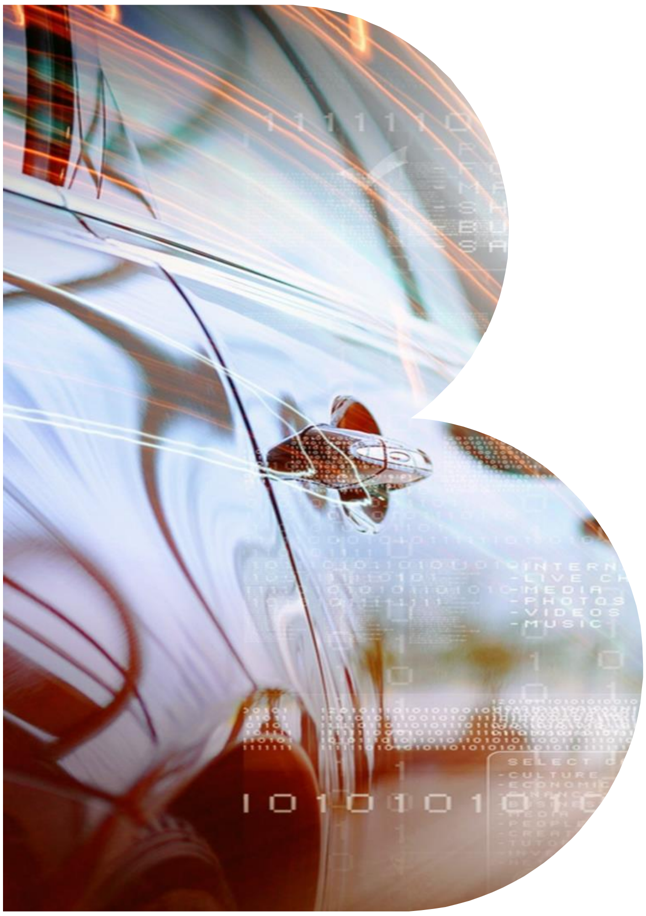


STUDY

Automated Vehicles Index

Q3 2016

Roland Berger GmbH - Automotive Competence Center &
fka Forschungsgesellschaft Kraftfahrwesen Aachen
July 2016

Dear Reader,

Connectivity between vehicles and the surrounding infrastructure is a constant subject of debate in relation to the introduction of highly automated driving. The focus is not only on using up-to-date data for maps, traffic volume information and hazard warnings, but also on generating and supplying this data with the aid of smart vehicle and infrastructure components. Only recently, Germany's Federal Ministry of Transport and Digital Infrastructure signed an innovation agreement that will involve equipping the test field on the A9 freeway with digital infrastructure. In collaboration with industry partners, high-precision real-time data on traffic flows, traffic volumes and road behavior will be made available in a cloud application for further processing and use in in-vehicle systems along parts of the public test route as of 2017. This issue of the AV Index thus takes the opportunity to examine the fundamental technical possibilities opened up by vehicle connectivity, highlight current developments and explore the hotly debated need for connectivity as a precondition for the launch of highly automated driving functions.

As ever, we also provide a comparative update on the competitive positions of individual national automotive industries. The countries' competitive positions have been updated based on the following indicators:

1. Industry: The state of technological development for vehicles designed and produced by the countries' OEMs, plus the scope and focus of corresponding research activities.

2. Market: Market size, represented by demand for advanced driver assistance systems as an indicator of user acceptance, alongside an assessment of the legal framework governing the operation of automated vehicles in each country.

Roland Berger GmbH and fka Forschungsgesellschaft Kraftfahrwesen mbH Aachen (fka) combine these indicators to produce the quarterly Automated Vehicles Index, which facilitates useful comparison of the competitive positions of the relevant automotive countries (the US, Germany, China, Sweden, the UK, South Korea, France, Italy and Japan), as well as using harmonized global benchmarks to measure these automotive markets against each other.

1. Key insights from the Automated Vehicles Index Q3 2016

OEM activities – German OEMs assert their leading position in a dynamic competitive environment

Germany's OEMs are still successfully defending their leading position. Their lead is attributable primarily to the systems they already have available in volume-produced vehicles. The international competitive environment is, however, becoming increasingly dynamic and intense. Various manufacturers have announced plans to launch specific automated vehicle functions in the months ahead.

Expertise – Different countries focus on different aspects of connectivity – The US and Japan concentrate on building the infrastructure for connected vehicles

The US and Germany lead the field in terms of automated vehicle expertise. Whereas virtually every country subsidizes the testing and demonstration of automated vehicles, approaches to connectivity research vary. One focus in the US and Japan in particular is on building the infrastructure for connected vehicles, as both countries see this as a key to realizing higher levels of automation.

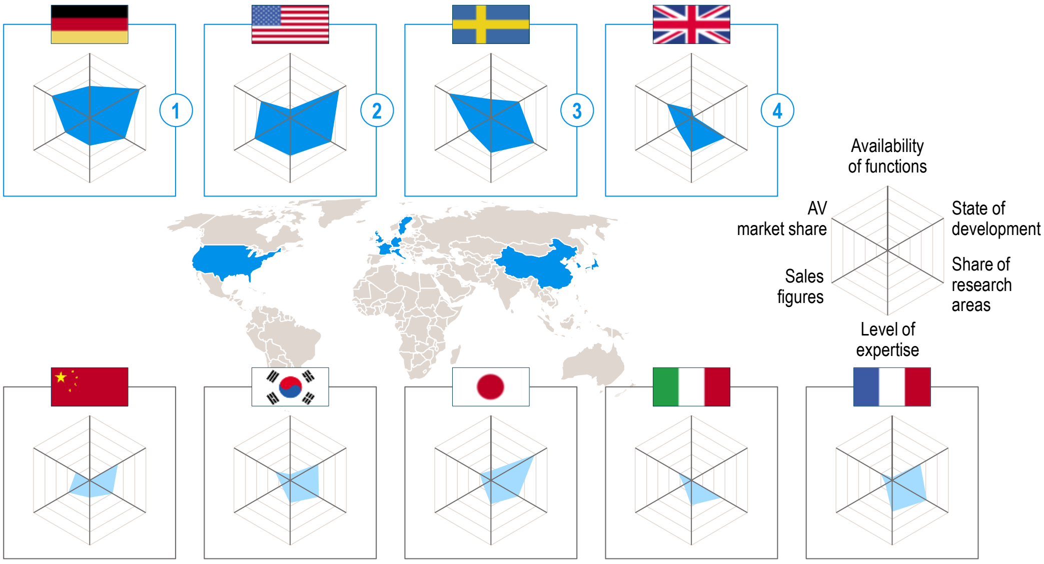
Legal frameworks – Germany adapts the Vienna Convention – South Korea begins the race to catch up – Singapore sets the pace in urban design concepts

Germany is taking another important step forward. The adoption of significant adjustments to the Vienna Convention, finally resolved by the cabinet in April, marks a major stride in the direction of automated driving. Yet even that is not enough to edge the US out of pole position. Much more far-reaching steps to simplify registration procedures are keeping the US well out in front. In the meantime, South Korea is planning its next steps toward the rapid roll-out of automated driving technology on Korean roads by creating public test fields. Other Asian countries outside the scope of our study are also planning to integrate automated driving in their urban design concepts: Singapore, for example, is already working on specific concepts to make cities more livable – and above all less congested with vehicular traffic – by deploying automated vehicle technology in local public transport and logistics.

Market volume – The US, South Korea and China benefit from the launch of relevant assistance functions in mass-produced models

In terms of market size, there is no movement in the top three slots compared to the last edition of the AV Index, with the US still ahead of Germany and Sweden. Yet even so, our underlying methodology finds that the US, South Korea and China in particular are benefiting from the launch of relevant assistance functions in mass-produced models. Within this dimension, South Korea and China have gained significant ground.

Figure 1: Comparison of the competitive positions of the world's leading automotive nations in the "automated driving" segment

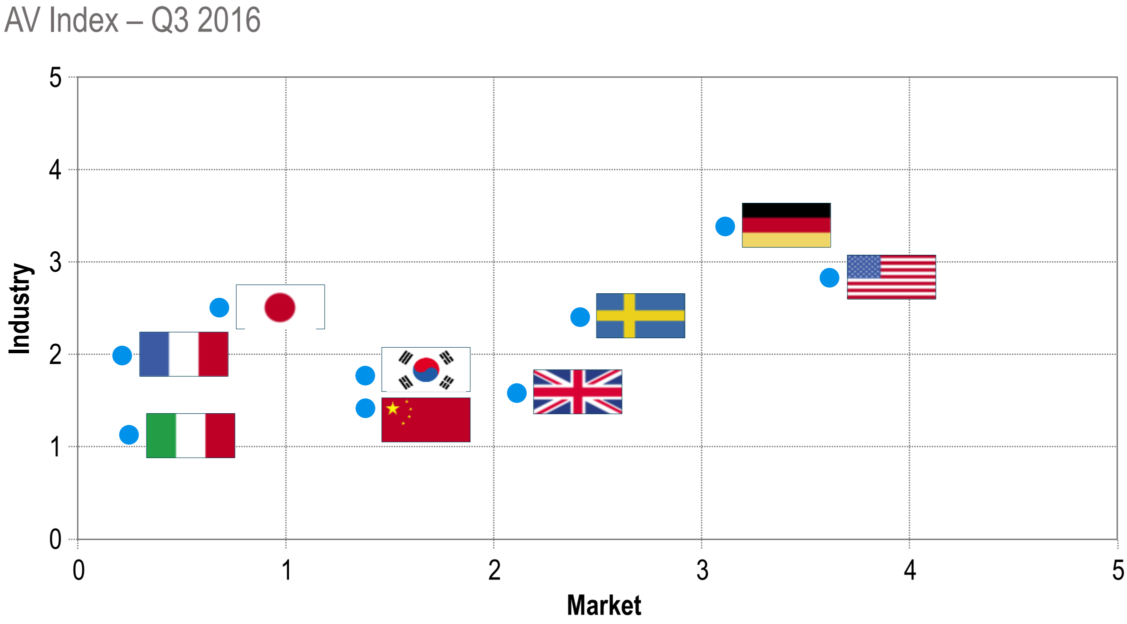


Source: fka, Roland Berger

2. Comparison of the competitive positions of the world's leading automotive nations – summary

Analyzing the industry and the market dimensions together enables us to produce a visual summary of the competitive positions of the world's leading automotive nations (Fig. 2).

Figure 2: Germany and the US are still out in front – The US extends its lead in the market dimension (AV Index – Q3 2016)

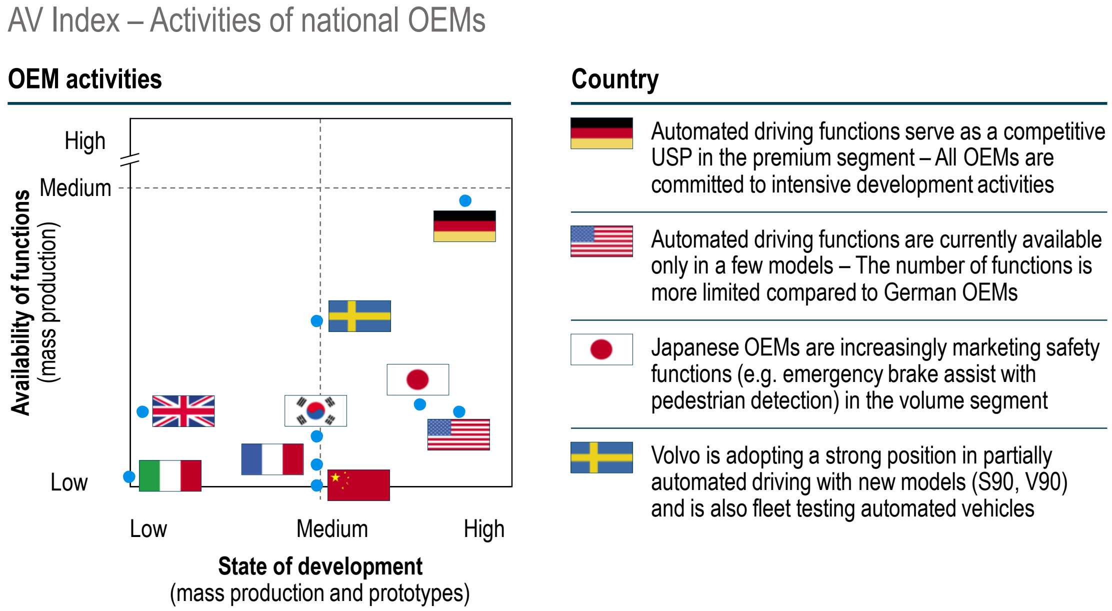


Source: fka, Roland Berger

Regarding the **industry indicator**, Germany was again able to defend its leadership over the US in the first half of 2016. However, Japan has moved up into third spot, trading places with Sweden in our ranking table. Changes have also occurred behind the leading group. Ramped-up vehicle automation activities are in evidence in South Korea and China, both of which have thus closed the gap on France. Overall, this will increase competitive pressure on the German automotive industry in the medium term. Close observation identifies OEM activities and expertise as the two criteria behind these changes.

Regarding the dimension **OEM activities**, the German car makers are still well ahead of their peers in the US (Fig. 3). The strength of Germany's OEMs is rooted in the high availability of automated driving functions in mass-produced vehicles. Especially in the premium segment, vehicle automation is used as a competitive USP. New driving functions are therefore implemented in most cases when new vehicle models (such as the Mercedes E-Class) come to market. This policy, however, is creating a dilemma for future vehicle models. On the one hand, new functions (such as remote parking) are quickly also marketed by competitors. On the other hand, the legal framework increasingly restricts the technological potential that is already there, such that certain functions in mass-produced vehicles are actually deactivated in some cases in order to comply with the law. Moreover, the international competitive environment remains highly dynamic. Practically every OEM has announced the launch of vehicles with automated driving functions in the coming months. Rapid market diffusion in all vehicle segments is possible especially for safety features. By the end of the coming year, Toyota and Lexus, for example, will be offering emergency braking assistants as standard equipment in virtually all models in the US. At the same time, international players who have not yet been at the center of the discussion are now also stepping out of the shadows. In recent months, Hyundai and Kia have positioned themselves very actively in the vehicle automation segment and are currently testing prototypes in the US (Kia Soul, Hyundai Tucson) and South Korea (Hyundai Genesis). At the Beijing Motor Show, Chinese OEMs too (such as Changan and BAIC) likewise showed off a variety of vehicle prototypes that are also factored into the study's assessment. The dynamism and intensity of OEMs' activities could in future receive even greater impetus from the potential market entry of new players (such as LeECO and Faraday), new start-ups, acquisitions designed to accumulate expertise (e.g. GM's purchase of Cruise Automation) and/or the option of cooperation between high-tech companies and incumbent OEMs (such as Google and FCA).

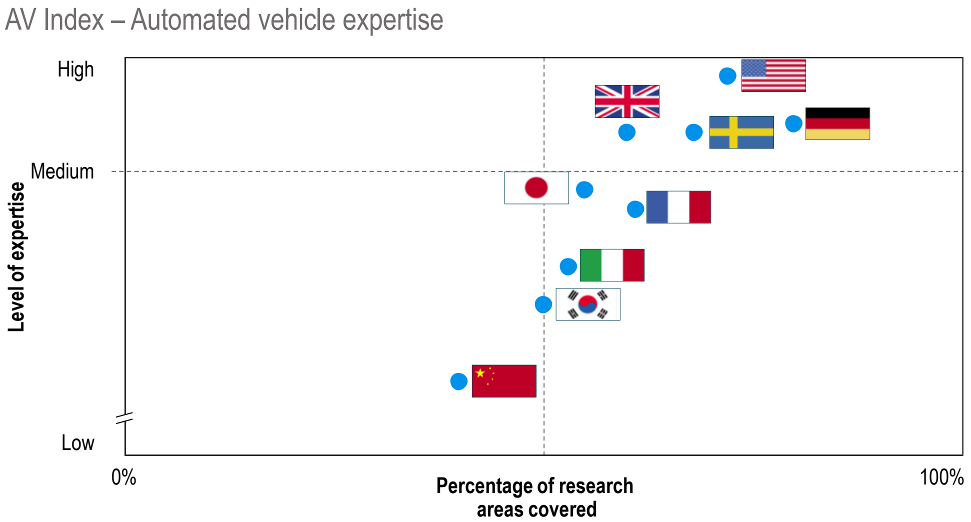
Figure 3: Intensified OEM activities are driving greater demand for the availability of AV functions in mass-produced vehicles (AV Index – Activities of national OEMs)



Source: fka, Roland Berger

The US and Germany still lead the field in terms of automated vehicle expertise (Fig. 4). As with the OEM activities parameter, South Korea has substantially improved its position and closed the gap on the mid-table countries. One reason is that South Korean universities and research institutes are increasingly bringing their development and testing activities into the international arena. One example is the testing of automated driving functions by the Korea Automotive Technology Institute (KATECH) within the framework of a development cooperation agreement with Ssangyong. Another is the development and testing of an automated taxi on the basis of a Hyundai Genesis at Seoul National University. However, global comparison does reveal variations in the focus of research in different national automotive industries. Whereas virtually every country subsidizes the testing and demonstration of automated vehicles, national shifts of emphasis exist in the field of connectivity research. One focus in the US and Japan in particular is on building the infrastructure for connected vehicles, as these countries see this as a key to realizing higher levels of automation. If the USD 4 billion research budget for automated and connected vehicles proposed by US President Obama is approved, the US could in future position itself as a global leading research hub in this field.

Figure 4: Germany and the US lead the field in terms of expertise – South Korea has improved its competitive position (AV Index – Automated vehicle expertise)



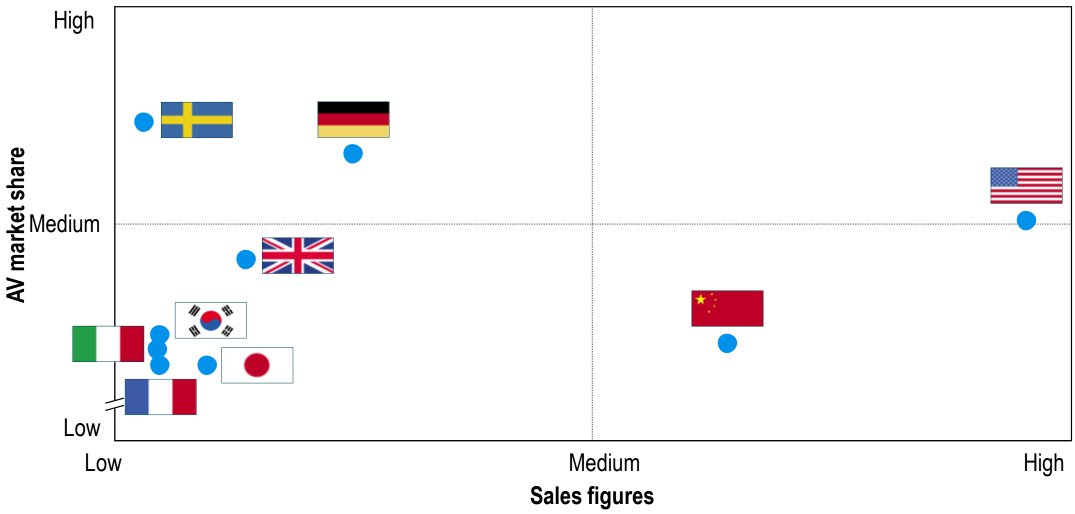
Source: fka, Roland Berger

For the **market** indicator, the distribution of leading positions between the US, Germany and Sweden remains unchanged (Fig. 5). A very large market volume (in absolute terms) for vehicles fitted with relevant assistance systems continues to give first place to the US. Germany and Sweden rank second and third respectively due to the very high specific share of new vehicles fitted with such systems.

Even so, the US was still able to extend its lead on the basis of our underlying methodology, in particular thanks to the launch of relevant assistance functions in mass-produced models. The models with particularly strong US sales figures produced by Toyota (including the Prius and RAV4) and Mazda (including the 3 and 6 models) are now available with relevant assistance functions, for example. South Korea has benefited especially handsomely from this development, followed by China.

Figure 5: The US, South Korea and China have benefited mainly from the launch of assistance functions in the volume segment (AV Index – Market potential for vehicles with advanced driver assistance systems[1], Q1 2016 through Q4 2016)

AV Index – Market potential for vehicles with advanced driver assistance systems[1], Q1 2016 through Q4 2016



1) Theoretical market ceiling for vehicles with ADAS fitted as standard or as optional extras

Source: IHS, fka, Roland Berger

Looking at the **legal framework** indicator (Fig. 6), although there has been no change in our fundamental assessment of the legal situation since the index was last published, Germany is taking another important step forward. The adoption of significant adjustments to the Vienna Convention, proposed within the framework of Germany's "Strategy for Automated and Connected Driving" and finally resolved by the cabinet in April, marks a major stride in the direction of automated driving. As our index shows, however, even that is not enough to edge the US out of pole position. Ultimately, Germany is merely defending its regular second place behind the US. Much more far-reaching steps like the simplification of registration procedures continue to keep the US well out in front – for the time being, at least. In the US too, more and more voices in government and industry are calling for amendments to the existing legal framework across all the federal states. That is all well and good, but sluggish implementation due to a lack of interstate agreement could put the US at a disadvantage.

Meanwhile, South Korea has begun the race to catch up and, by creating public test fields, is planning its next concrete steps toward the rapid roll-out of automated driving technology on Korean roads. By contrast, Japan – a country open to the introduction of automated driving functions up to now – only recently announced that driverless cars (vehicles with no steering wheel or pedals) cannot be tested on public highways.

It also seems worth mentioning the discussion about the **liability** of autopilots and the fundamental recognition of computers as future drivers, which flared up at the start of the year. The debate was originally initiated by technology group Google as a question to the US transport authority NHTSA; and the latter has essentially advocated recognizing computers as drivers, albeit subject to conditions that remain to be defined. The topic was also recently raised in Germany by the Federal Ministry of Transport and Digital Infrastructure and is being tackled as part of the "Strategy for Automated and Connected Driving" that we touched on earlier. In the strategy paper it has submitted, the ministry highlights two points in particular. One is clarification of liability based on the possibility of giving equal legal status to autopilots and human drivers, which could also prompt changes in road traffic regulations. The other is the establishment of an ethics commission representing the academic community, the automotive industry and the digital economy. This commission will be tasked with drawing up clear guidelines for algorithms to determine how vehicles are to behave in risk situations.

Figure 6: Relevant legal amendments by key pacesetters for the introduction of automated driving (AV Index – Overview of legislation in key regions)

AV Index – Overview of legislation in key regions

	General	Registration	Testing and safeguards
US	> Individual legislation in each state facilitates fast ratification of legal amendments > Vienna Convention not ratified	> Operation of automated vehicles on public highways is explicitly permitted in a few selected states (e.g. Nevada, Michigan and Virginia)	> Private test sites used by universities and industry (e.g. Michigan M City) > Tests on public highways in selected states
Europe	> Most countries have ratified the Vienna Convention > Germany, Sweden, the Netherlands and the UK are calling for swift adjustments, but all EU member states must reach agreement	> Heavy restrictions on registration. In Germany, for example, vehicles can only be registered as test vehicles > Vienna Convention currently prevents the launch of highly automated functions (e.g. ECE R79)	> Private and public test fields > Public "Digital Test Field" for infrastructure and connectivity established on the A9 freeway, additional test fields planned in Baden-Württemberg and Lower Saxony
China	> Few concrete measures at present, but positive legal conditions for automated driving (Vienna Convention not ratified)	> Several suggestions on how to handle registration of automated vehicles, but no concrete steps yet taken	> Mostly national research projects with corresponding funding for selected Chinese projects
Korea	> South Korean government has decided to ease legal restrictions relating to automated driving (e.g. by abolishing speed limits for automated vehicles)	> Concrete adjustments planned to support the launch of automated vehicles	> Concrete plans to set up public test fields
Japan	> Legal initiatives for automated vehicles on the political agenda, but slowed significantly of late	> Registration possible above all as test vehicles on public highways	> Private and public test fields > Recent announcement that fully automated vehicles cannot be tested on public highways, limited necessary safeguards

Source: Press research, fka, Roland Berger

3. Focus on connectivity

Connectivity continues to gain ground in vehicles, driven primarily by the demands of customers and lawmakers

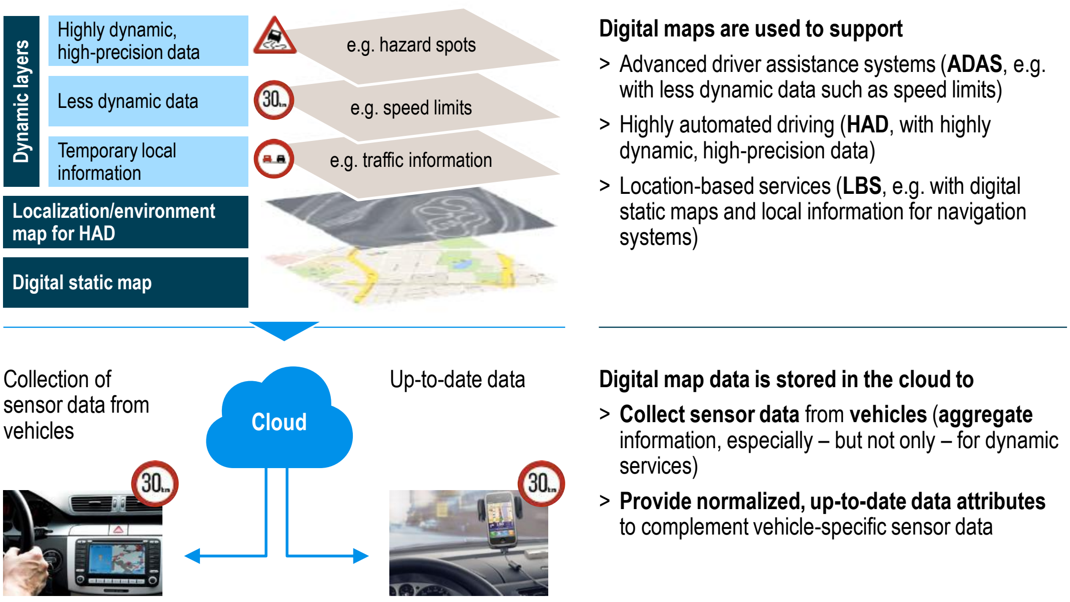
Approximately a third of new vehicles in the US and roughly 10% of vehicles in Europe currently have internet connectivity. In future, more and more cars will be fitted with SIM cards that connect them to their environment and provide safety and entertainment services to drivers and passengers alike. Traditional SIM cards will increasingly be replaced by built-in (embedded) SIM cards that can be programmed by the OEM and allow drivers to change provider without having to replace the SIM card.

However, the automated and cooperative vehicle functions of the future, some of which are supplied with data from mobile networks, place potentially heavy demands on communication technology (e.g. availability). Existing connectivity solutions based on today's mobile networks are not sufficient. Narrow bandwidths and excessive latency in some cases lead to the slow transfer of high-precision map data.

Automated driving – High-availability, high-definition maps and redundant auxiliary communication forms such as V2X are essential

High-resolution digital maps containing additional information are fundamental to automated driving (Fig. 7).

Figure 7: High-precision, high-availability maps are fundamental to highly automated driving



Source: Bosch, Roland Berger

For safety reasons, what is known as the environment model will be generated and stored in a suitable form in the vehicle itself. At the same time, internet connectivity will allow it to receive a bidirectional supply of up-to-the-minute mapping data.

Near-field communication (vehicle to vehicle/infrastructure/V2X) also opens up ways to supply vehicles and/or infrastructure elements with selected data without having to set up a mobile link.

Mobile communications and near-field communication – Complementary approaches with different focuses in Europe and the US

As things stand, it is anyone's guess which communication technology will in future become established as the standard for vehicle connectivity. Respondent experts in Europe currently see a focus on mobile communication technology, especially with a view to new near-field networks that could become reality when the new 5G mobile network is launched in 2020. On the other hand, the US – driven by government initiatives – is concentrating on a near-field communication technology called Dedicated Short Range Communication (DSRC) that is based on wireless LAN and uses radio-frequency communication to connect infrastructure elements to vehicles.

Neither technology will get by without investment. London is one of many cities and municipalities in Europe that are advocating minimal infrastructure spending and instead focusing fully on vehicles, high-availability mapping data based on mobile communication standards, and the continued development of the latter.

*"Some OEMs already use special 3D maps in test vehicles and proclaim that they will need no extra infrastructure communication in order to provide highly automated driving functions of level 4." **Iain Macbeth** (Transport for London)*

Outside Europe too – in Singapore, for example – there is a preference either for existing technology or technology that has already been commissioned as the basis for launching automated vehicles, making cities more livable and, above all, relieving urban congestion.

*"We want to very quickly introduce automated driving functions in local public transport and logistics to make our cities more livable. To do so, we are backing self-driving vehicle technologies that essentially get by with no new infrastructure technology. At the same time, we advocate connectivity with existing infrastructure components such as our new electronic toll system, which is used in many vehicles." **Pang Kin Keong** (Permanent Secretary of Singapore's Ministry of Transport)*

Especially in central urban areas with well-developed mobile networks and low speeds, a multitude of information with relevance to automated driving functions can be transferred via mobile communication. On intercity journeys, where speeds are higher, V2X communication could nevertheless be a sensible way to broaden the scope of vehicle sensors by using direct communication with other vehicles and infrastructure. On this basis, it would also be possible to develop cooperative and automated driving functions with significant safety and efficiency potential (e.g. cooperative ACC and traffic merging assistants).

The US' National Highway Traffic Safety Administration (NHTSA) has published a proposal to make built-in DSRC systems compulsory. It supports widespread introduction in all new vehicles and infrastructure elements as of 2018, partly because it wants to keep traffic management independent of mobile networks. Key intersections will be seen as central elements that are to be fitted with these communication features.

*"For the launch of safe automated driving functions, we prefer vehicle-to-vehicle and vehicle-to infrastructure communication near intersections." **Greg Larson** (California Department of*

Transportation)

A lack of global standards and different approaches make it harder to get connected and automated vehicles to market

Ongoing development of powerful mobile communication standards such as 4G LTE Advanced and 5G will improve bandwidths, availability and latency, but will in particular also facilitate near-field networks as a high-availability alternative to established mobile communication technology. However, the absence of global standards and high levels of investment for near-field communication (V2X) and the various approaches currently being adopted, as evidenced in some of the interviews we conducted, clearly show the scale of the challenges that will face governments, telecommunication providers, OEMs and suppliers in relation to vehicle connectivity.

4. Methodology

The relative competitive position of the different automotive nations is measured on the basis of two key indicators: the industry and the market.

Industry

> OEM activities: The current state of the country's automotive industry in terms of the availability of (partially) automated driving functions in mass-produced vehicles and their realization in prototype vehicles;
> Research and expertise: The country's position on knowledge and expertise in research areas of relevance to automated vehicles, as represented by the research activities of the top universities and relevant research programs.

Market

> Legal framework: Comparison of the legal frameworks for operating and driving automated vehicles;
> Market volume: Comparison of total sales figures with the share of vehicles sold that have relevant driver assistance functions.

The individual indicators are weighted by Roland Berger and fka and compiled in the Automated Vehicles (AV) Index. Each indicator is ranked on a scale from 0 to 5). The index facilitates useful comparison of the competitive positions of the relevant automotive nations (the US, Germany, China, Sweden, the UK, South Korea, France, Italy and Japan). National automotive markets can also be compared on the basis of harmonized global benchmarks. The index thus reveals the extent to which each of the countries surveyed is able to participate in the growing market for automated vehicles. The indicators we apply are assessed based on the following parameters:

OEM activities

> The availability and performance of the (partially) automated driver assistance systems that are available in current vehicles, differentiated by vehicle segment;
> The state of technological development, measured by the number and complexity of automated driving functions that the country's automotive industry currently makes available in mass-produced vehicles or has demonstrated in prototypes.

Research and expertise in the field of automated vehicles

> The expertise in driver assistance systems and advanced levels of automation possessed by those of the country's universities and research institutes that are strongest on research;
> The scope and breadth of research topics covered in the fields of sensors, vehicle intelligence and validation/testing, as well as adjacent fields such as connectivity and digital infrastructure in light of the depth of expertise.

Legal framework

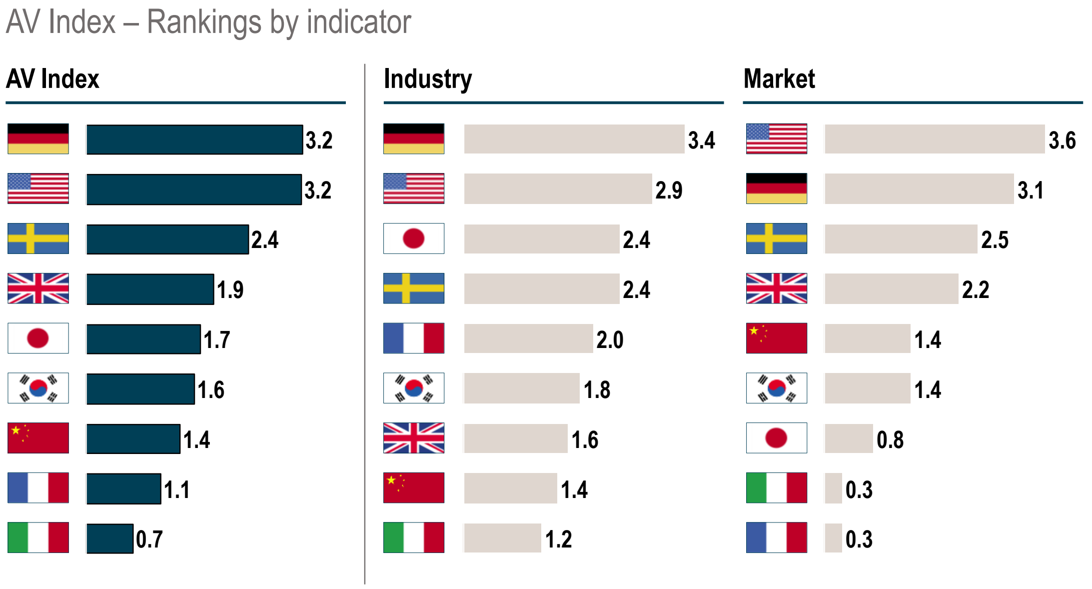
> Legal conditions governing vehicle registration and operation, subject to due account for civil law, public law and existing norms and standards;
> Legal constraints with regard to liability issues and driver behavior law.

Market volume

> Sales figures for all vehicles in each country, plus the share of vehicles fitted with driver assistance systems on SAE levels 2 and higher (e.g. congestion assistance systems).

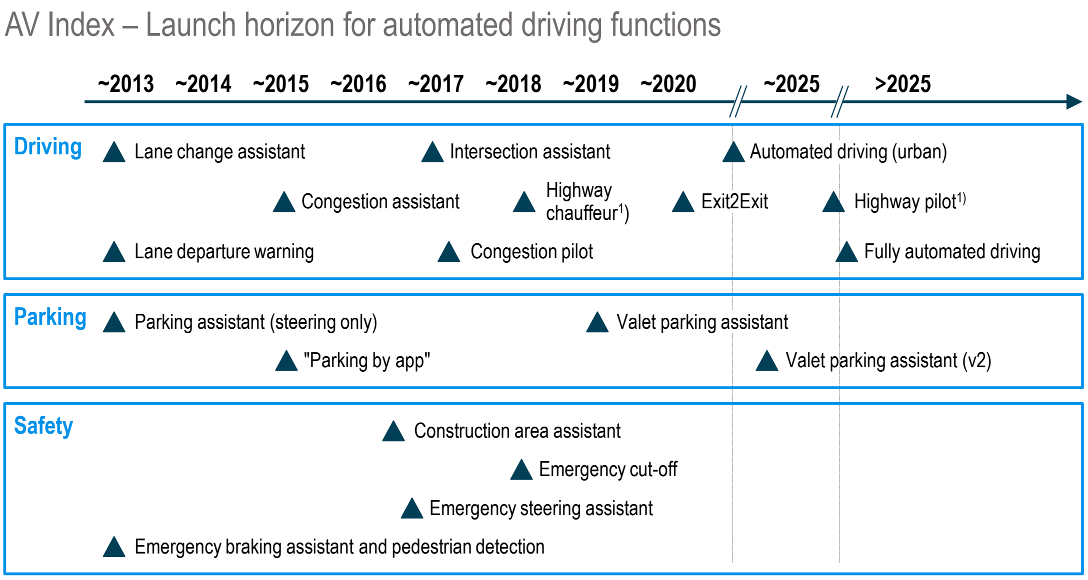
5. Appendix

Figure 8: Germany and the US lead the AV Index – Sweden lags some way behind in third place
(AV Index – Rankings by indicator)



Source: fka, Roland Berger

Figure 9: OEM activities are benchmarked on the basis of driver assistance functions, including fully automated driving
(AV Index – Launch horizon for automated driving functions)



1) Highway pilot = highway chauffeur + higher level of automation

Source: Press research, conference papers, fka, Roland Berger

Figure 10: Driver assistance functions of relevance to the index are those on SAE level 2 and higher (AV Index – SAE level definition)

AV Index – SAE level definition

SAE level	0	1	2	3	4	5
	Human driver monitors the driving environment			Automated driving system ("system") monitors the driving environment		
Name	**No automation**	**Driver assistance**	**Partial automation**	**Conditional automation**	**High automation**	**Full automation**
Narrative definition	The full-time performance by the human driver of all aspects of the dynamic driving task, even when enhanced by warning or intervention systems	IThe 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 will perform all remaining aspects of the dynamic driving tasks	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 will perform all remaining aspects of the dynamic driving task	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	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	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
Execution of steering and acceleration/ deceleration	Human driver	Human driver and system	**System**	System	System	System
Monitoring of driving environment	Human driver	Human driver	Human driver	**System**	System	System
Fallback performance of dynamic driving task	Human driver	Human driver	Human driver	Human driver	**System**	System
System capacity (driving modes)	n/a	Some driving modes	Some driving modes	Some driving modes	Some driving modes	**All driving modes**

Source: SAE Int., J3016, fka, Roland Berger

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