an attempt to compare the innovation output of the worldwide car manufacturers a recent study determined the number of innovations presented within the year 2011 per car manufacturer. In this study innovations were defined as any publicly presented development in cars which provides a customer benefit and is perceived as new by the public (Center of Automotive Management, 2012a). While it certainly has to be acknowledged that a simple counting of innovations neglects the relative importance of innovations, this study nevertheless provided an interesting insight. The analysis revealed that, measured by innovation output, all three German car makers rank among the top five of car manufacturers worldwide. Consequently, the heavy investments of German car companies in R&D transfers directly into a comparably high innovation output, as measured by tangible product innovations. Chart 8 shows the number of innovations presented per car manufacturer in 2011.

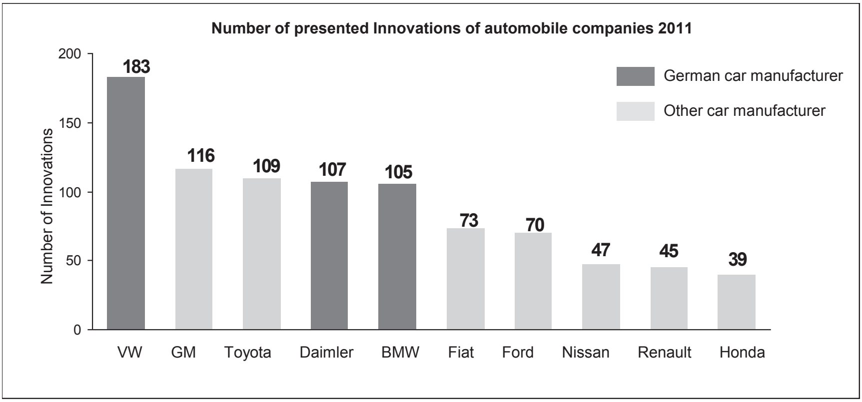

Chart 8: Number of innovations presented per car manufacturer in 2011, Source: Center of Automotive Management (2012a, p.91)

Finally, the focus of the innovation output analysis will be further narrowed down by looking only at innovations in the field of driver-assistance systems. This analysis reveals that, in terms of driver-assistance innovations, the three German car makers rank highest among all car manufacturers worldwide. Chart 9 shows the number of innovations in the field of driver-assistance systems, which were presented by car manufacturers in 2011.

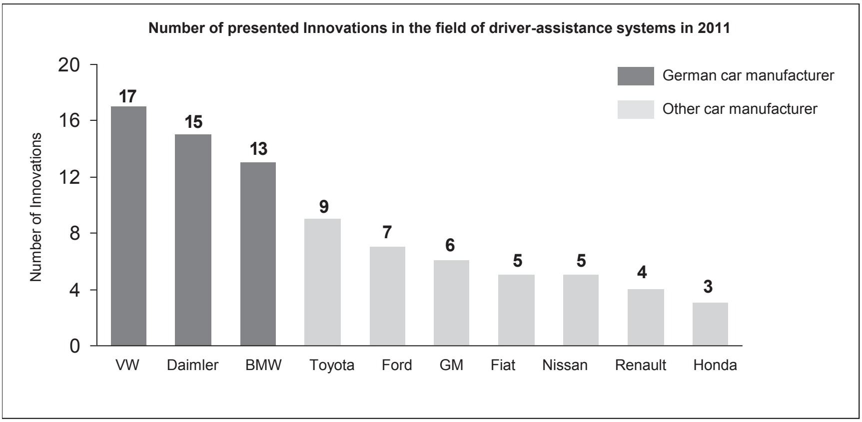

Chart 9: Number of driver-assistance innovations presented per car manufacturer in 2011, Source: Center of Automotive Management (2012a, p.50)

Conclusion
In sum, this industry sector analysis demonstrated the importance of the German automobile industry for the domestic economic welfare and its relatively strong position in terms of the worldwide car production. With more than 15 billion Euros in R&D expenditures, the three major German car manufacturers account for a large proportion of the worldwide research in the field of automotive technologies. These investments have enabled the German car makers to present 395 product innovations in the year 2011 alone, more than any other country's industry sector. While other car makers score higher on production volume, the German car makers capitalise strongly on their innovativeness to position their products in the premium segment. Especially in the field of safety and comfort innovations, such as driver-assistance systems, the German car makers have presented more product innovations than any other country's car producers.

2.7 Chapter Conclusion

The present chapter has provided an overview of currently available driver-assistance systems and has critically discussed the potential benefits and potential risks associated with this technology. In sum, the discussion showed that the benefits clearly outweigh the risks, at least from an objective point of view. On an individual level, the decision can, however, be substantially different. An analysis of the current market situation of ADAS showed that Advanced Driver-Assistance Systems are currently still niche products with low customer awareness and marginal market penetration rates. The chapter ended with an overview of the German car industry, which invests more into the development of driver-assistance technology than any other country's industry sector.

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