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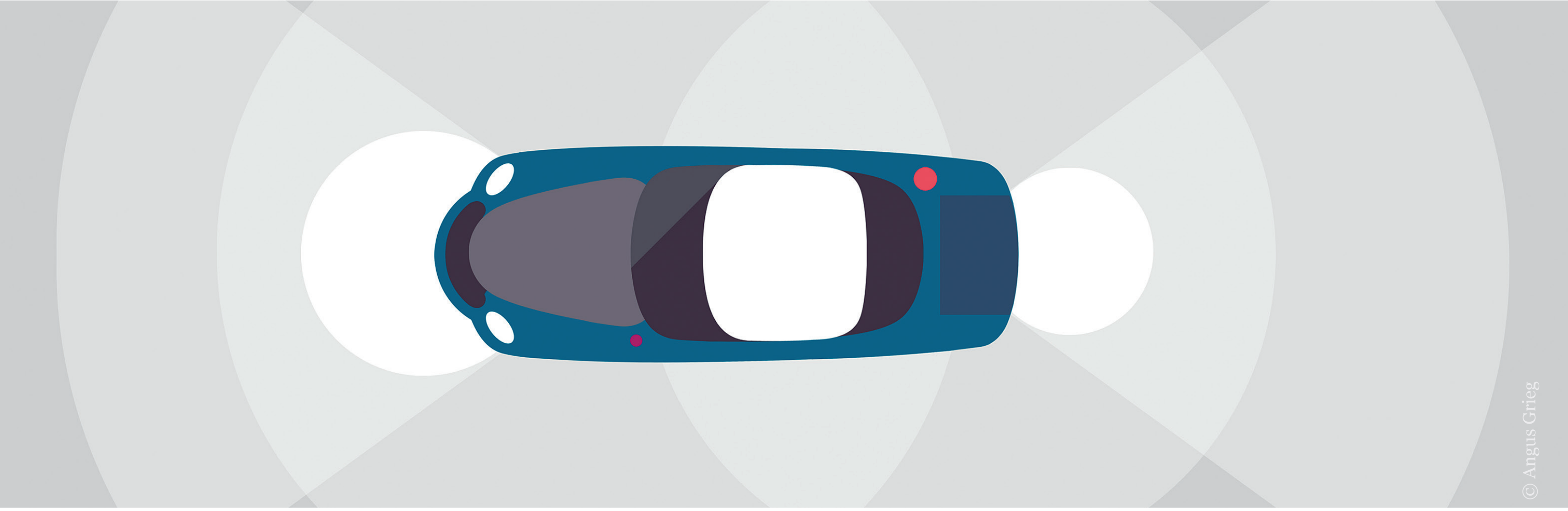

SEMICONDUCTORS

Advanced driver-assistance systems: Challenges and opportunities ahead

Semiconductor companies can help take ADAS applications to a new level—provided that they are ready to embrace change.

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Demand for advanced driver-assistance systems (ADAS)—those that help with monitoring, warning, braking, and steering tasks—is expected to increase over the next decade, fueled largely by regulatory and consumer interest in safety applications that protect drivers and reduce accidents. For instance, both the European Union and the United States are mandating that all vehicles be equipped with autonomous emergency-braking systems and forward-collision warning systems by 2020. A recent McKinsey survey also suggests that car buyers are becoming even more interested in ADAS applications that promote comfort and economy, such as those that assist with parking or monitoring blind spots.

Although ADAS applications are still in their early days, original-equipment manufacturers (OEMs) and their suppliers realize that they could eventually become the main feature differentiating automotive brands, as well as one of their most important revenue sources. And the same technologies that enable today's ADAS offerings could also be used to create fully autonomous vehicles, which are now a major focus of research and development, both at OEMs and at high-tech players that have recently entered the automotive sector, including Google. Any ADAS technology that gains early support could therefore have an advantage if self-driving cars reach the market.

Many semiconductor companies—even some that have not traditionally participated in the automotive sector—now offer ADAS products or are developing them. As with any new technology, however, much uncertainty persists about the market, including how consumers will respond to more advanced applications in which a computer controls or assists with steering and other critical driving functions. In the first part of this article, we address some of the most pressing questions about ADAS, touching on future demand, technical challenges, and the evolving competitive landscape. The second part of the article looks at ADAS from a semiconductor perspective, describing how companies can capture more value by expanding their offerings beyond hardware, collaborating directly with OEMs, and differentiating their technologies based on safety and security features.

The opportunities and challenges ahead

Although ADAS technology has the potential to transform the automotive sector, its current annual revenues—which range from about $5 billion to $8 billion, according to most sources—are modest compared with those for other automotive systems. For instance, 2015 revenues were about $30 billion for audio and telematics and about $60 billion for climate control. Part of the problem is that many of the most promising ADAS applications are still being refined or have not yet hit the market; still others are expensive and mostly available in premium cars. But one of the most important factors inhibiting demand may be a lack of consumer awareness. In a recent online survey of more than 4,500 car buyers in five countries conducted by McKinsey, many respondents were unfamiliar with ADAS applications, and few purchased cars with this technology (Exhibit 1). The survey offered reason for optimism, however, since it revealed that the repurchase rate for those who did buy a vehicle with ADAS was quite high, ranging from 87 to 89 percent. This finding suggests that once consumers become familiar with ADAS, they will prefer cars with these features.

Even though industry experts hold different opinions about 2015 revenues and growth prospects for ADAS, most expect to see an annual increase of more than 10 percent from 2015 to 2020. For instance, one leading analyst predicts 16 percent growth during this period, and a second predicts 29 percent growth (Exhibit 2). This could give the segment one of the highest growth rates in the automotive sector and related industries. However, with the base price for cars remaining relatively stable (with a compound annual growth rate of about 1 percent), semiconductor companies and other suppliers may face pressure from OEMs and customers to keep ADAS costs low, even as the technology becomes standard. In consequence, we predict that growth in ADAS value may proceed at a slower rate than growth in unit volume.

ADAS technology: Overcoming limitations to ensure active, autonomous safety

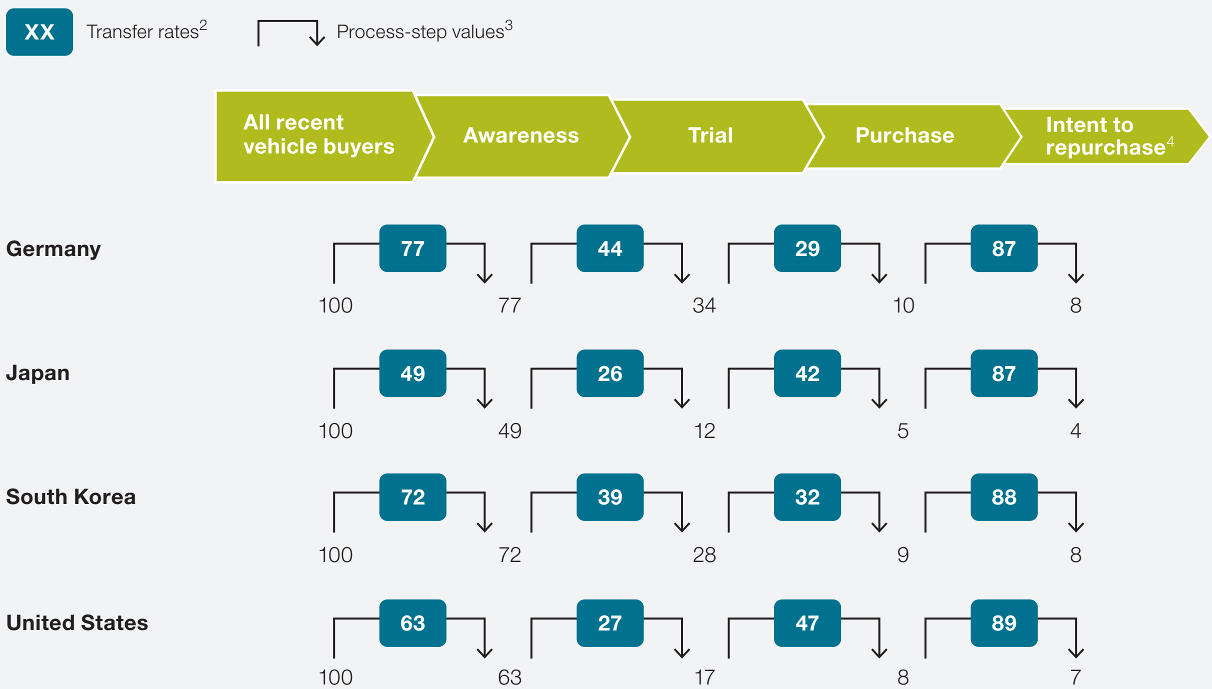
One factor that could influence ADAS uptake is the rate at which the technology advances. Although semiconductor companies and other players have made important enhancements in recent years, there is much room for improvement. For instance, forward-collision warning systems still have difficulty identifying objects when a vehicle is traveling at high speeds. A typical ADAS application incorporates many technologies, as shown in Exhibit 3, but four stand out with regard to the challenges they present: processors, sensors, software algorithms, and mapping.

Processors. Electronic control units (ECUs) and microcontroller units (MCUs) are essential for most ADAS applications, including autonomous driving. For ADAS to advance, processors need better performance, which could be enabled by multicore

Exhibit 1

Many car buyers are still unaware of the technology for advanced driver-assistance systems.

Transfer rates and process-step values in the consumer decision journey for advanced driver-assistance systems in selected countries, %[1]



[1] The online survey included 4,500 car buyers in China, Germany, Japan, South Korea, and the United States.
[2] % of buyers moving from one stage of the consumer decision journey to the next.
[3] % of all recent vehicle buyers that reach a given step of the consumer decision journey. Figures may not sum, because of rounding.
[4] Includes consumers who said they would definitely or probably purchase cars with ADAS features.

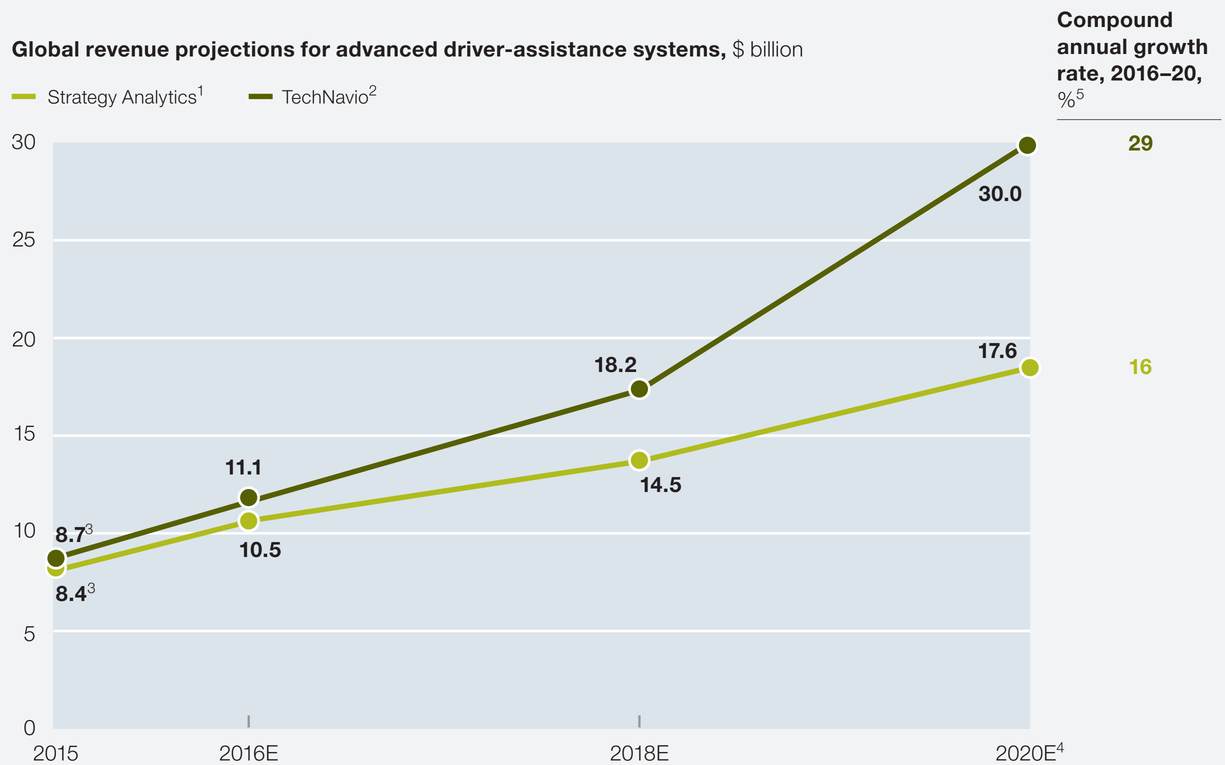
Source: McKinsey survey on connected cars, 2015

architectures and higher frequencies, as well as lower power-consumption requirements.

Sensors. These devices gather information on their immediate environment, such as pedestrians and oncoming cars. Most have a limited measurement range and signal bandwidth, which makes it difficult to distinguish between “signal” (for example, obstacles in the road) and system “noise.” It is especially difficult for sensors to track moving objects during less-than-ideal environmental conditions, such as rain and fog.

Many industry players are trying to improve individual sensors. They are also attempting to optimize system performance through better sensor fusion—the coherent combination of data from multiple sensors. On the hardware side, intersensor communication is a major challenge because it requires high bandwidth and solutions for preventing network overloads.

Exhibit 2 **The market for advanced driver-assistance systems is expected to show strong momentum through 2020.**



[1]Includes autonomous emergency-braking system, adaptive cruise control, forward-collision warning, lane-departure warning, parking assistance, back-side monitoring, night vision, driver monitoring (eg, for fatigue), and traffic-signal recognition.
[2]Also includes adaptive front lighting and heads-up display.
[3]Most sources estimate 2015 revenues between $5 billion and $8 billion.
[4]2018–19 compound annual growth rate used to derive 2020 market size for Strategy Analytics and TechNavio forecast.
[5]Figures may not sum, because of rounding.

Source: IHS; SBD; Strategy Analytics; TechNavio; McKinsey analysis

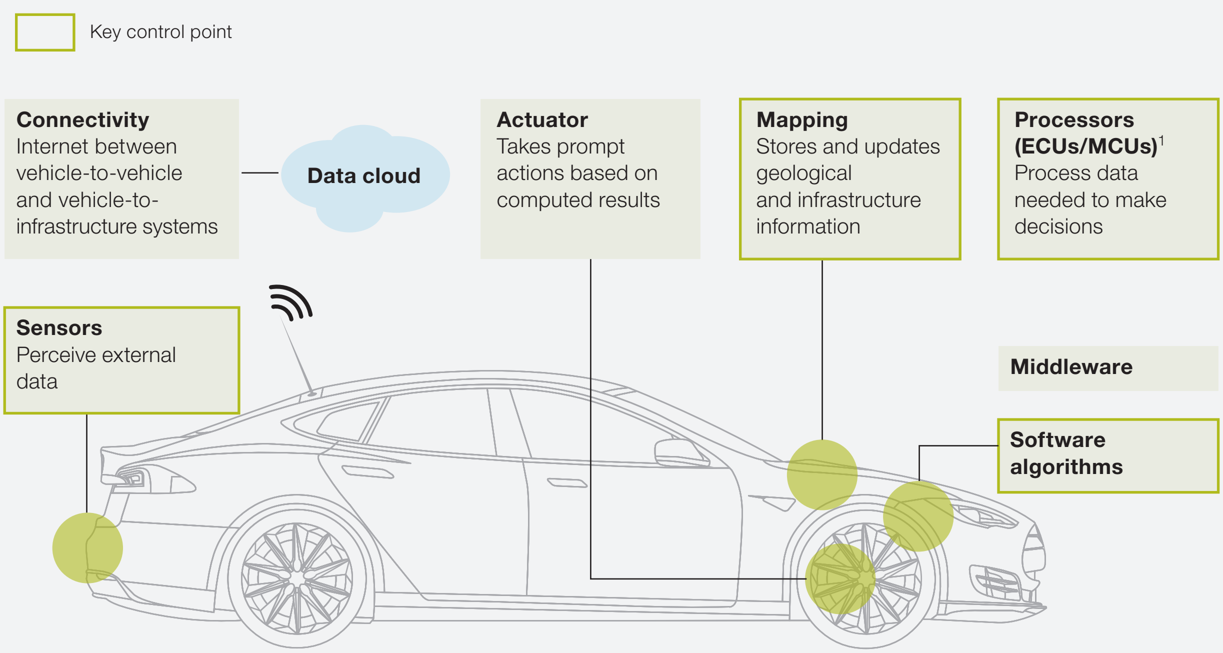
Players are currently optimizing the partitioning and distribution of system architecture to address this issue. On the software side, the fusion of image and nonimage data is particularly challenging. Some OEMs and tier-one suppliers are working together with academia to address this challenge, as can be seen in Daimler's collaboration with the Karlsruhe Institute of Technology and the University of Ulm.

The limited functionality of today's sensors, combined with their high cost, may be the greatest constraint to ADAS uptake. Many companies are making progress on both fronts, however. As one example, Mobileye and various start-ups are trying to improve the functionality of camera-based solutions, which typically have difficulty detecting obstacles during rainstorms or in other situations when visibility is limited. If camera-based solutions catch up to radar and lidar in functionality, they could eventually dominate the ADAS market because of their lower cost. "One box" solutions that combine lasers and cameras may also become popular because they are less expensive than radar or lidar alone. This is an important development, since experts believe that semiautonomous driving will not become a reality until the industry has a cost-effective lidar system that is fully integrated with other sensors.

Software algorithms. Running on ECUs and MCUs, algorithms use the input from sensors to synthesize the environment surrounding a vehicle in real time (going above and beyond the processing that sensors have already completed). The algorithms then provide output to the driver or specify how the system should actively intervene in vehicle control. This could require some of the most complex in-car-software integration ever created, since any decisions that the algorithms specify, such as the application of emergency brakes, are critical to ensuring safety.

In response to developments in sensor fusion, the industry is about to transition from embedded software running on a single ADAS-specific ECU to software platforms running on centralized ECUs or MCUs. These software platforms have a higher level of abstraction to allow flexible integration of sensor-fusion algorithms. Industry players are now focusing on creating such algorithms, which allow for more accurate synthesis of sensor data and more efficient processing, because they will help prevent data overload or slowdowns. Another priority is creating algorithms that allow for safer car navigation and more accurately predict all possible human behavior—including potentially irrational responses—in various situations, such as when a collision between two cars appears imminent.

Exhibit 3 **Four control points in advanced driver-assistance systems are key for autonomous driving and product differentiation.**



[1] Electronic control units/microcontroller units.

Source: McKinsey analysis

Mapping. When GPS coverage fails, such as during tunnel travel, detailed and accurate mapping systems can help prevent accidents. These systems also store geographical and infrastructure information, making updates as needed, and communicate with onboard sensors to determine a car's exact location. OEMs and other players in the automotive industry are looking for lower-cost methods to construct and maintain maps. Some of the most recent solutions include deploying "mapping cars" equipped with 3-D lasers and 360-degree high-definition cameras. Map developers are also leveraging data from sensors installed on commercial fleets, such as FedEx, as well as GPS data from drivers.

An evolving competitive environment

Many players are aware that regulators will require vehicles to be equipped with certain ADAS applications over the next five years, and they are already preparing to capture growth. This activity is triggering unprecedented changes in the automotive industry. First, more established high-tech companies, including semiconductor players, are actively pursuing ADAS opportunities, even if they did not previously have a presence in the automotive sector. For instance, Intel, NVIDIA, Panasonic, Qualcomm, Samsung, and Sony are going after such opportunities, including those related to sensors, ECUs and MCUs, systems, and systems on a chip. In addition, many start-ups and other small to midsize companies in the high-tech and automotive sectors are now trying to capture market share. These include GestureTek, Hawk-Eye Innovations, and IntelliVision, all of which have specialized expertise in image processing and computer vision.

In another active shift, OEMs—once the primary drivers of automotive innovation—may now be more willing to collaborate with semiconductor companies and other tier-two suppliers whose technologies facilitate their development of ADAS. Similarly, both tier-one and tier-two suppliers are aggressively pursuing mergers and acquisitions to ensure they have all the capabilities needed for ADAS, including software capabilities.

How semiconductor companies should approach the ADAS opportunity

Semiconductor companies now receive moderate revenue from ADAS—less than \$2 billion in 2015, compared with \$29 billion for automotive electronic systems—but this is expected to grow rapidly. To ensure that they capture full value, semiconductor companies must decide where, how, and when to compete (in other words, they need to choose whether to be early entrants or fast followers). This could involve rethinking their product focus on hardware, since branching out into software will offer more opportunities, and developing new strategies for collaborating with OEMs. Companies that move quickly and establish themselves as ADAS players may gain the most when the market moves into a phase of even higher growth.

Where to play: Opportunities in hardware and beyond

We investigated ADAS hardware opportunities for semiconductor companies through 2025 using a model that considered various factors, including expected end-market adoption and price erosion for systems and components. We found that overall revenues could increase steadily, reaching about \$4.6 billion to \$5.3 billion in 2025. Parking-assistance systems may generate the most revenue for semiconductor players, followed by automated emergency braking, adaptive cruise control, and forward-collision warning. For system components, the best opportunities appear to be in processors (generating an anticipated 37 percent of total revenue) and optical semiconductors (28 percent), as Exhibit 4 suggests.

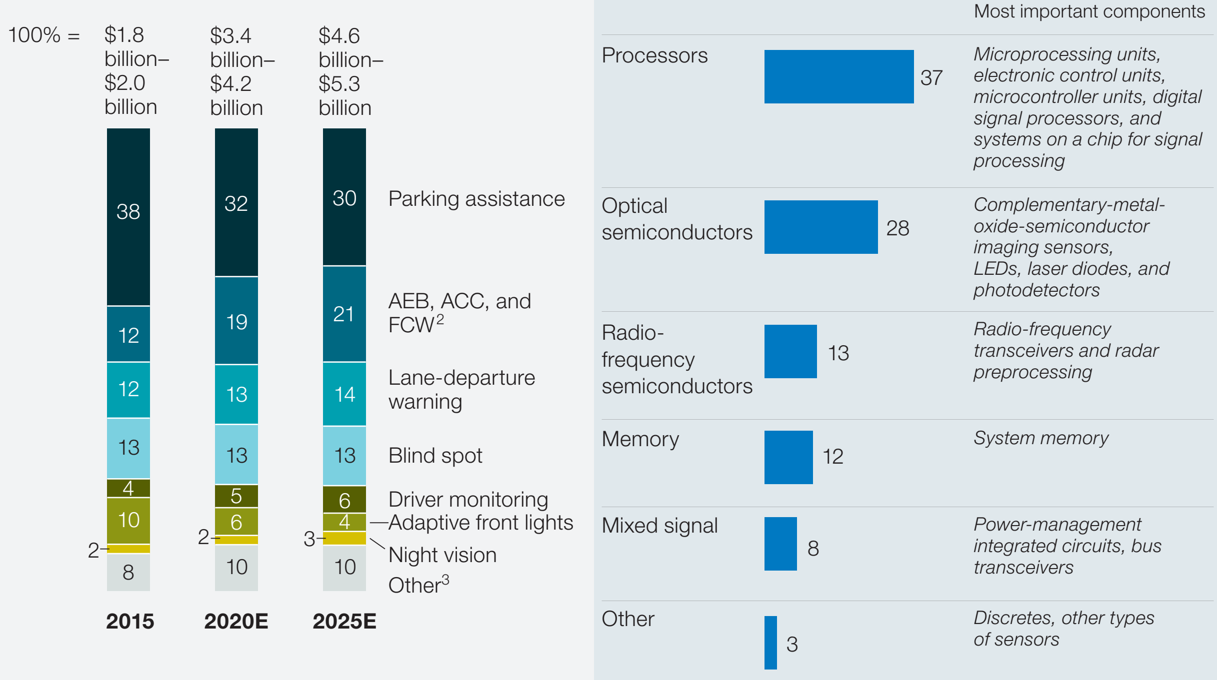
With processors and sensors expected to account for most revenues, it makes sense for semiconductor companies to consider competing in these segments by creating differentiated offerings. In addition to hardware, which still accounts for most of their revenues, semiconductor companies could capture value by expanding their offering into software and algorithms.

Processor enhancements. Those players with experience in adjacent industries, such as consumer, mobile, or data processing, could be best positioned to improve processor performance—the most important selling point. Since fast processors are found on the smallest nodes, they require huge investments in R&D and manufacturing. Sales in the automotive market alone will not justify these investments, so semiconductor companies may need revenue from other sectors to receive a decent return on investment. In addition, players with experience in adjacent industries may be able to adapt some of their products for ADAS applications, reducing development time. For instance, NVIDIA adapted its Tegra platform, which was originally developed for gaming devices, smartphones, and tablets, for use in automotive systems.

Exhibit 4 **For semiconductor companies, processors and optical semiconductors are expected to account for most hardware revenues for advanced driver-assistance systems in 2025.**

Semiconductor revenue in advanced driver-assistance systems per application, %[1]

Semiconductor revenue distribution on device types in 2025, %[1]



[1]Figures may not sum to 100%, because of rounding.
[2]Autonomous emergency braking, adaptive cruise control, and forward-collision warning.
[3]Includes, among other categories, back-side monitoring and traffic-signal recognition.

Source: McKinsey analysis

Sensor enhancements. Many different types of sensors exist, but three are most important for ADAS. The first and most cost-efficient option involves optical sensors and camera-based solutions. These sensors are versatile and can assist with a wide range of ADAS functions, but they are easily affected by poor weather conditions and other environmental hazards. Optical sensors and camera-based solutions also require complex software algorithms to recognize objects, such as pedestrians and other vehicles.

The second category involves lidar systems, which use a scanning laser to generate a complete 3-D image of the environment. Unlike optical sensors, lidar is less sensitive to weather conditions and directly provides the location of objects around the vehicle. But the lidar systems with the greatest range—100 meters surrounding a vehicle in all directions—are large and typically require external mounting. Although prices have fallen in the past decade, dropping from many tens of thousands of dollars to less than $10,000, they are still too expensive for deployment, and further price reductions are necessary to enable their adoption in ADAS. Lidar systems with a more limited range, such as those that can detect obstacles within ten meters in a single direction, have already been incorporated into some cars. For instance, Continental has offered short-range lidar for some time.

Finally, ADAS often incorporates short- and long-range radar using electromagnetic waves in the range of 20 to 80 gigahertz for determining the distance, speed, and direction of objects. These sensors function better than others during adverse weather conditions, but they typically involve compromises in measurement range and angle. For instance, long-range radar can detect obstacles up to 250 meters away, but the measurement angle is quite narrow. In consequence, adaptive cruise control often combines long-range radar with short-range radar, which has a wider measurement angle.

Although sensors generate less revenue than processors, semiconductor companies may prefer to work in this area because scale is of lesser importance, and it is easier to differentiate products. In fact, many sensors are required to be application specific, with different performance levels and signal-processing capabilities for their ADAS applications. As with processors, semiconductor companies may gain an advantage if they have experience in adjacent industries—for instance, creating complementary-metal-oxide-semiconductor image sensors for the consumer market—since that will facilitate product development. One challenge in adapting products may involve customizing them to meet specific automotive requirements, including those for safety.

Software. Moving into the software space may be difficult, since semiconductor companies often lack advanced software skills. To compete, they may need to build their software skills internally or undertake mergers and acquisitions with players that have the necessary capabilities.

Semiconductor companies should consider bundling hardware with nonsilicon offerings—both software (for instance, drivers, operating-system adoption, and codecs) and algorithms, including those used for real-time processing of sensor data. Bundling may generate more value than simple hardware enhancements, such as improved memory or central-processing-unit performance. In addition, semiconductor companies could attempt to provide more modules or integrated solutions, such as systems on a chip. OEMs may prefer modules and integrated solutions, including software, over single-component solutions because they provide better performance, require much less effort to implement, and make them less dependent on tier-one suppliers.

How to play: Strategies for standing out from the crowd

The changing automotive market offers new opportunities for semiconductor companies, but it will also be intensely competitive. Three factors may be crucial to winning market share: strong working relationships with OEMs, collaborations with other players across the value chain, and product differentiation based on safety and security features.

Strong relationships with OEMs. Although OEMs have long relied on tier-one suppliers to provide innovative components, they are willing to take a much more active role in ADAS development. In fact, OEMs may eventually assume the lead because the systems found in fully autonomous vehicles must work together closely. If they drive ADAS development, OEMs will have the freedom to select the best subsystems—including sensors and general control systems—from a variety of tier-one suppliers, rather than relying on a single source. Taking charge of ADAS development would also ensure that OEMs have a better chance of differentiating themselves from competitors for both driver-support and autonomous-driving functions.

The need to develop innovative ADAS technologies is prompting OEMs to collaborate more closely with tier-two suppliers, thereby giving these suppliers a more critical role in vehicle design and manufacture. The exact assistance that an OEM requests will vary by company and application, so semiconductor companies should be prepared to provide different types of support. For instance, they might actively help OEMs with integration, assist with the development of customized integrated systems, or support the optimization of system performance.

Semiconductor players that are able to build strong relationships with OEMs may have an advantage, as will those with the ability to locate or assign field engineers near their partners. Companies can also create new relationships by demonstrating their capabilities at trade shows or by reaching out to OEMs to offer development support.

Multiple collaborations across the value chain. Numerous nontraditional automotive players and small to midsize businesses are now trying to capture value from ADAS. Semiconductor companies could pursue multiple collaborations with these players—even those that may be competitors or customers. For instance, they may seek to complement their hardware knowledge through partnerships with competent software players that have strong automotive track records. In some cases, two or more semiconductor companies may work together. For example, Renesas Electronics collaborates with more than 150 companies, including other semiconductor players, on infotainment and ADAS capabilities. By collaborating with multiple players, semiconductor companies may develop high-quality solutions that differentiate them from competitors. They may also reduce costs, optimize resource use, and decrease time to market. While many semiconductor companies may form partnerships with existing players, they could also consider collaborating with start-ups that offer strong solutions.

Differentiation through safety and security. ADAS technologies already have high safety requirements, and these will increase as applications take more active control of cars. In fact, many future ADAS technologies will be rated at Automotive Safety Integrity Level D, the classification reserved for components or systems where a malfunction poses the risk of injury or death. ADAS security requirements are also among the highest because the consequences of a hacker's interference with steering, braking, or other vehicle functions could be catastrophic. Already, there have been some well-publicized hacks on non-ADAS vehicle systems, such as those that locate, unlock, and start cars.

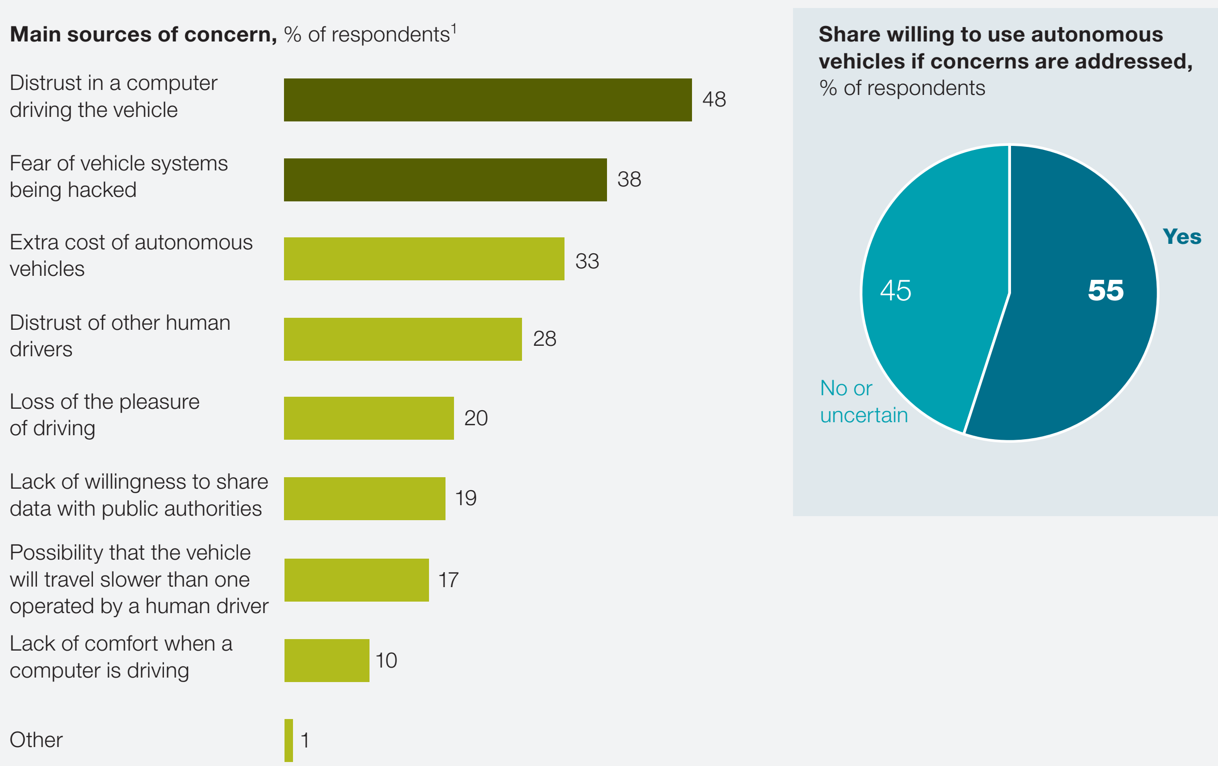
The recent McKinsey survey on connected cars confirmed that consumers are concerned about the safety of ADAS autonomous-vehicle offerings. When asked about autonomous driving, almost half of respondents expressed distrust about the computers that control the vehicle, and 38 percent stated that they feared hacking. However, more than half of respondents said they would be willing to use an autonomous vehicle if their concerns were addressed (Exhibit 5).

Since safety and security issues could derail the ADAS market, it would be helpful for semiconductor companies to become familiar with Automotive Safety Integrity Level risk-analysis methods and perform them during the earliest stages of product development, thereby eliminating any potential for component or system-level failures. As products advance in development, semiconductor companies may need to conduct extensive testing that evaluates the safety of the ADAS component and the entire system under different environmental and operational conditions.

Autonomous driving is supported by cloud data, car-to-car communication, and car-to-infrastructure communication. In consequence, ADAS systems must link to a vehicle's communication module directly to enable fully autonomous driving. Although these modules have intrinsically secure connections, additional protections will be needed. Advanced hardware firewalls, incorporated network-level security elements (for instance, crypto chips), and

Exhibit 5

Despite reservations about autonomous driving, more than half of surveyed drivers would use this technology if their concerns are addressed.



[1]Based on responses from car buyers in China, Germany, Japan, and South Korea (n = 3,500); data from US respondents were not available for this question at the time of publication.

Source: McKinsey survey on connected cars, 2015 support of virtualization technologies are opportunities for semiconductor companies to differentiate their products in security.

When to play: The advantages of early entry

Some semiconductor companies are hesitant to enter the ADAS market because the technology is not yet mainstream. Although their caution is understandable, our research suggests that early entry may provide long-term benefits.

First movers may have a chance to shape the industry—for instance, by helping to establish technical standards or defining fundamental system-design architecture. And companies that secure intellectual property for their ADAS technology early could potentially collect royalties over a longer period, as Bosch did when it created the controller-area-network bus system that became an automotive standard for many years. Since there are only a limited number of technical solutions for ADAS, fast followers may also find that the best ideas have already been patented. Even those that create innovative solutions will have to abide by decisions earlier players made about technical standards and system architecture, even if they are not optimal for their own products. Consider what happened with telecommunications: Qualcomm, as a first mover, successfully pushed many of its own technologies into the LTE standard for wireless communication. Other companies must now adhere to these standards, while Qualcomm receives royalties for its technologies.

Early entry may also make sense when considering the customer base and the industry. OEMs need to screen and prioritize their ADAS suppliers now, since automotive design cycles are long, so first movers may be best positioned to capture value when sales volumes increase. They could also gain a long-term advantage because OEMs and tier-one suppliers may want to stick with trusted, well-known suppliers as they develop next-generation technologies to create fully autonomous vehicles, which are expected to reach the broad market between 2025 and 2030. This is not to say that fast followers cannot succeed, however—only that they may encounter more difficulties and capture less value than companies that aggressively pursued ADAS opportunities early on.

■ ■ ■

ADAS applications may represent the next critical business opportunity in the automotive sector, and semiconductor companies are well positioned to capture it. Their technological expertise—always valued by OEMs—is now more important than ever, especially if they can provide components and solutions that improve system-level capabilities. But it may be equally vital for semiconductor companies to adapt their traditional business model by expanding into software and integration capabilities and by developing new strategies for working with OEMs and various players throughout the value chain. Those companies that take action now, while the ADAS market is still in its early days, may emerge as the winners. ■

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