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SMART MOVES REQUIRED – THE ROAD TOWARDS ARTIFICIAL INTELLIGENCE IN MOBILITY

September 2017

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EXECUTIVE SUMMARY

Artificial intelligence (AI) is a “hot topic” across many industries today. Many products and services are currently being sold as “intelligent,” but in most of those cases it is rather a form of advanced analytics (AA). For all of the talk of what AI may be able to achieve in theory, the question remains: is it all hype, or is it an important technology that companies inevitably need to master in the future? In our view, the next-level improvement by AI is a massive driver of competitive advantage. This is even more the case for the automotive industry and the mobility sector than it is for most other sectors since, in automotive, AI leads not only to productivity improvements but also to new products and businesses.

Players in automotive/mobility are thus contending not only with the overall question of what AI means for their sectors, but also with several more specific questions: how important is machine learning (ML) for the automotive/mobility industry? How receptive are consumers towards usage of AI in mobility and what are the core applications of ML technology in automotive and mobility? What challenges towards monetizing the technology do automotive and mobility players need to tackle?

This McKinsey report provides guidance on these pressing questions and develops an industry-level perspective on the new mobility and automotive market environment. To this end, we conducted primary research in the form of consumer surveys and technology investment landscape analysis as well as interviews among multiple AI stakeholder groups to form a forward-looking perspective.

Behind the hype, ML is a significant source of competitive advantage for the next decade(s)

ML is a major approach to realize AI. It implements AI by using data rather than explicitly programmed rules. Applying a practical working definition, the technology is able to deliver in three key areas in automotive/mobility: act upon highly complex situations (as measured by the amount of data needed to describe it); cope with a large number of situations that cannot be covered adequately by explicit programming; improve over time without explicit instructions, learning from data of previously unknown situations in an unstructured way.

In the mobility industry, ML will not be optional; it will be a technological foundation and the source of significant competitive advantage. For example, ML is required for autonomous driving (AD), at the very least in image recognition, where human programming cannot possibly keep up.

MCKINSEY RESEARCH AI IN AUTOMOTIVE

Total of 3,000 consumers surveyed on AI applications in the US, Germany, and China

Industry and academia collaboration – industry leaders, tech players, AI start-ups, and academics

AI start-up and investment analyses

ML-based applications show significant opportunities

One clear finding of the research bodes well for AI's development: not only do consumers expect AI to have a large impact, they understand that AI will be a game changer. Contradicting general expectations, the vast majority is open to the ways AI might improve their lives with only 25 percent seeing a major risk associated with AI. The interest in/acceptance of AI in general is also true when it comes to its applications to automotive/mobility. Nearly 50 percent of surveyed consumers feel good about the idea of family members using fully autonomous vehicles. This openness is primarily driven by three aspects of AI in mobility: the increased levels of comfort and convenience offered by AI applications in general; the prospect of vastly improved safety through AD (i.e., zero accidents) with 76 percent of consumers convinced that AD will reduce accidents; the macro-benefits to environment (e.g., potential reduction of emissions) and society (e.g., potential optimization of traffic flow, less required parking space in city centers). Openness to AI in mobility is especially prevalent among Chinese consumers, young people, and those living in urban areas.

This overall interest in what AI could enable in automotive/mobility technology also leads to a considerable willingness to pay for those features. What's more, there are high expectations around the topic, with the average of all consumers expecting full autonomy to be widespread on the road already in about five years.

It is the potential of ML to improve productivity and build on consumer interest by unlocking entirely new product offerings and therefore new value pools that will drive the technology's significant impact on the automotive/mobility industry. In this context, we have identified a number of exemplary application areas of ML in automotive/mobility, which fall into three distinct categories: process optimization and increased productivity (often rooted in AA, but enhanced by ML); new or enhanced products (mainly enabled by ML); entirely new (vertical) businesses along customer use cases, making use of these new products.

To benefit from AI, several challenges need to be overcome

The application of ML technology in a mobility environment engenders such complexity, that it will require new structures around the mobility ecosystem. This is due to the fact that, for example, the diversity of the set of stakeholders in the new industry landscape and the technology that supports it will require completely new commitments including partnering, systems, and ways of working. Also, there will be a number of ML-enabled systems in and around the car, some embedded with occasional communication/updates to a back-end, some cloud based pushed real time to the car. To navigate in this orbit, we see three kinds of challenges:

Coping with the accelerating race for technology. Most of the underlying algorithms/approaches for ML in automotive/mobility are readily available. However, significant gains still have to be made in the actual implementation and embedding of the technology. Approximately 500 companies in the ML in automotive/mobility ecosystem are working to build the technology know-how necessary to claim their position(s) in the value chain. A total disclosed investment of about USD 52 billion has been made since 2010 into those companies, which is more than the USD 32 billion (disclosed) investment in all shared mobility/e-hailing start-ups in the same timeframe. Nearly all of that investment (97 percent) has come from nonautomotive players (PE/VCs and tech players) and has gone largely to full-solutions providers developing AD and in-vehicle experience solutions. The development of such investments shows that the race is accelerating: the amount of investment in the past four years has quadrupled as compared to the previous four years.

Regulations and standards. “Automotive grade” requires higher safety standards and more accuracy than many current ML use cases. In general, for automotive and mobility, a regulatory involvement is likely, together with coordination of industry standards, to allow for scale as well as the integration of various systems. Current players in that space need to watch out for legislative developments and might actually shape the respective standards early on during the development of the technology and its applications (cf. ABS systems).

A shift in business model. The emergence of new business models poses a challenge for OEMs that historically were able to stick to their classical model. Many of these new business models might shift the OEMs’ businesses more towards B2B relations (e.g., fleet sales, mobility services to municipalities) with typically lower margins. New services, however, could also open up new business models that involve direct and sustained end-customer interactions and present the opportunities and challenges that accompany deeper, ongoing end-customer relationships. One example is a model in which instead of selling cars to a third-party e-hailing company, OEMs offer the service directly to end customers and maintain ownership of the autonomous vehicle (AV) fleet. Services like these require the vehicles to become more software centered; in an end state, they should become more like smartphones, with latest updates as a must-have.

Putting ML on the road requires some smart moves

OEMs are well positioned to profit from the aforementioned developments, especially due to the embedding control point. What’s more, a majority of consumers are looking to car manufacturers to lead the development of autonomous functions and expect them (rather than tech players) to bring those to market. The level of trust in the OEMs is also much higher than that in tech players when it comes to bringing fully matured autonomous functionality to the market. Against this backdrop, OEMs should now make five smart moves to leverage their position for success: focus on core application areas, leverage breadth of data, drive standards, grow tech and business partnerships, and hedge business models.

We wish to express our appreciation and gratitude to the German Association of the Automotive Industry (VDA) for their support and valuable contributions. In particular, we would like to thank Dr. Joachim Damasky, Henry Kuhle and Graham Smethurst.

1

AI IN MOBILITY AND AUTOMOTIVE – INDUSTRY BUZZ OR INDUSTRY BUSTER?

1.1 Not everything that is new is AI; many applications actually build on traditional methods

AI is today's industry "hot topic." Many products and services are currently being sold as "intelligent," but in most of those cases it is rather a form of AA (e.g., an evolution from conventional algorithms) that is the enabler of those features, e.g., predictive maintenance in manufacturing.

AI, however, is more than complex calculations involving massive amounts of data. It is the ability of machines and systems to learn to deal with situations far beyond the initial inputs of software programming. It is their capacity to – much like humans – process, interpret, and make decisions based on massive amounts of entirely new inputs based on prior experience.

Although AI has existed since 1950, it has only gained wider functional applicability recently (see Text Box 1). This has been made possible through new approaches (e.g., deep learning) and training methods, better and more powerful computing hardware, and the availability of large amounts of data through the cloud.

Despite these developments, we are still only at the beginning of the AI disruption. The current state of the art is "narrow AI," which is able to outperform humans but only in very specific tasks. Developments in this field are occurring at a rapid pace. For example, ML-based methods surpassed human abilities in image recognition in 2015 and a deep-learning system beat the world champion of the board game Go in 2016 – one of the most complex board games in existence. Autonomous driving, while being very complex, still represents narrow AI.

The level and nature of specific AI technology required differs very much by application. For example, narrow AI comprises classic navigation systems as well as autonomous driving with approximately 1 GB of data per second – 1 million times more data than current navigation systems handle.

Beyond this narrow AI comes "general AI," which matches human abilities across many areas (including scientific creativity, social skills, and general wisdom), and finally "super AI," where the technology outperforms humans in every field. This presumes the continued growth of available computing power. Today, computers have already surpassed the computational-power equivalent of a mouse brain, and if the exponential progress of computing power following Moore's law continues, they will reach human-level power by 2030.

The focus of this report is AI systems that use ML – specifically deep learning techniques – to enhance or create new application areas in the automotive/mobility sector. See Text Box 1 for definitions of the levels of AI, the types of ML, the branch of ML most applicable to the automotive/mobility sector, and the network types that comprise it.

Text Box 1 – the nomenclature of AI

For the purpose of establishing a common understanding, we define various AI-related terms as they are used in this report.

Artificial intelligence (AI)

is intelligence exhibited by machines and systems, with machines mimicking functions typically associated with human cognition. There are three levels of AI:

The lowest level is narrow AI, the current state of the art with existing software that automates a traditionally human activity and often outperforms humans in efficiency and endurance in one specialized area, e.g., playing board games, predicting sales, and forecasting the weather. Autonomous driving is also a case of narrow AI, albeit one with significantly higher complexity than all currently available applications.

General AI/human-level AI describes the capacity of machines to understand their environment and reason and act accordingly, just as a human would in all activities across all dimensions, including scientific creativity, general knowledge, and social skills.

Super AI, the highest level of AI, is reached when AI becomes much smarter than the best human brains in practically every field. Super AI systems can make deductions about unknown environments. There is much uncertainty and debate about whether and how this state could be reached, and what its implications will be.

Machine learning (ML)

describes automated learning of implicit properties or underlying rules of data.

It is a major component for implementing AI since its output is used as the basis for recommendations, decisions, and feedback mechanisms with regards to a previously unknown situation.

ML is an approach to creating AI. As most AI systems today are ML based, the terms are often used interchangeably – particularly in the business context.

It involves training algorithms on sample input data to optimize its performance on a specific task so that the machine gains a new capability. The trained ML algorithm then uses its learning experience to better make predictions based on previously unseen data (such as recognizing a certain type of animal on an image).

ML systems are mainly trained using three methods

- **Supervised learning.** The ML system is provided with example input data that is similar to the data that the ML system should learn to predict. The provided data is labeled, i.e., the desired output is included in the data.

- **Unsupervised learning.** The input data does not contain labels, and the ML system needs to find its own metrics and categorizations based on recognizing structure in the data.

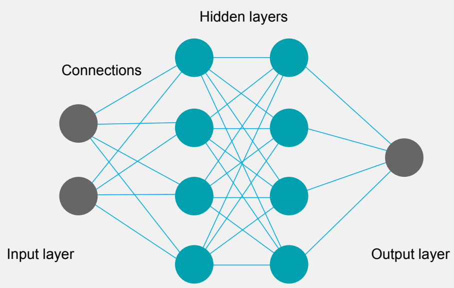
- **Reinforcement learning.** The ML system selects actions to maximize the payoff based on a reward function – i.e., machines and software agents automatically determine the ideal behavior within a specific context using trial and error to maximize their performance.

Deep learning

is a branch of ML. It deals mainly with neural networks that consist of many layers, hence the name "deep." Since the 2010s, deep neural networks have been the most successful ML approach in many areas.

Deep neural networks can be applied to all three types of learning mentioned above. They work well for many pattern recognition tasks without alterations of the algorithms as long as enough training data is available.

Thanks to these properties, deep neural networks can be applied to a broad range of tasks from visual object recognition to the board game Go. Neural networks consist of nodes, called neurons, which are organized into layers. Neurons in different layers are linked to each other with a system of weighted connections.



Data is presented to the network at the input layer, which communicates with subsequent hidden layers.

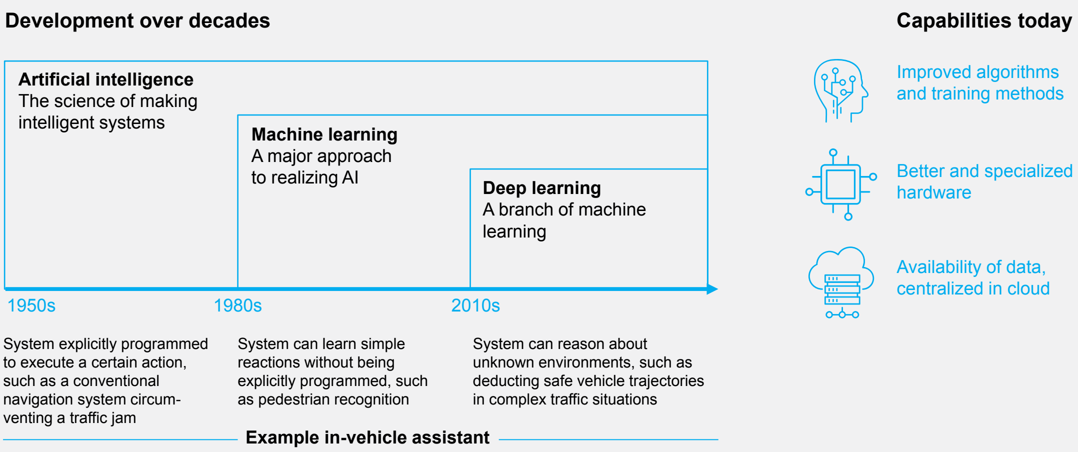
Each hidden layer processes the signal of the previous layer, thereby transforming it into a more abstract form. Finally, the output layer transforms the signal from the last hidden layer into the output signal. This specific neural network is "fully connected."

Two of the most common types of deep neural networks are convolutional and recurrent

- **Convolutional neural networks** are often used for visual input data. The system of connections between their neurons aims to exploit the hierarchy of features, e.g., by interpreting pixels as part of a nose, a nose as part of a face, and a face as part of a full cat.

- **Recurrent neural networks** are typically used for speech recognition and other forms of natural language processing. The sequence of inputs is important in these applications, which requires dynamic behavior of the network. Recurrent neural networks achieve this by feeding their output back into the network as input.

Deep learning is the current state of the art in AI, the potential of which has only recently been unlocked through advances in computing power and the availability of big data



SOURCE: McKinsey

1.2 We pragmatically describe ML for mobility along three main criteria

ML implements AI by using data rather than explicitly programmed rules and is the element that makes AI functional in a wide range of real-world use cases. Applying a practical working definition, the technology is able to deliver in three key areas in automotive/mobility:

- Act upon highly complex situations (as measured by the amount of data needed to describe it)
- Cope with a high number of situations that cannot be covered adequately by explicit programming
- Improve over time without explicit instructions, learning from data of previously unknown situations in an unstructured way.

1.3 ML is not optional – it is a significant source of competitive advantage for the next decades in automotive/mobility

For the automotive/mobility industry, ML will not be optional. It will be the technological foundation and the source of significant competitive advantage for decades to come. For example, in autonomous driving (AD), ML is required, at the very least, for image recognition, where human programming cannot possibly keep up.

Human-level image recognition typically requires systems with dozens of millions of parameters that are set (trained) on a supercomputer for two to four weeks – a task that would take 1,000+ person years, even if it could be done manually.

AD example: the most likely setup will be an AI-based system with some conventionally programmed guardrails.

- **For decision making, ML may be just one part of the solution.** ML will not be the only solution, as it is very difficult to trace and analyze potential malfunctions in a neural net. But without ML, the vehicle might not be able to react to every situation. This is especially the case since manually driven cars and pedestrians will create a very wide range of situations. Exceptions to general rules are a safety necessity, and it would be too difficult for a human programmer to anticipate every possible situation and program the appropriate vehicle reaction. Most likely, the solution will be a combination of both forms (i.e., ML and pure programming). There will be guardrails within which ML can play. These guardrails are necessary to ensure verifiability of systems.
- **For image recognition, however, ML is absolutely necessary.** The sheer scale of the networks required to reach the level of human ability makes any approach other than ML impractical. For the past 20 years, only ML techniques have been used for image recognition, reaching superhuman object recognition ability in 2015. This is the case because neural-net-type applications have a structure similar to the human brain, extracting different levels of abstracted features and making for optimal image recognition.

2

ML-BASED AUTOMOTIVE/ MOBILITY APPLICATIONS SHOW SIGNIFICANT OPPORTUNITIES – ESPECIALLY BECAUSE CONSUMERS' OPENNESS IS HIGHER THAN EXPECTED

2.1 Surprisingly, there is little reluctance from consumers towards AI – especially in light of applications that bring convenience and comfort

One clear finding of the research bodes well for AI's development: not only do consumers expect AI to have a large impact, they understand that AI will be a game changer (Exhibit 1).

Specifically and contrary to expectations, the vast majority is open to the ways AI might improve their lives with only 25 percent seeing a major risk associated with AI. This openness is primarily driven by three aspects: the increased levels of comfort and convenience offered by AI applications (e.g., 75 percent of consumers would be interested in having an AI-driven robot to do housework); the safety aspect (zero accidents) since 76 percent of consumers are convinced that AD will increase road safety and reduce accidents in the future; and the overall societal impact, since AI technology might reduce emission, optimize the flow of traffic, and lower the need for parking areas in cities, etc.

Consumers' general interest in/acceptance of AI also applies to the technology's application to automotive/ mobility: 84 percent think AI will play a major role in the automotive industry and consider it a great opportunity.

Contrary to expectations, there is even high consumer acceptance of the AI use case of AD; 47 percent would feel good if family members used fully autonomous vehicles (Exhibit 2). This sentiment is especially prevalent among Chinese consumers, young people, and those living in urban areas. Similarly, 70 percent of consumers think the government should legalize AD (15 percentage points more than in 2015) (Exhibit 3). Also here, convenience is the most important factor for consumers to switch to AD (70 percent).

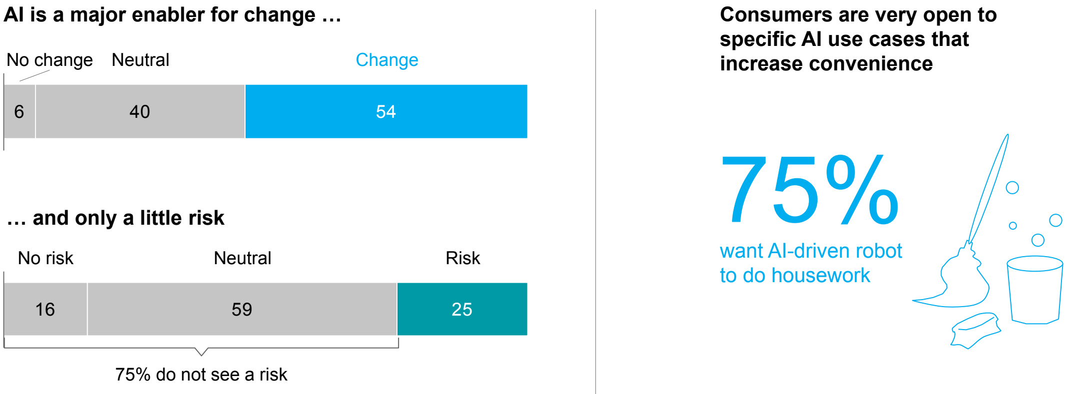
This overall interest in what AI could enable in auto-motive/mobility technology leads to a considerable willingness to pay for those features. Of the consumers who indicated "high interest" in AD features (24 percent of those surveyed), 46 percent are willing to pay over USD 4,000 for AD features on their next car. There are high expectations around the topic of AD, with the average of all consumers expecting full autonomy to be widespread on the road in about five years – probably a tight timeline for both the development of technology and the rollout of the relevant regulatory framework.

AD features are so important to consumers that 65% would switch OEMs for better AD functionality – over 90% for young consumers and those living in large cities.

EXHIBIT 1

More than 50% of consumers see AI as a major enabler for change and few see a major risk – overall, they are very open to AI use cases that make their lives easier

Share of respondents, percent

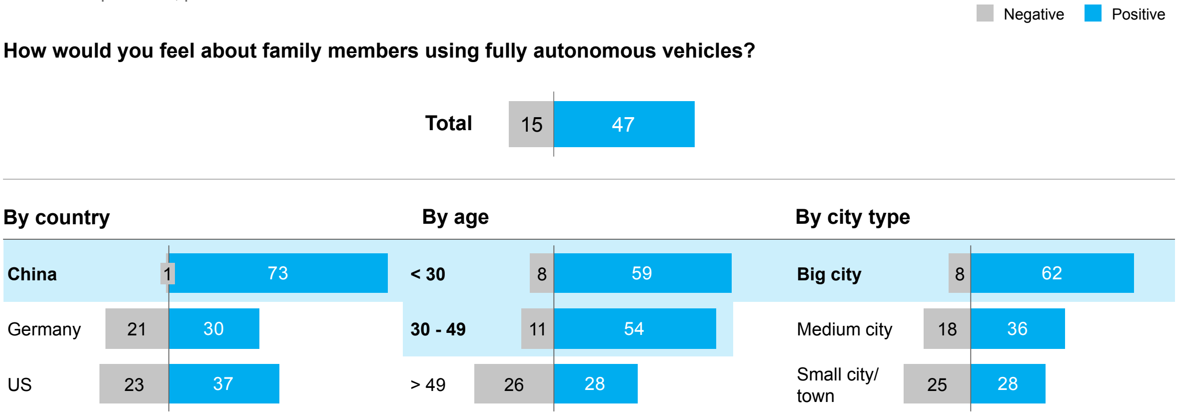


SOURCE: McKinsey "Future of mobility" consumer survey 2017

EXHIBIT 2

Heterogeneous picture – 47% of consumers accept AD already today with highest interest in China, amongst younger respondents, and people living in bigger cities

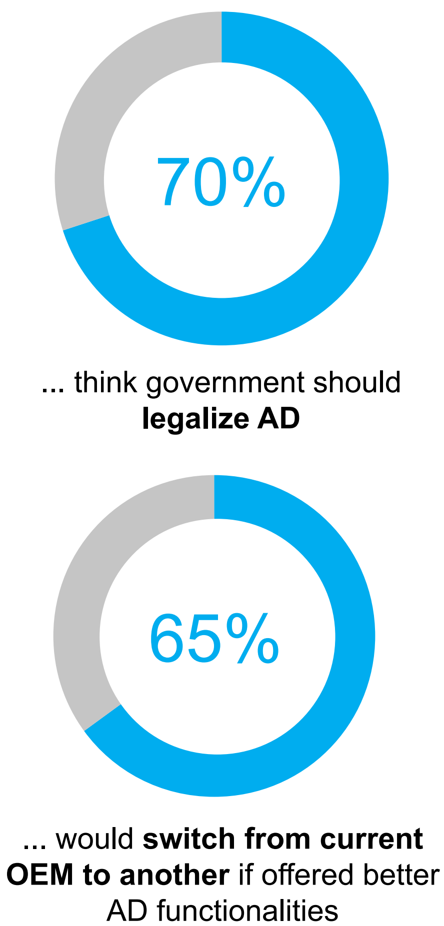
Share of respondents, percent



SOURCE: McKinsey "Future of mobility" consumer survey 2017

EXHIBIT 3

General interest in and acceptance of autonomous functionalities is high amongst consumers



SOURCE: McKinsey "Future of mobility" consumer survey 2017

2.2 New value pools are created through AI-based/-enhanced applications – however, many require exploration of new business models from automotive players

There are two key reasons why ML's impact on the automotive space will be especially significant.

Processes, products, and even businesses are in play. For many industries, the impact of ML will largely be felt in operations and internal processes. Specifically, improvements in product and service quality, internal process optimization, boosts in yield, and increases in production efficiencies, e.g., via cost reductions in supply chain, manufacturing, R&D, and support functions, will all be the result of ML. In automotive, however, on top of those process improvements, the product itself will be fundamentally affected by ML, and even new businesses will result from the new products. The technology will be the foundation of new vehicle functionality related to, among other advances, AD and in-vehicle experience. This opens the door to the creation of new revenue pools and the redistribution of existing ones.

Behind the digital curve. Automotive's starting point puts the industry in an especially challenging position as it contends with the disruptions and opportunities that ML presents. As a very traditional industry, automotive has a lower "digital quotient" than many other industries, and the gap between where the industry is now and the promises of AI is massive by comparison.

Based on the large consumer interest and the above-mentioned reasons, we have identified a number of exemplary application areas of ML in automotive/mobility (Exhibit 4). They fall into three distinct categories:

- Process optimizations and increased productivity (often rooted in AA, but enhanced by ML)
- New or enhanced products (mainly enabled by ML)
- Entirely new (vertical) businesses, along customer use cases, making use of these new products.

The new businesses might first be rolled out in private and enclosed areas, such as mines and factory yards. This is due to a better ability to control the environment (e.g., broadband connection), less strict regulation, and – for certain applications – a clear business case for the innovation.

In the following, we detail three application areas of AD, illustrating the changes that driverless vehicles could bring about: robo-taxis, autonomous long-haul trucking, and innovative last-mile delivery formats.

EXHIBIT 4

Based on that definition, we have identified a number of exemplary application areas

ML-based automotive/mobility applications

New businesses	▪ End-to-end city mobility provider ▪ Autonomous logistics (capacity as a service) ▪ Industry vertical applications, e.g., yard management ▪ …
New/enhanced products	▪ AD (L4/L5) ▪ In-vehicle experience (e.g., emotion recognition, voice assistant) ▪ …
Process optimizations	▪ Predictive maintenance in manufacturing ▪ Automated quality testing ▪ Robotics in manufacturing ▪ …

SOURCE: McKinsey

Snapshot I: Robo-taxis

The huge business potential of robo-taxis results primarily from their significantly lower cost per mile compared to privately owned (conventional and autonomous) vehicles

The business case

“Robo-taxi” is the moniker given to the concept of a self-driving, e-hailing, individual mobility solution. The business potential of the model is huge and largely driven by the savings to customers compared to the TCO of a privately owned AV. A lower number of car sales from the rising penetration of the model would be at least in part counteracted by an expected 20 percent increase in miles traveled due to the added convenience and greater access to mobility that robo-taxis would offer.

Maturity level

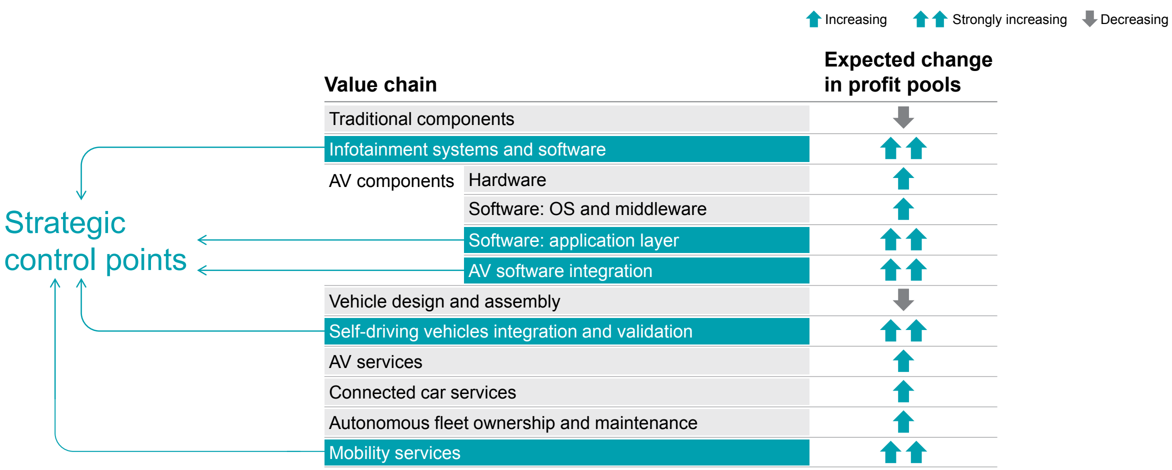
The further development of robo-taxis will occur in three stages:

- The first stage, robo-taxi 1.0, will only be feasible for a very limited number of US passenger miles, and therefore not gain the relevant economies of scale to deliver peak profitability.
- Robo-taxi 2.0 will have wider application and unlock further profits due to improved economies of scale, which opens up its application to the majority of passenger miles.
- Robo-taxi 3.0 will open up the field to offer service unrestricted by geography or time (i.e., anywhere and anytime).

Many players have set ambitious timelines for the development and introduction of robo-taxis. Start-ups are the players first out of the gate with announcements of reaching L4/L5 AVs in 2018. Software player Oxbotica has raised USD 200 million to develop purpose-built robo-taxis. OEMs and tech players plan to reach this milestone between 2019 and 2022. Tesla is one of the pioneers among OEMs with its plans to launch peer-to-peer AV sharing in 2018. Apple has not yet announced a date, but the tech player is rumored to be working on next-generation mobility projects.

EXHIBIT 5

For robo-taxis there will be 5 main strategic control points in the value chain



SOURCE: McKinsey

Implications for the competitive landscape

There will be four main strategic control points in the future robo-taxi landscape, each giving a significant profit advantage to the player that owns it (Exhibit 5):

- **Infotainment systems and software** control the customer experience, and their success depends on the degree to which they are able to seamlessly connect the elements of a passenger's journey.

- **Software application layer and AV software integration** is critical for safety and ride performance. The barriers to entry are high for this space as its foundation is proprietary technology that requires significant investment and highly specialized talent to develop. Owning this control point could provide leverage on connected car services.

- **Self-driving vehicle integration and validation** is critical for safety and ride performance as well. It also presents high barriers to entry, as it requires a proven track record in quality assurance for large-scale commercialization of highly engineered products. Owning this control point will enable the offering of additional connected car services to further reduce operating costs.

- **Mobility services** leverage big data to, among other things, optimize routing. Owning this customer-facing control point positions providers to leverage network effects and economies of scale to monetize connected car services.

Certain players will have inherent advantages over others along certain control points. For example, OEMs will have the advantage in vehicle integration and testing. Given that several players have already invested in mobility services, this trend provides additional opportunity for OEMs to grow further in this field. Starting with larger cities, OEMs are well positioned to roll out robo-taxis in several phases. Prerequisite for this endeavor is the ability of OEMs to develop the relevant capabilities, either in-house or via partnering with strong global or local players. Other players from different sectors, however, will most likely also invest in new capabilities to maintain and grow their positions in the value chain (e.g., mobility service providers).

Snapshot II: Autonomous trucks

Autonomous long-haul trucking will be implemented in three stages, of which the first is already around the corner in terms of technology availability

The business case

Autonomous long-haul trucking will be implemented in three distinct stages. In the first stage, platoons of two or more trucks will be electronically linked to accelerate and brake together, allowing them to drive closely behind each other. This improves fuel efficiency due to decreased air resistance and could eventually only require one driver in the leading truck. Since it requires overlapping driving routes, not all deliveries can employ platooning. Furthermore, platooning would be mainly applicable on highways and less so in urban environments. For this reason, a limited investment in logistics infrastructure would be needed to ensure all terminals are next to highways.

In the second stage, automation allows for fully autonomous driving – in platoons if possible – in constrained environments such as highways, with drivers only required for conventional pickups and drop-offs. This requires similar infrastructure investments as for platooning, but even fewer drivers, which leads to additional cost reductions.

In the final stage, full autonomy enables end-to-end driverless transport, where most driver involvement is eliminated throughout except for specialized cargo or vehicles.

Maturity level

Compared to passenger vehicles, truck components and data systems today are already quite standardized. Together with the relatively specific use cases, the first autonomous functionalities will be technologically ready soon, especially for use on constrained environments such as highways. Platooning will most likely be the first stage of autonomous truck operation, followed by driverless trucks on highways and fully autonomous trucks.

Implications for the competitive landscape

Similar to robo-taxis, there are several strategic control points that are essential to gain access to the emerging profit pool, while other components of the value chain will lose importance (Exhibit 6). The most critical ones are the following:

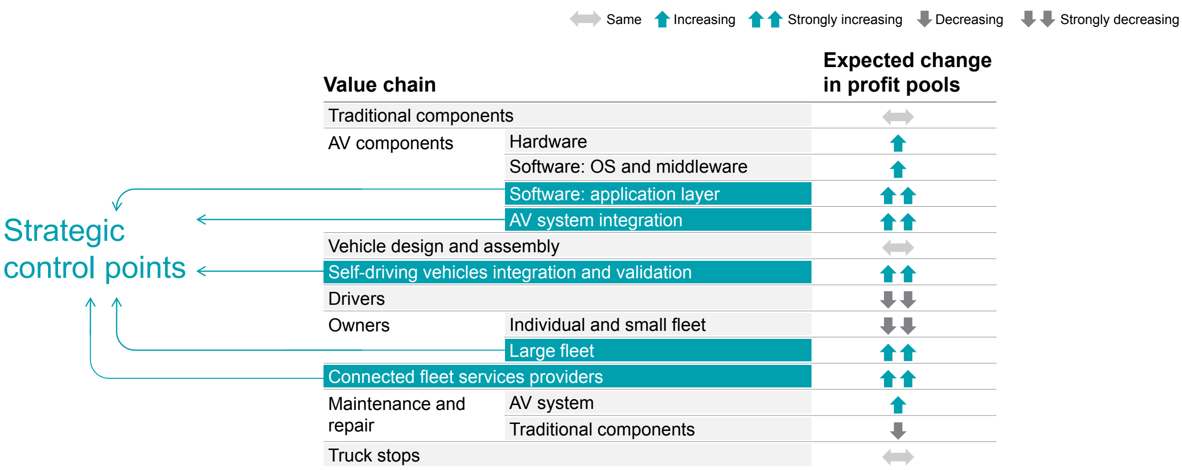
Providers of AV software and system integrators will be in a strong market position.

- **Large fleet owners and fleet service providers** will have the scale and resources to update their vehicles, capturing the most control in the future value chain.
- **Drivers and individual owners** will see significant decline.

OEMs do not have the same strategic/capability advantage in the area of logistics as the large-scale logistics companies. However, the opportunity to build strong partnerships and penetrate vertically (e.g., by taking the fleet ownership and providing the fleet to logistics providers) is a possible scenario worth exploring (as discussed in Chapter 4).

EXHIBIT 6

The value chain of autonomous trucks will also be controlled by 5 strategic control points



SOURCE: McKinsey

Snapshot III: Integrated solution for last-mile delivery

Autonomous delivery vehicles are a promising candidate to meet the rising demand of customers for delivery innovations

The business case

The logistics industry is among the top customers of commercial vehicles and is likely to become even more important, given that its global revenue pool is expected to continue to grow at 6 percent per year until 2025. In Germany, for example, today's last-mile logistics market alone is already comprised of approximately 100,000 vehicles, which is even more than the number of taxis in the country.

For the industry's last-mile players, the introduction of delivery innovations such as same-day delivery, time-window delivery, and instant delivery is currently a top priority in order to fulfill emerging customer demands and to tap into a new value pool. However, while consumers are becoming increasingly demanding with regard to last-mile service offers, their willingness to pay is very low, with most consumers only willing to pay a premium of USD 1 or less for fast and reliable delivery. Yet even in dense urban areas, the last-mile cost for same-day deliveries is double that for standard deliveries (around USD 3 vs. USD 1.50 for a 10 percent volume share of same-day deliveries). Thus, the premium customers are currently willing to pay is clearly not sufficient to cover the extra delivery cost.

Accordingly, technological advances that are revolutionizing courier, express, and parcel (CEP) players' cost structure are needed to make the last-mile innovations economically viable for more households and fuel the industry's growth aspirations. If, in addition, these advances also result in significant last-mile cost reduction potential for standard deliveries, all the better. These advances are backed by customers' preferences, with two-thirds rooting for legalization of trucks and vans with autonomous functions.

For 64 percent of customers, this legalization should even come before autonomous passenger vehicles, so that the trucks/vans can act as testing ground for those technologies.

As it stands, autonomous delivery vehicles (ADVs, e.g., vans or minivans) represent this critical technological advance because it is the dominant technology for automating the delivery of up to 80 percent of parcel volumes, with AI playing a key role in their development. However, despite the considerable potential that the new technology offers, one of the current challenges is automating the last 10 meters towards the consumer's doorstep. To realize full potential, technological solutions to automate handover, thus allowing (unattended) delivery at the doorstep, are required. Besides ADVs, this represents a challenge for other means of autonomous delivery like drones and driving droids as well. Nonetheless, ADVs are superior to alternative technologies, for the following reasons:

Superior cost position. ADVs have a cost advantage compared to drones and droids in almost all geographies – especially in rural but also in urban areas (Exhibit 7). And to return to the initial same-day example: with ADV technology, the last-mile cost for same-day delivery drops well below USD 2 and thus makes this use case economically viable.

What's more, compared to traditional last-mile delivery, the cost advantage of ADVs with parcel lockers is around 40 percent, assuming labor costs of about USD 24 per hour. However, the cost advantage diminishes in regions where labor costs are lower, with the break-even point at USD 10 to 12 per hour.

Superior operating feasibility. ADVs fit the standard operating model and are suited for most deliveries. In those areas where there are drawbacks, ADVs will be complemented by drones and droids. The latter, however, have shortcomings themselves in some of the main application areas of the ADVs (e.g., limited capacity of droids, operational challenges of operating a large number of drones in an urban area), and therefore will not be able to replace them.

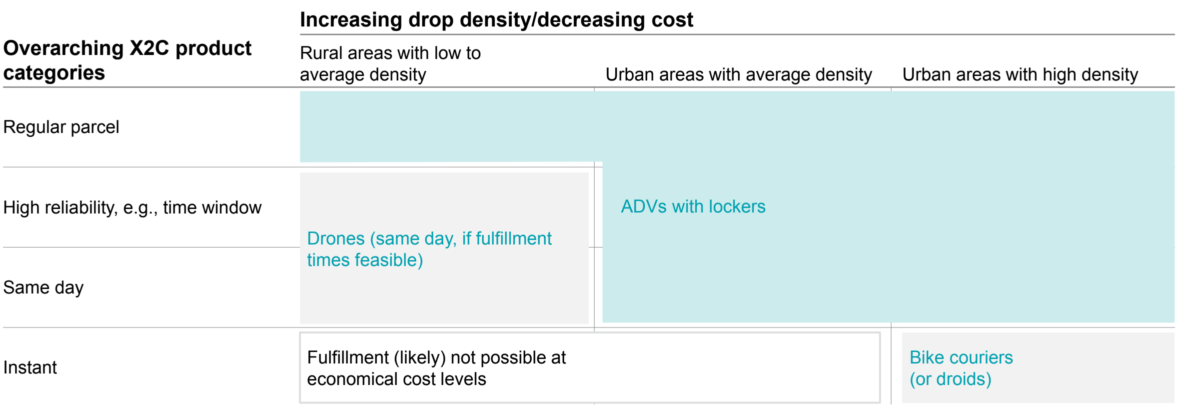
Maturity level

The race for entry into the ADV technology market has started. The technology can be expected to develop stepwise, and the introduction of early-stage applications is going to happen very soon:

- **StreetScooter**, a start-up founded to build electrovans, has been acquired by Deutsche Post DHL. Besides further linking automotive and logistics sectors (e.g., via cooperation with Ford), StreetScooter has already developed an ADV prototype that autonomously follows staff within certain geographic boundaries.
- **Volvo** is testing a self-driving refuse truck for similar use cases.
- **Google** filed a patent in 2016 for a fully autonomous vehicle with a mounted parcel locker.
- **Amazon** reportedly founded a team to focus on driverless vehicle technology also for last-mile applications.

EXHIBIT 7

For last mile delivery, ADVs with lockers are the dominant technology for most products and areas



SOURCE: McKinsey

Implications for the competitive landscape

As digital technologies will become much more important in this new last-mile market, tech players especially have an opportunity to enter this field, which is currently dominated by logistics players and OEMs. These developments would trigger a redistribution of power but would also allow for new (data-based) value pools. For any player in this field – both new and incumbent – there are a number of potential new business models, e.g.:

- (IT) services for technical operation of autonomous fleets
- (IT) services for optimizing routing, district planning, and offering capacity management as a service, given that you have autonomous fleets
- Operating last-mile delivery brokerage platforms
- Full-service models for last-mile delivery fleets (e.g., with a piece rate per delivery capitalizing on delivery-cost savings)
- Data monetization (e.g., traffic information, predictive maintenance for streets).

Some automotive companies are already working on integrated delivery concepts for last-mile delivery (e.g., Mercedes-Benz Vision Van, MAN RIO – Loadfox). Aside from automotive, players from other domains are also involved in last-mile delivery, including Amazon in retail and Uber's UberEATS in tech.

At the current stage, it is too early to make an assessment of which of these approaches will be able to establish themselves in the long run. Several challenges around the realization of the new technologies and business models remain, especially for incumbents that are not used to these data- and technology-driven models. AI is an important enabler for OEMs in establishing themselves in this field. Possible ways to successfully approach the challenges will be discussed in the following chapters.

Given the possibilities that ML can bring, the automotive industry is one of the industries that will profit most from ML. However, as big as the opportunity might be, there are also steep hurdles and vast complexity to overcome for those who want to reap the benefits of ML. The speed of change is staggering, and automotive players will find it hard to keep up – especially when creating and rolling out new, primarily data-based business models.

3

HOWEVER, FOR ANY AUTOMOTIVE PLAYER TO BENEFIT FROM ML, SEVERAL CHALLENGES NEED TO BE OVERCOME

3.1 These opportunities will likely only flourish in new ecosystems , which are challenging for the various stakeholders

The application of ML technology in a mobility environment is so complex that it will require new structures around the mobility ecosystem. One possible AI-enabled mobility environment is illustrated in Exhibit 8: each OEM can have its own AI system or be part of a system with multiple OEMs and non-OEM partners, where all vehicles have the same embedded AI. Each system collects driving data and transmits it back to an OEM-owned, AI back-end system, where it is used to further refine the algorithms. Updates to the AI systems are sent to all vehicles as appropriate to ensure that all vehicles of one ecosystem have the same standard/level of AI and behave in the same way. Despite a high number of different ML-enabled systems in and around the car, only two ML systems need to be deeply embedded in the vehicle: AD and in-vehicle experience, since the amount of data they need to process with are too large to transmit, and timing is critical as well as safety relevant. Other ML systems (e.g., predictive maintenance) can be mainly cloud based, giving more flexibility in terms of update cycles, computing power, and power consumption. Other third-party AI systems may be connected as well across several OEMs. For example, a neutral server could connect a number of AI back-end systems with traffic management systems (e.g., in a given country, region, or city) for optimal safety and traffic flow.

Another scenario is insurances tapping into the driving data to offer usage-based policies.

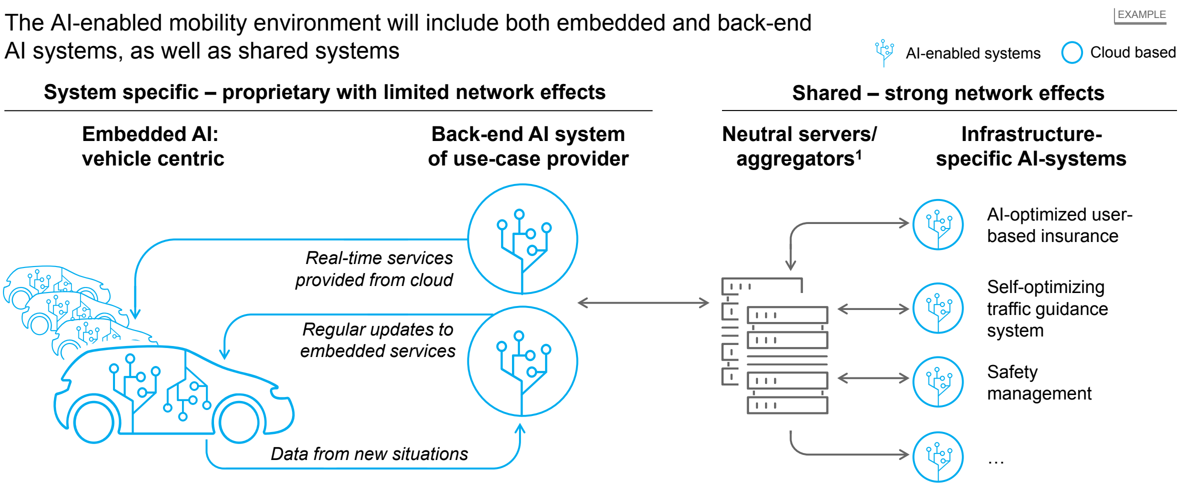
Many open questions remain, for example:

- **Central, back-end AI system.** Will each OEM have its own back-end AI system or will they cooperate with each other or other players? Will different ecosystems share data, e.g., self-driving “corner cases”? Will there be industry standards similar to ISO certificates?
- **Neutral server and use-case-specific AI systems.** Who will own and operate the server (e.g., governments)? What will be the aggregation level (e.g., municipality, country, region)? How many neutral servers will exist? How can cybersecurity be ensured?

All of the above systems feature a different set of stakeholders (including third parties), specific technology constraints, and local circumstances and regulation, which require completely new commitments, systems, and ways of working.

EXHIBIT 8

The AI-enabled mobility environment will include both embedded and back-end AI systems, as well as shared systems



1 E.g., 3rd party, regulatory

SOURCE: McKinsey

3.2 To navigate in this orbit, we see a couple of enabling themes to be addressed

To navigate in this orbit, we see three kinds of challenges: the technological challenges, especially around embedding the technology into the vehicles, the regulatory standards, and the challenge of defining appropriate business models.

The accelerating race for technology

In theory, the AD problem is solved, but embedding is required to make it real. Many of the underlying algorithms/approaches for ML in automotive/mobility are already available in theory.

> **"By 2020, the average [Internet user] will generate 1.5 GB of data per day [...] and autonomous cars 4,000 GB* per day"[1]** – Brian Krzanich, CEO Intel
>
> *This is based on one hour driving per day which means 66 GB per minute driven

However, significant gains still have to be made in the actual implementation and embedding of the technology. Two examples are AD and in-vehicle experience, as the amounts of data they need to deal with are too large to transmit in their entirety and quality of output, and timing is critical and safety relevant. While most current ML use cases are run in a back-end environment (with sufficient computing power, appropriate hardware, electricity usage), embedding requires technological (hardware) advancements and connection solutions. Assuming improvements in infrastructure (e.g., 5G rollout, sensors on road signs), the embedding can be reduced to a certain degree. However, guaranteeing full coverage, e.g., of cellular networks, is virtually impossible, so a certain amount of embedding will always be required.

The field and its players are rapidly changing to arm themselves for the race. The growing importance of the technological aspect is shown by the results of an analysis of the mobility start-up and investment landscape, which shows high investment in companies working on AI.

Around 500 companies are working in this space, with investments since 2010 totaling over USD 50 billion, which is more than the USD 32 billion (disclosed) investment into all shared mobility/e-hailing start-ups in the same timeframe. The timing of these investments shows that the race is accelerating: the amount of investment in the last four years has quadrupled as compared to the four years before that.

A more granular look shows that AD and in-vehicle experience are indeed the largest clusters of AI in mobility, accounting for 91 percent of the total investment volume. Overall, a few very large moves account for the bulk of investment in the industry (e.g., Intel's acquisition of Mobileye), followed by a long tail of smaller deals. The high demand for AD leads to a dynamic market – start-ups and tech corporations entering the market and many other players supplementing in-house capabilities through acquisition. Total disclosed investments in AI related to AD amount to USD 33.5 billion since 2010 and have significantly accelerated over the past few years. With USD 13.6 billion investments, the company landscape for in-vehicle experience is much smaller compared to AD. There are fewer start-ups due to the stronger presence of large tech players from outside of the automotive industry, who adapt their consumer and home electronics products and expertise to in-vehicle use. Specifically, they integrate virtual and voice assistants for use in cars, e.g., Alexa, Siri, Cortana, or AliGenie, often in close cooperation with OEMs.

Investments in companies focusing on other applications are on a much smaller scale, with only USD 4.1 billion since 2010; however, these are likely to have been complemented by significant in-house investment activities not captured in this type of analysis. The sub-clusters resemble the applications of the previously mentioned landscape, with traffic/infrastructure (including digital map services and dynamic traffic information services) on top.

1 https://newsroom.intel.com/editorials/krzanich-the-future-of-automated-driving/

The relation of these clusters is depicted in Exhibit 9. Companies that work in the same field (shown as nodes) are arranged by cluster, with the relative position of the clusters depending on how relevant these sub-clusters are to each other. A connection between nodes means that there is some overlap between two companies, and the size of the nodes is proportional to the number of connections with other nodes. Overall, it is clear that the entire field is strongly interconnected.

> **“It is a giant mess – everyone understands the pressure, but only a few act in a considered way”**
> Chief strategy officer of a leading start-up

EXHIBIT 9

Many use cases also emerge from the start-up and investment landscape analysis, with AD and in-vehicle experience capturing the bulk of the investment

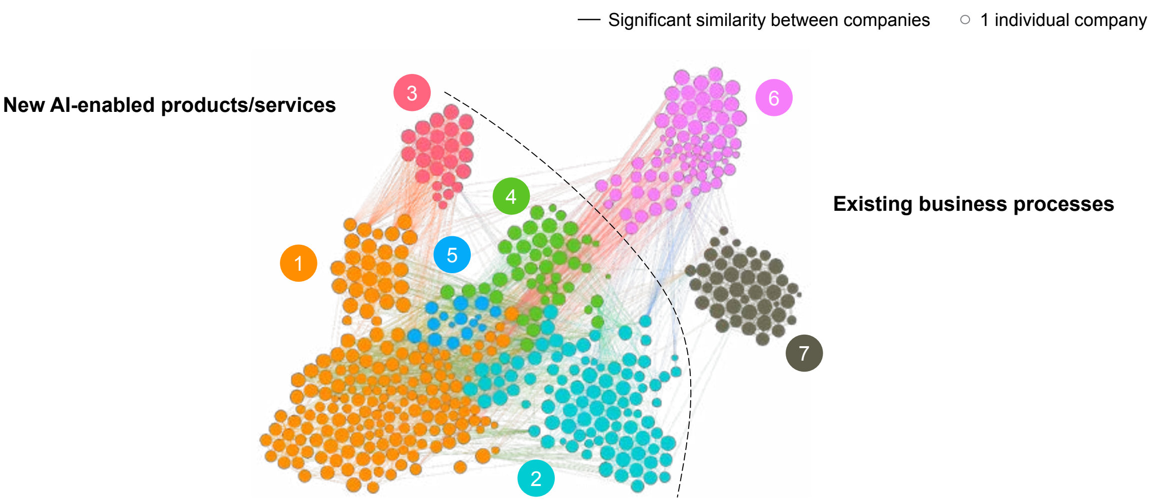
	Clusters	**Total disclosed deal size since 2010,** USD billions	**Investments in 2010 - 13**	**Investments in 2014 - 17 YTD**
New AI-enabled products/ services	1 AD	33.5	6.2	27.3
	2 In-vehicle experience	13.6	3.2	10.4
	3 Traffic/infrastructure inspection	1.1	0.2	0.9
	4 Fleet management	0.6	0.3	0.3
	5 Predictive maintenance	0.1	0.04	0.1
Existing business processes	6 Manufacturing and SCM	2.2	0.4	1.8
	7 Quality assurance	0.02	0.02	0
	Total	**51.1**	**10.4**	**40.7**

Compared to ***USD 32 bn*** *investments in shared mobility services*

Ratio: 3.9

Total investments by investor type, percent	
Tech player (HW)	36
Tech player (SW)	34
VC/PE and public offering	27
Auto player	3
Total	USD 51.1 bn

Cluster map (474 companies in the mobility/AI space)



SOURCE: SILA team; CapitalIQ; PitchBook

One example of this is the way in which predictive maintenance is positioned between AD, fleet management, and traffic/infrastructure inspection.

What is striking is that nonautomotive players are leading the investment charge with about 97 percent of investments in companies working on AI in mobility coming from nonautomotive players (PE/VCs and tech players) and going mainly to full-solution providers developing AD and in-vehicle experience. Tech players, in particular, are aggressively entering the market, accounting for 70 percent of these investments, with hardware players Intel, Nuance, and Samsung in the lead.

Interest in AI in mobility also shows no sign of declining. In recent months alone, several substantial AI-related investments have been made, and new venture capital funds have been set up. For example, Google set up Gradient Ventures in that field, Element AI raised over USD 100 million to enable companies to use ML, Microsoft Ventures established its own AI fund, and Toyota invested USD 100 million in Toyota AI Ventures, which is looking to invest in AI and robotics start-ups.

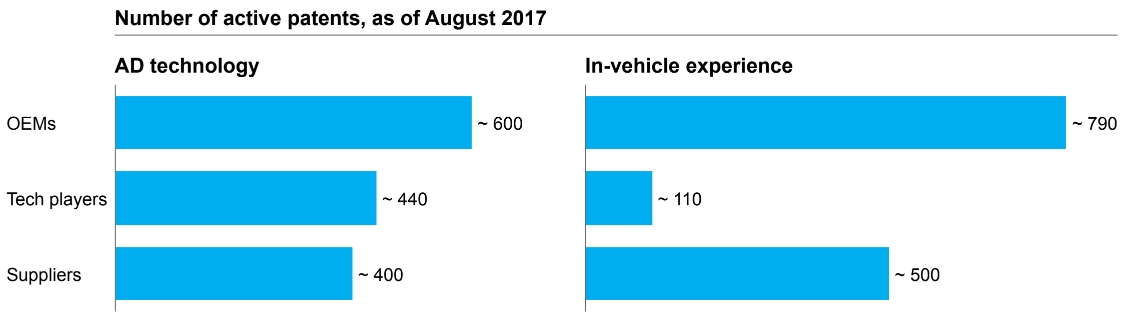
That said, automotive players are not idle – they are investing significantly to develop expertise in-house. For example, more than 40 percent of patents in AD involving AI belong to OEMs (Exhibit 10). However, Waymo owns the single-largest patent portfolio out of all players in that field (over 200 patents), which is twice as many as the leading OEM. OEMs and suppliers dominate development in in-vehicle experience, holding more than 85 percent of all patents in this area. OEMs are showing the strongest in-house activities (over 50 percent). Tech players are seemingly underrepresented, as many patents related to elements of in-vehicle experience such as speech and gesture recognition are not specific to automotive. Microsoft, for example, is estimated to possess more than 1.000 patents on speech recognition alone.

It would take one large OEM (> USD 100 billion revenue) only six days to collect the volume of driving data that one young/rising car manufacturer has amassed over its entire lifetime, if all of the cars it sold last year were able to upload data in the same way.

Tech players, OEMs, and suppliers each have their own natural industry advantages. In general, the split occurs with software/data on one side and vehicle functionality on the other but is not always clear-cut. For example, large amounts of driving data are required to train and improve self-driving algorithms. Waymo's cars are far ahead, having driven almost 3 million miles

EXHIBIT 10

Automotive players exhibit significant in-house activities related to AI in AD and in-vehicle experience technology



SOURCE: Innography; McKinsey patent analysis autonomously on public California roads. At the same time, Tesla is the only OEM to systematically capture conventional real-world driving data and has logged over 4 billion miles already. Given the size of their fleets, however, large traditional OEMs could catch up in a matter of days if they were able to start capturing driving data in the same way just from the cars sold over the past year.

Partnerships are formed in order to benefit from each other's advantages. Recognizing their own assets and limitations in the context of the technology and talent that will be needed to bring AV to market, both OEMs/suppliers and tech players are seeking alliances. These partnerships take on a couple of forms, for example:

- **Tech-driven alliances.** Tech players such as Nvidia, Mobileye (Intel), and Baidu convene many OEMs and/or suppliers around a common platform to establish an ecosystem and maximize the amount of data (Exhibit 11).

- **OEM-centric ecosystems.** OEMs seek to build up their in-house tech capabilities through targeted acquisitions, investments, and collaborations, typically bringing in expertise in deep learning, computer vision, and mapping tech.

- Examples include GM's acquisition of Cruise Automation and their partnership with IBM, or Ford's collaborations with a crowdsourced mapping firm and multiple AI start-ups.

Interestingly, Waymo follows a more confined approach and partners mainly with just one OEM (Fiat Chrysler), which supplies its vehicles, and a car rental company to service its fleet.

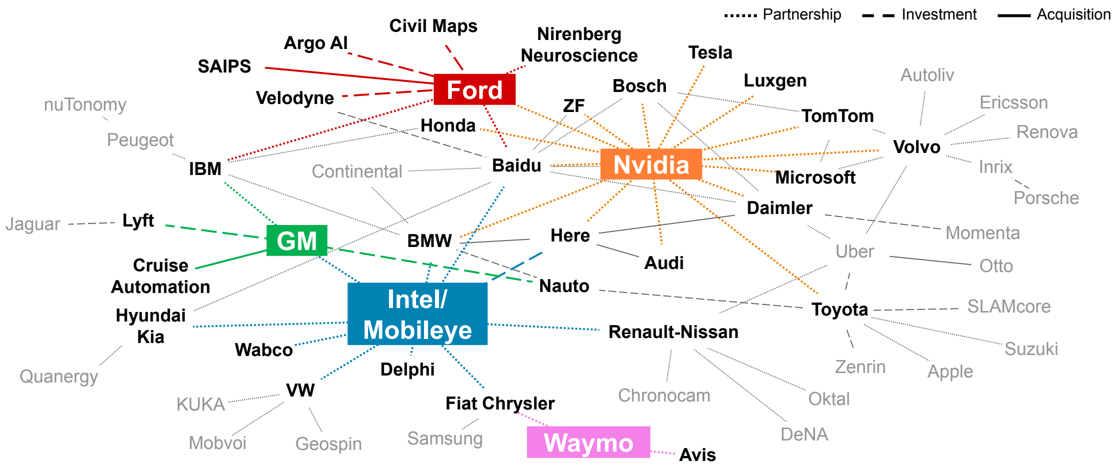
"[…] the folks with decades of experience building cars really know what they're talking about when it comes to assembly plants and how they put things together"[2]
– Kyle Vogt, CEO Cruise Automation

2 http://fortune.com/2017/07/17/brainstorm-tech-cruise-gm-culture/

EXHIBIT 11

NOT EXHAUSTIVE

While for AD, 2 main technology alliances have emerged around Nvidia and Intel/Mobileye, many OEMs also invest in or cooperate with smaller tech start-ups



SOURCE: Press research; McKinsey

Regulations and standards

"Automotive grade" requires higher safety standards and higher quality of output than most current ML use cases. We would expect ML to be used for specific tasks, however, in combination with conventionally programmed (i.e., explicitly written by a human programmer) "guardrails" to ensure automotive grade safety and quality. This is especially important in developing and implementing standardized safety tests for AVs. Many of the boundary conditions for this will most likely be defined by governments and the regulatory frameworks they establish. While some jurisdictions have enabled the testing of AVs on public roads, a comprehensive and consistent set of rules for widespread deployment has not yet emerged.

With safety being of paramount concern, guidelines and quality standards need to be detailed while striking a balance between protection and innovation. The government could also play a part in operating or at least legislating the neutral server as detailed in Chapter 3.1 ensuring information exchange between vehicles and traffic infrastructure, which itself might need technological upgrades to accommodate AVs.

Current players in this space have to proactively engage in the regulatory process and shape the standards early on during the development of the technology and its applications (cf. ABS systems) to allow for scale as well as to ensure the integration of various systems (e.g., OEMs, traffic management system).

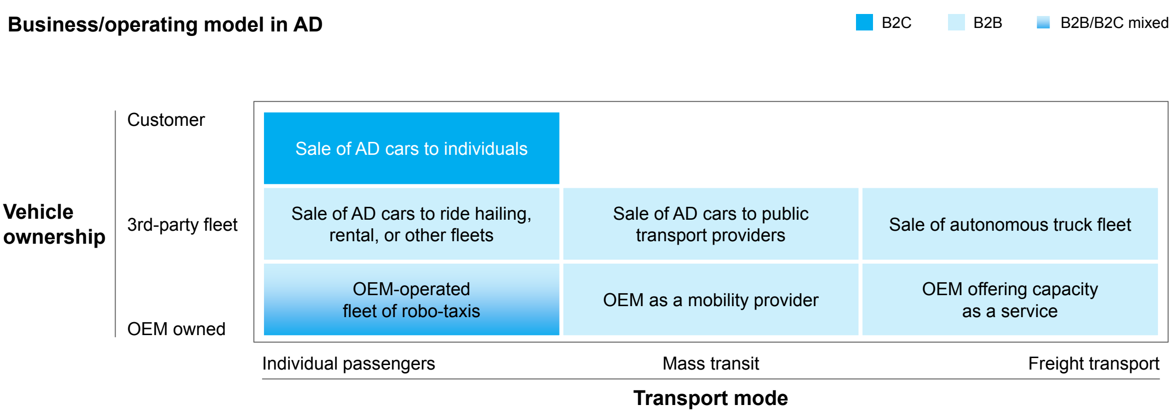
It is highly likely that in the future, regulations and circumstances, e.g., infrastructure, will differ by geography and even city by city, since the rollout might occur in phases that might not necessarily be coordinated. Standards, e.g., on interface and data type, may differ by stakeholder. These conditions require a high degree of adaptability.

A shift in business model

Not only will AD revolutionize what cars are capable of, it will enable new forms of vehicle usage and thus new business models for OEMs. The emergence of new business models poses a challenge for OEMs that historically were able to mainly stick to their classical model of car sales to individuals. Certainly, the current model of traditional vehicle sales to consumers and businesses will continue, with AD as an extra feature. Beyond this, however, are other modes of ownership and novel AI-enabled services that OEMs will need to consider, such as the ones in Exhibit 12:

EXHIBIT 12

New business models emerge with the risk towards B2B margin levels



SOURCE: McKinsey

“Value creation will come from end-customer services rather than vehicle or hardware sales”
– Mobility expert

Business-to-business operating models:

- **Third-party fleets.** With declining private vehicle ownership and the economies of scale of AD, OEMs will have more and larger fleet operators as customers. In individual transportation, this could mean an Uber-style e-hailing model powered by the OEM and in cooperation with a third party that owns the fleet. In freight transport, an OEM could be the backbone of autonomous delivery solutions for logistics players.

- **OEM-owned fleets.** Pushing the aforementioned trends even further, OEMs could become providers of transportation employing a fleet of AVs that they own. For passengers, OEMs could offer robo-taxi fleets and supplement or even replace public transit networks with larger mobility providers acting as an agent for these modes of transportation. At the freight transport level, they could offer a fleet for autonomous parcel and truck services. In these cases, rather than monetize their assets in one-off sales, revenue would be generated as recurring fees for mobility services.

Business-to-customer operating models:

- **Sales to individual customers.** The obvious option is to sell vehicles to individual customers, which is close to OEMs’ current mode of operation. Moreover, the rise of AI will also change the automotive service landscape. Given the high complexity of AD systems, OEMs are expected to capture a larger share of the aftersales service market in maintenance and repairs.

- **Services of OEM-owned fleets.** Given that many players have already acquired capabilities in mobility services, they could also offer the robo-taxi directly to end users, again bringing in recurring service revenues rather than one-off sales revenues.

Many of these new business models might shift the OEMs’ businesses more towards B2B relations (e.g., fleet sales, mobility services to municipalities), which alone might put additional pressure on margins. On the other hand, the emergence of new services, as discussed above, will open up new business models and hence new profit pools. The services require the vehicles to become more software-centered. The automotive industry is not the only one preparing for the future mobility environment. Apart from the tech challengers detailed earlier, unexpected players are also investing in new transport solutions. For example, Alstom, a rail transport firm, recently acquired a minority stake in Easymile, a provider of AD software and last-mile mobility solutions.

4

PUTTING ML ON THE ROAD REQUIRES SOME SMART MOVES

In the report thus far, we have argued that:

- AI will be a significant source of competitive advantage for the coming decade(s).
- ML-based automotive/mobility applications present significant opportunities, especially in new products and new businesses.
- For any automotive player, however, several challenges emerge.

By a margin of 4 to 1, consumers expect that it will be OEMs – and not tech players – who advance the technology and bring AVs to market. Interestingly, this ratio is highest in China, a country with few established OEMs (Exhibit 13). OEMs rank even better when it comes to trust. 73 percent of consumers trust them to bring fully matured autonomous functionalities to the market, which is a factor of ten higher than those who trust in tech players. Again, this ratio is highest for Chinese consumers (79 percent as compared to 5 percent). Hence, the OEMs are well positioned to meet this consumer expectation and profit from it, especially due to their unique position at the embedding control point (as discussed in Chapter 2).

Leveraging the above-mentioned advantages, there are five smart moves OEMs can make now to leverage their position for success (Exhibit 14):

Focus on core application areas. In determining the appropriateness of developing various ML application areas in automotive/mobility, OEMs should consider:

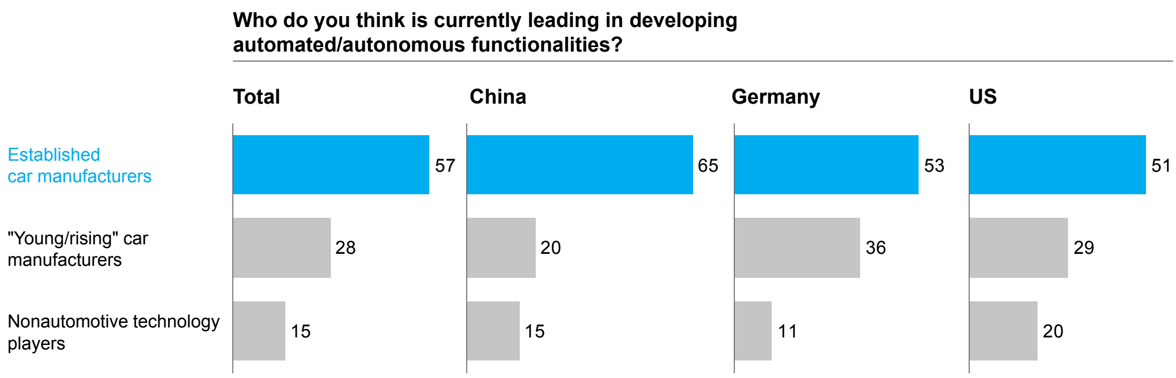
- **Profit pool.** What will be most relevant to or demanded by end users, and what will be the size of the new revenue pools?
- **Competitive landscape.** How many and which other players do I expect to play in the relevant field? What advantages do they have over me?
- **Market position.** Where do I stand vis-à-vis others (e.g., first mover, always with the newest technology) and what do I need to offer from a strategic point of view?
- **Control point logic.** Which control points do I naturally own or have access to?

Leverage breadth of data. A prerequisite to creating new business models is better access to customers and their behavior in various contexts by improving the collection of data from consumers. The importance of this cannot be overestimated: for almost all applications that involve ML, a vast amount of data is necessary for gaining insights into consumer behavior and for the refinement of algorithms.

EXHIBIT 13

Consumers perceive car manufacturers as the leading players in developing autonomous functions and expect them rather than tech players to bring those functions to market

Share of respondents, percent



SOURCE: McKinsey "Future of mobility" consumer survey 2017

Without this data, ML systems will not be applicable to real-life situations, as they will not have sufficient information to react in an intelligent way to previously unobserved situations. Beyond that, fully developing application areas that rely heavily on data collection (e.g., traffic guidance) might also require the development of standards across OEMs to enable data pooling.

Drive standards and regulation. Proactively shape new standards together with other automotive players and the government. Acting too late in this area might constrain OEMs and impose boundaries that prevent them from capturing the full potential.

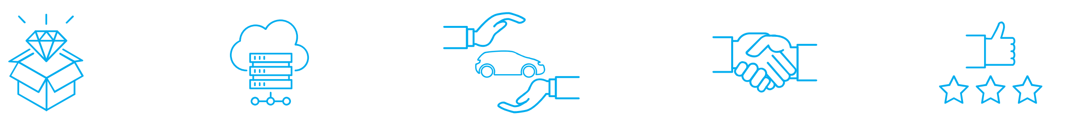
Grow tech and business partnerships. Business models will often require capabilities that are not available in-house. For areas that are long-term sources of differentiation, select an appropriate partner to gain access to the required technology or customers. Tech players, for example, have a natural advantage when it comes to AI technology, accessing the relevant talent or the availability of data. For areas where the value is shorter term, and no major source of differentiation exists, select or build up suppliers. Establishing partnerships is indispensable to the pooling of resources, talent, and abilities and, thereby, to the acceleration of AD development.

This is particularly true if AD technology is rolled out incrementally over a longer period of time, which diminishes any first-mover advantages and prolongs the amortization of development costs.

Business model hedging. There will be a plethora of potential new business models. Build business cases and select from available business models based on the degree to which you want to be involved. Develop a diverse set of models early, with the expectation that some will fail, relying on the successful ones to mitigate the risk. In this fast-paced environment, learning by doing is the appropriate way to proceed.

EXHIBIT 14

OEMs are well positioned to gain access to newly created or AI-enhanced profit pools



Focus on core application area	Leverage breadth of data	Drive standards and regulation	Grow tech and business partnerships	Business model hedging
Select which area offers the best opportunity	Access customers by improving collection of data	Proactively shape industry together with other players and governments	Select the right partner to gain access to technology or customers	Prioritize business models based on expected impact and run early pilots to learn by doing

SOURCE: McKinsey

OUTLOOK: THE TIME FOR ACTION IS NOW!

As discussed, a wide range of stakeholders have roles to play in the development of the ML-enabled mobility ecosystem. The main push, however, will need to come from the automotive industry by developing reliable and secure AD technology in the first place. Accomplishing this feat in parallel to the existing challenges of developing electric cars and further optimizing conventional fuel engines will be a Herculean task. But by negotiating the right partnerships, acquiring strategic AI assets, and positioning themselves to implement new business models, OEMs can make quick progress in an industrywide shift that will profoundly change the nature of mobility and transport.

APPENDIX

Methodology

This report is based on two main sources: a start-up and investment landscape analysis, and a consumer survey. These findings are further supported by interviews with industry experts, a patent analysis of AD and in-vehicle experience as well as in-depth analyses of robo-taxis, autonomous trucks, and last-mile solutions.

McKinsey's Start-up and Investment Landscape Analysis (SILA)

This research includes a market scan using a proprietary, self-optimizing, big data engine, which combines input from a variety of VC-/PE-relevant data sources. Through semantic analysis of keywords and network analytics, relevant companies, clusters, and industry moves are identified within the investment landscape of AI in the automotive industry.

McKinsey's 2017 consumer survey

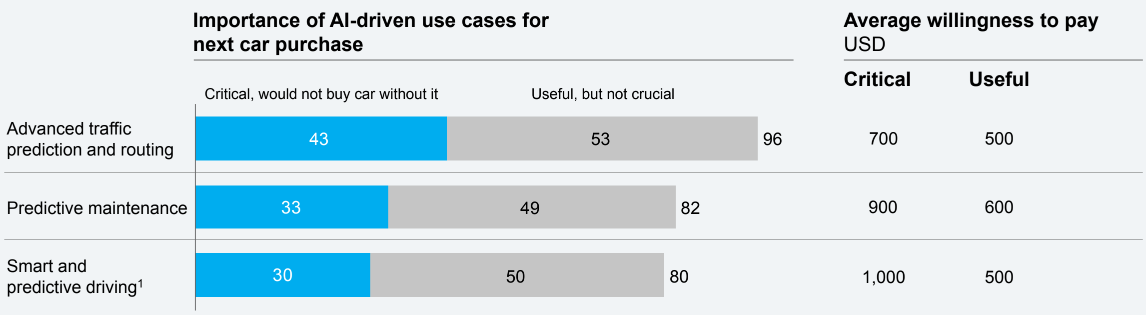
McKinsey conducted a survey of more than 3,000 end consumers in July 2017, evenly split among the US, Germany, and China. The selection of participants is representative of the age, gender, and city type distribution of the population.

This survey focused on consumers' attitudes and preferences regarding AI in automotive, including new automotive business models, trust in AD, data usage and data safety, and attitude towards electric and commercial vehicles.

Further key findings from the 2017 McKinsey consumer survey and other proprietary McKinsey research

Nevertheless, also the other use cases are highly demanded by consumers and are a must-have in the long run

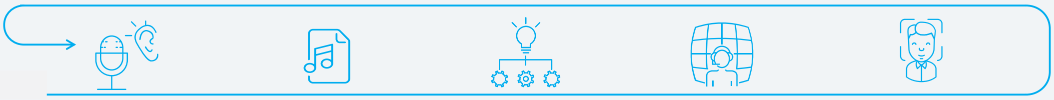
Share of respondents, percent



1 E.g., calendar pickup, preference-based routing

SOURCE: McKinsey "Future of mobility" consumer survey 2017

This AI integration will be standard for in-vehicle experience



Process	Understand the context	Define short list of options	Make final recommendation	Execute recommendation	Learn for future use cases
Required AI systems	Emotion, voice, and gesture recognition	Connected infotainment solutions	Decision making	Virtual assistant, human machine interfaces, and natural language	Eye tracking and driver monitoring

AI relevance

No AI needed

AI indispensable

SOURCE: McKinsey

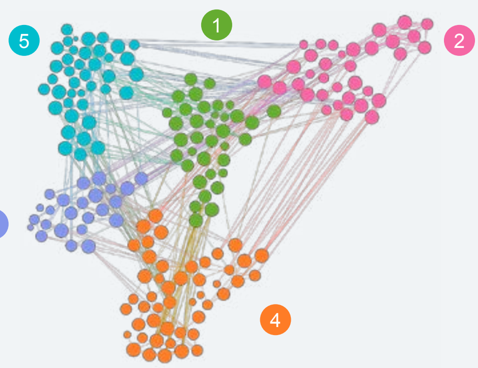
AI and AD investment landscape

Flat | Accelerating | Strongly accelerating

Clusters	Total disclosed deal size since 2010 USD billions	Investment acceleration	Number of companies
1 Autonomous solution provider	20.2	Strongly accelerating	36
2 Sensors/semiconductors	11.3	Flat	34
3 Safety assistance for partial AD	1.4	Accelerating	24
4 Environment monitoring software	0.5	Strongly accelerating	47
5 Decision making software	0.2	Strongly accelerating	40
Total	**33.5**	Accelerating	**181**

Cluster map (171 companies)

— Significant similarity between companies ○ 1 individual company



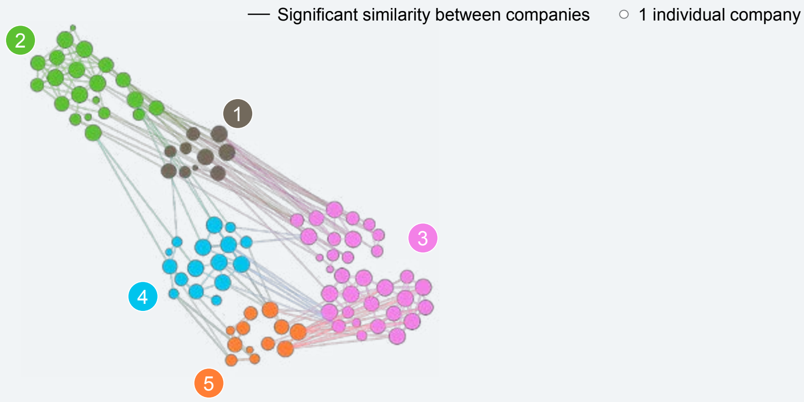
SOURCE: SILA team; Capital IQ; PitchBook

AI and in-vehicle experience investment landscape

Flat | Accelerating | Strongly accelerating

Clusters	Total disclosed deal size since 2010 USD billions	Investment acceleration	Number of companies
1 Integrated solution	10.5	Strongly accelerating	10
2 Hardware	2.6	Flat	21
3 Infotainment software	0.2	Accelerating	33
4 Voice assistant	0.2	Flat	16
5 Gesture/emotion recognition	0.2	Strongly accelerating	12
Total	**13.6**	Accelerating	**92**

Cluster map (171 companies)

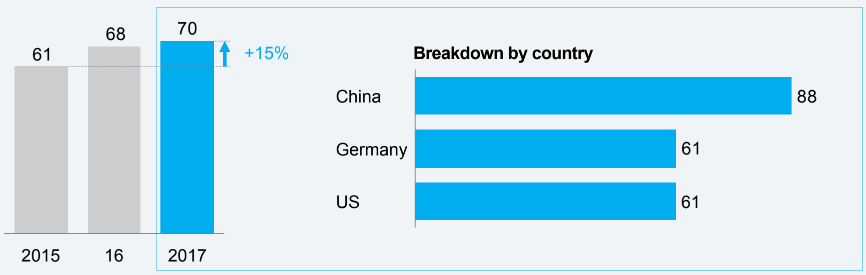


SOURCE: SILA team; Capital IQ; PitchBook

Over 2/3 of respondents are in favor of the legalization of autonomous vehicles – an increase of 15% over the 2015 survey

Share of respondents, percent

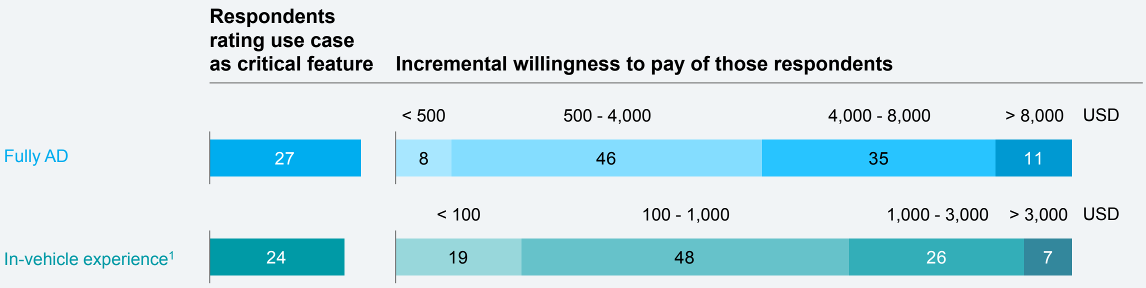
Government should legalize use of cars with AD functions



SOURCE: McKinsey "Future of mobility" consumer survey 2016 and 2017

Highest willingness to pay for autonomous mobility and in-vehicle experience compared to other use cases, over USD 4,000 for AD and over USD 1,000 for in-vehicle experience

Share of respondents, percent

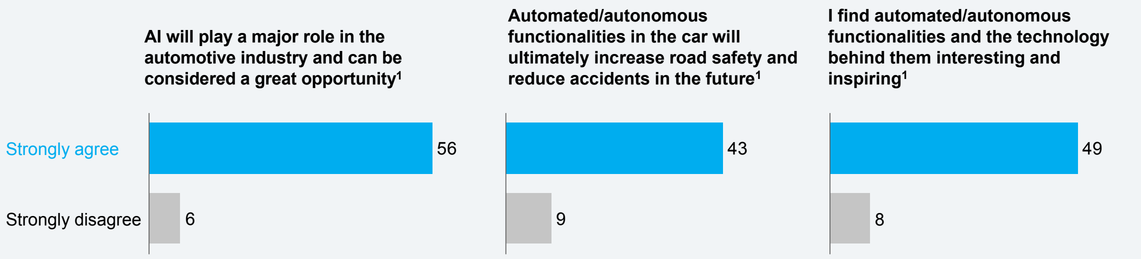


1 Gesture control, voice assistant, emotion recognition, and reaction to emotions

SOURCE: McKinsey "Future of mobility" consumer survey 2017

The perception of AI in the automotive industry and autonomous vehicles is very positive, with only a small minority not believing in the technology's long-term viability

Share of respondents, percent

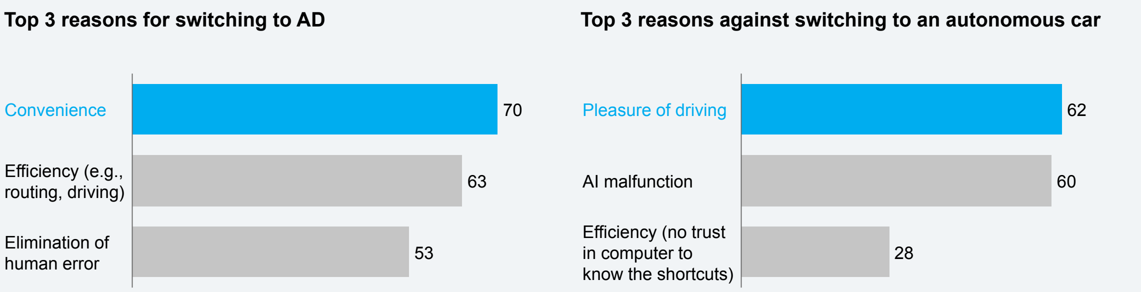


1 Other respondents neither agreed nor disagreed

SOURCE: McKinsey "Future of mobility" consumer surveys 2017

Convenience through freed-up time is biggest motivation to switch to AD, loss of control and as a result no pleasure of driving is the biggest reason against switching

Share of respondents, percent

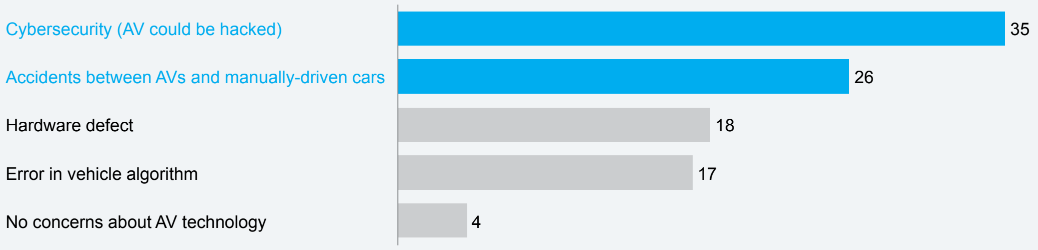


SOURCE: McKinsey "Future of mobility" consumer survey 2017

Cybersecurity and accidents between autonomous and manually-driven vehicles are the largest customer concerns in the field of AD, therefore safety has to increase

Share of respondents, percent

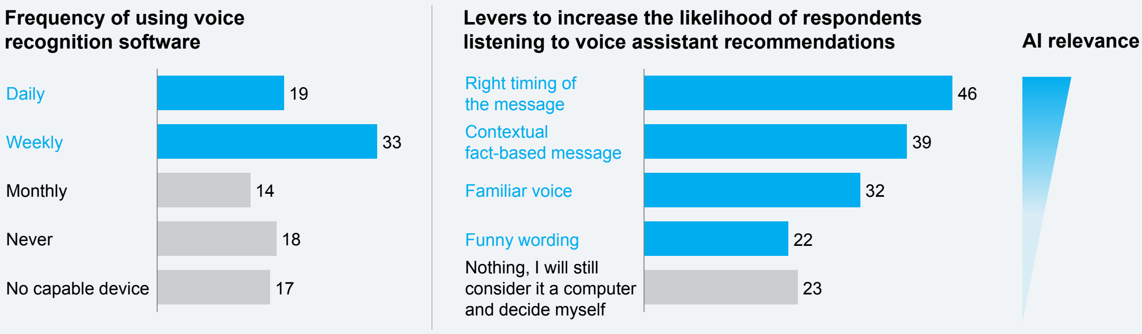
Biggest concern in the field of AD



SOURCE: McKinsey "Future of mobility" consumer survey 2017

AI as key for in-vehicle experience – more than 50% use voice recognition software at least once a week, but likelihood of listening to recommendations have higher AI relevance

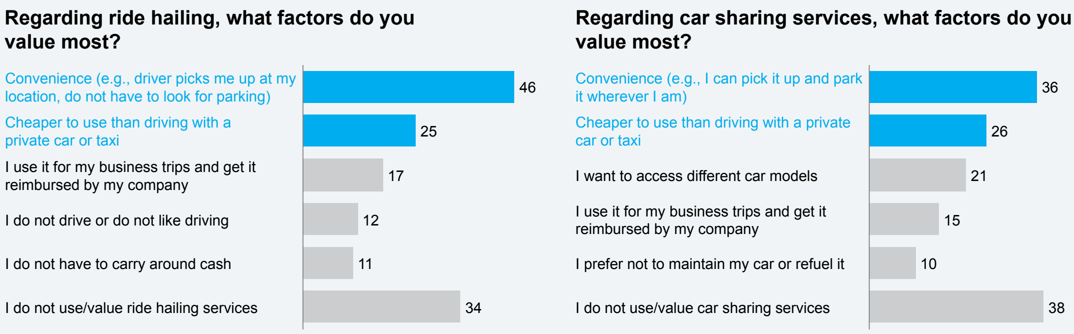
Share of respondents, percent



SOURCE: McKinsey "Future of mobility" consumer survey 2017

Convenience is the biggest reason for consumers to use shared mobility services, followed by financial advantages

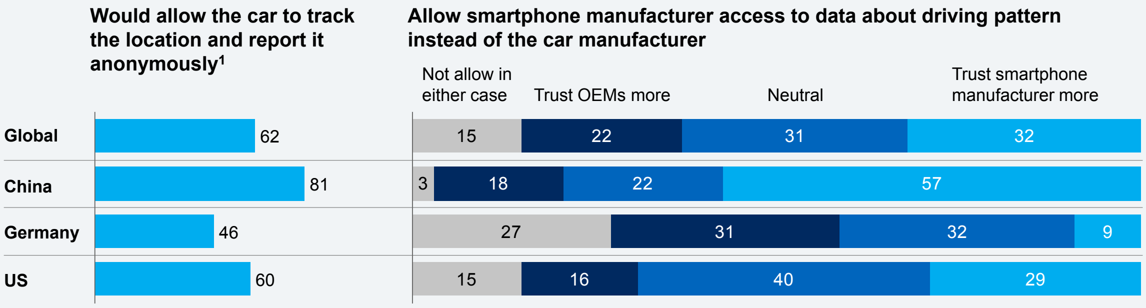
Share of respondents, percent



SOURCE: McKinsey "Future of mobility" consumer survey 2017

Trust in OEMs, relative to smartphone manufacturers, highly depends on the region –
trust in general is lower, except for Chinese customers

Share of respondents, percent

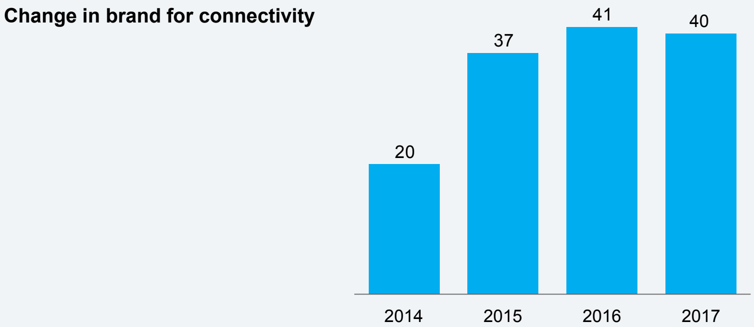


1 E.g., to enable carmaker to improve the next generation of cars

SOURCE: McKinsey "Future of mobility" consumer survey 2017

Willingness to change car brand for connectivity services has remained constant over the last years

Share of respondents (strongly) agreeing, percent



SOURCE: McKinsey “Future of mobility” consumer survey 2016 and 2017

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McKinsey Center for Future Mobility
September 2017

Design contact: Visual Media Europe
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