



Rebooting Autonomous Driving


accenture

While Autonomous Driving (AD) has not lived up to the promise of its most ardent promoters, it still has big transformational potential. Like it looks today, the market will be shaped by evolutionary approaches, not a big bang disruption. Evolution is in line with the strengths of established vehicle manufacturers rather than disruptive tech startups—if they play their cards right.

Summary

Artificial Intelligence (AI) is the key enabler of AD—a core disruptive force in the automotive industry.

A decade ago, when deep learning marked the breakthrough in computer vision and tech players started to invest in AD technology, most observers expected a quick market shakeout with new entrants taking the lead. After 10 years of increasing investments, however, it is clear that deep learning alone will not be able to make full AD possible. Business leaders need to better understand these technical ramifications—at least on a high level—to make value-driven decisions.

Here we explore AI's technical challenges to help illustrate the market opportunity and its trajectory. AD is not about to disrupt incumbent automotive firms' business models, but the cost of doing nothing is steep. If Original Equipment Manufacturers (OEMs) go all in and fundamentally transform their products and processes, the new configuration plays to their strength: they can use their increased assets in the field to collect an even richer dataset.



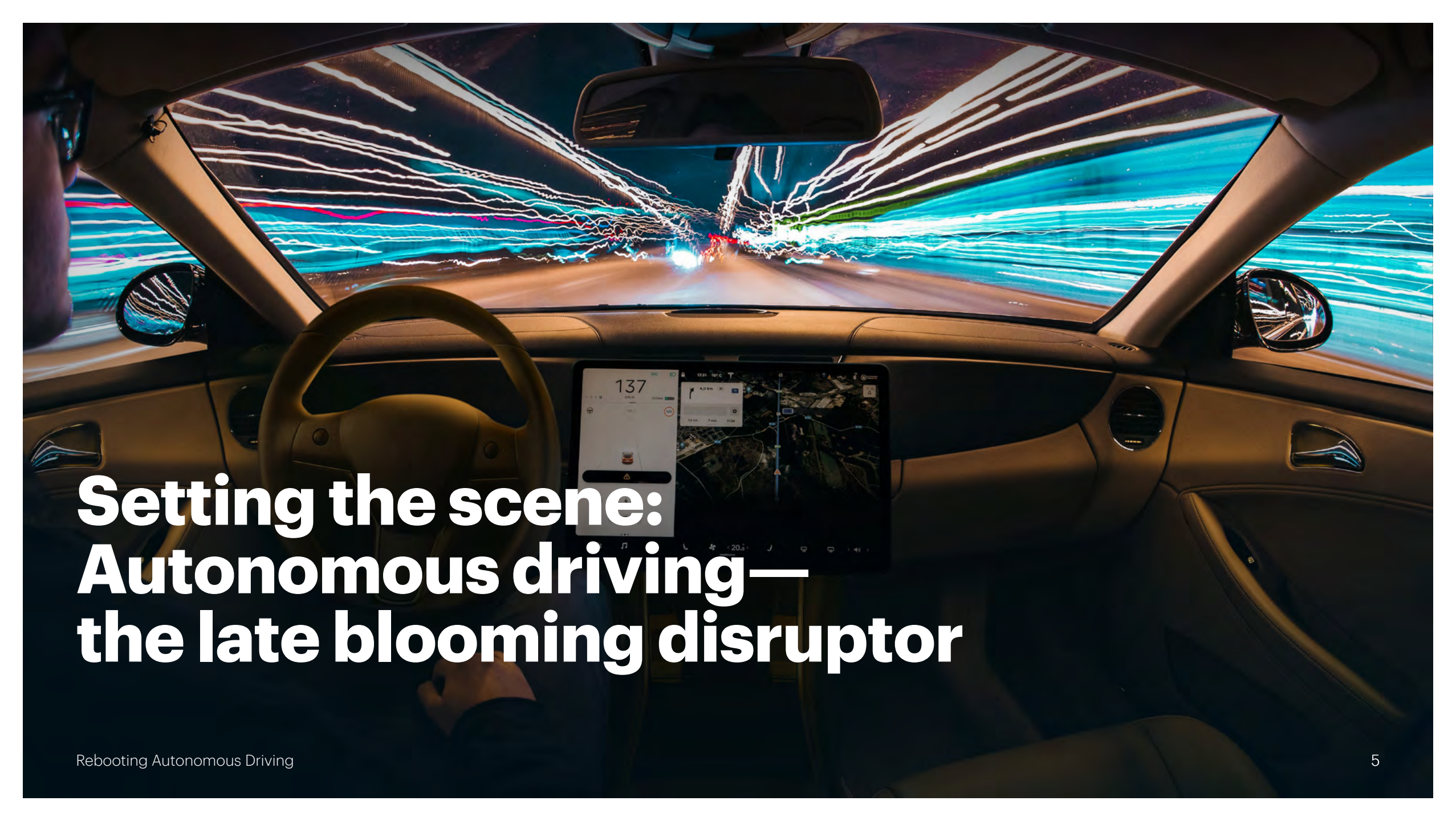


To succeed in the AD market, OEMs will need to become much more software-driven than they are today. Only a software-first model will help OEMs to leverage all the data necessary to push automation using a mechanism Tesla calls “shadow mode.” Shadow mode entails equipping every car with AD technology that continuously runs in the background—without linking to driving actuators. This process compares the driver’s behavior with system decision-making. Shadow mode is an ingenious—yet demanding—mechanism to source edge cases from human drivers.

With this, OEMs have an enormous asset in their favor—namely, millions of owners/drivers. With human beings at the wheel, OEMS can collect real-world data from around the world

under all environmental circumstances. This big data will help drive the very future of AD. Only the combination of drivers and an always-on shadow mode enable the semi-automated detection of edge cases. Unlike small electric vehicle startups and other newer players that have only small fleets on the road (as well as the tech industry at large), established OEMs’ massive fleets will provide an enormous advantage in this rebooted market. The real currency is not just data—it is also the collection of various edge cases. And the bigger the fleet, the better and more diverse data that can be collected.

OEMs already have an enormous asset in their favor—namely, drivers themselves.



Setting the scene: Autonomous driving— the late blooming disruptor

Four trends in the automotive market are forcing OEMs to rethink their products and business models: connectivity, AD, shared mobility and electrification (CASE). Out of all these megatrends, arguably, AD—combined with car sharing—has the most far-reaching potential to substantially disrupt the traditional automotive business model.

If unrestricted driverless cars were to become a reality, the current car ownership model would lose commercial viability. Similar to the market disruption that online streaming caused the video rental business, today's ownership model would endure a significant shakeup. In mobility's case, ownership of individual assets would be replaced by access to managed devices. A fleet of autonomous vehicles could permanently circle through metropolitan areas, picking up and dropping off passengers or goods as needed.

However, full AD (the kind envisioned in futuristic books and movies) is still a long way from becoming a reality—if it ever happens. Daunted by complex technical and regulatory challenges—not to mention staggering investment needs—many OEMs have scaled back research and development in recent years. At the same time, abandoning AD altogether risks misreading the market and missing out on a strategic opportunity.

This situation presents complications. While full AD is far off, the disruptive potential can still unleash its power of “creative destruction” in smaller increments by reinventing selected operational areas like logistics or valet parking. Such innovations could completely reshuffle these market segments within a few years, and vehicle manufacturers would lose their grip on monetization if their products could not cater to the right use cases.

Here we lay out several key strategies to help incumbent auto manufacturers to keep up with challengers from the outside and industry innovators from the inside. We conducted in-depth interviews with 16 senior decision-makers from

leading companies in the automotive arena—from OEMs to tier one suppliers, startups and tech players—around the globe (particularly in Europe, Asia and North America). These interviews help us estimate the market size and trajectory.

Abandoning AD altogether risks misreading the market and missing out on a strategic opportunity.

“AD has a lot of uncertainties coming from sensing or sensor data. That's the biggest flaw.”

Product Manager,
Leading Semiconductor Company¹


Easily fooled

Because AD relies on AI—specifically, deep learning—the challenges become ever more entangled and complex.

For example, associating patterns on a purely syntactical level is prone to misconception and thus easy to fool. Without additional technology (like Vehicle-to-Everything—or V2X), a car would not be able to differentiate a computer-printed stop sign from an actual traffic signal. Another example: a computer vision system cannot recognize a red traffic light with a broken glass cover because its algorithm is trained on the emission of red light. It has no concept of a visor—not to mention a concept of a broken object. This is what data scientists call a “barrier of meaning.”² Humans, on the other hand, have no difficulty understanding that a visor is broken and that the stop signal remains valid.

User videos show an Advanced Driver Assistance System (ADAS) vision process that mistakes the moon on the horizon for a yellow traffic light and slows down.³ This missing dimension of understanding meets a data distribution known as a long tail curve. This makes the subsequent combination and recombination of scenarios endless.

To make matters even more complex and challenging, applying subtle changes to an image’s pattern can consistently fool algorithms. This is called adversarial machine learning. An adversary can willfully and fundamentally manipulate the pattern association process. Cornell University has demonstrated such physical hacks by slightly modified stop signs (manipulated with spray paint or stickers) that AI systems “confidently” misread as speed limits.⁴ Another troublesome demonstration was the development of adversarial fashion—a textile with printed pictograms that reliably fools AD systems.



“When we look at humans, there are infinitely complex scenarios because how you form common sense is based on all experiences in life—AI misses this”

Senior Manager, Leading German OEM⁵

Mission impossible: Level 5

Missing common sense is arguably the root cause for deep learning systems being insufficiently robust.

Neural networks miss an intuitive and constantly updated model of the world that links physical, spatial or temporal information together.

To cater to all possible real-world events, AD systems would need an infinite dataset. This conundrum essentially means that Level 5 AD (anytime, anyplace a human could drive) is impossible as long as systems cannot process meaning in a human-like way—which is not even on the horizon. Current systems are based on supervised learning and statistical data association—and this will not allow for driving capabilities with a similar level of freedom and adaptability as humans. Driving tasks will eventually require higher levels of cognition like experimental learning (intervention) or scenario making (counterfactuals). Humans and other animals are able to learn from little data by using experimentation, analogies and prior knowledge.

This provides the ability to “fill in the blanks” based on a diverse set of preexisting experiences. These experiences are key to making predictions that are actual extrapolations from existing data (as opposed to mere interpolations within a given data set, as with supervised learning systems).

Neural Networks – Their Potential and Limitations

Several technological developments are relevant for AD, but each has specific limitations. For example, a Convolutional Neural Network (CNN), as used in computer vision, processes single images as an analog and static input. To mirror humans’ spatial memory or scenic understanding, several research projects involve adding a temporal component to neural networks. One method is the use of Recurrent Neural Networks (RNNs). RNNs introduce an additional feedback cycle that provides something similar to human short-term memory. An even more human-like approach

includes Spiking Neural Networks (SNNs), which incorporate a new hardware design called neuromorphic computing. This allows the network to use dynamic signals like the human brain, enabling them to learn in real time and process spatiotemporal information. However, there is an ongoing controversy among the different schools of deep learning: while the promoters of neuromorphic computing argue that no natural intelligence uses backpropagation mechanism as learning, the proponents of CNNs point out that complex SNNs lack learning algorithms and training methods.



The evidence from unprecedented field trials has humbled even the bravest futurists. Today it is clear: supervised learning based on large sets of labeled data and brute force computing is insufficient to take the appropriate step toward the next level of AI.

There are a number of experimental approaches that seek to broaden the set of instruments, including transformers, self-attention mechanisms, causal modeling or—ultimately—self-supervised learning. Additionally, there are increasing efforts to establish learning techniques more inspired by the human brain. These typically involve applying a combination of brain-inspired hardware and software using neuromorphic computing and Spiking Neural Networks (SNNs). But all these approaches remain within a computational paradigm—that is, they assume the mind is a computer.

This is a century-old conjecture, yet there is no evidence that meaning can be derived from computation—an idea first formulated by Gottfried Leibniz in the 17th century.⁶ And even after centuries of research and insights, there is no understanding yet on how to conceivably crack the barrier of meaning. Also, the last 50 years of AI have seen no substantial progress in the quest for General Artificial

Intelligence, and the recent hype around deep learning has done little to nothing to change that situation.

This cursory examination leads to three important conclusions about AI:

1. It needs to be restricted in application.
2. It requires additional technology to provide redundancy.
3. It always needs some form of human oversight (at least via a remote operating center).

These three factors present serious impediments to the business case. However, it is worth exploring the market opportunity and what parameters would drive a well-balanced approach.

“There is a layer of knowledge that is missing in AI. AI does not have a map of world knowledge like humans have. There is no judgmental thinking, no subconsciousness, no map of knowledge. Therefore Level 5 AD will not be possible.”

Senior Manager, Chinese Premium OEM, (ex-Tesla)⁸



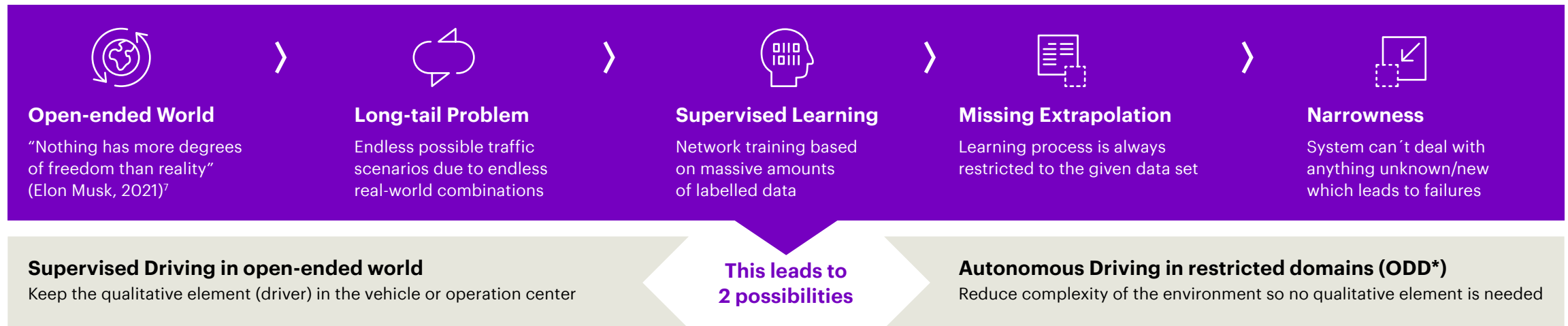
There is little point to betting on the next technology breakthrough. After spending a decade united under one paradigm, deep learning is back to foundational research. And that research points toward different directions. If a particular technology is in research mode, practical application is typically years away. This setback is actually good news for established OEMs.

Their ownership-based business model is not on the brink of disruption by an exponentially growing access economy. The playing field is leveled again with incumbents having a substantial advantage: tech players might have the upper hand in funding or analytics and software capabilities, but they do not operate large fleets of cars that they can use to harvest a diverse set of big data assets.

The evidence from unprecedented field trials has humbled even the bravest futurists. Today it is clear: supervised learning based on large sets of labeled data and brute force computing is insufficient to take the appropriate step toward the next level of AI. (Figure 1)

Figure 1. AI Barriers

Fundamental technical limitations of Artificial Intelligence systems in the context of Autonomous Driving



* Operational Design Domain: Operating conditions under which a given driving automation system or feature is specifically designed to function including geographic & environmental restrictions + traffic & roadway characteristics
Source: Accenture

The background features a dark scene with vibrant, glowing light trails in shades of blue and green. These trails appear to be moving across the frame, possibly representing data flow or motion. In the upper right, a portion of a car's front end is visible, including the headlight and grille, rendered in a semi-transparent, glowing style that blends with the light trails.

AV Market Outlook: Restarting the race for incumbent OEMs

Indeed, it is highly likely that the established, ownership-based automotive business model will remain intact, especially without fundamentally eliminating the human factor from the driving process.

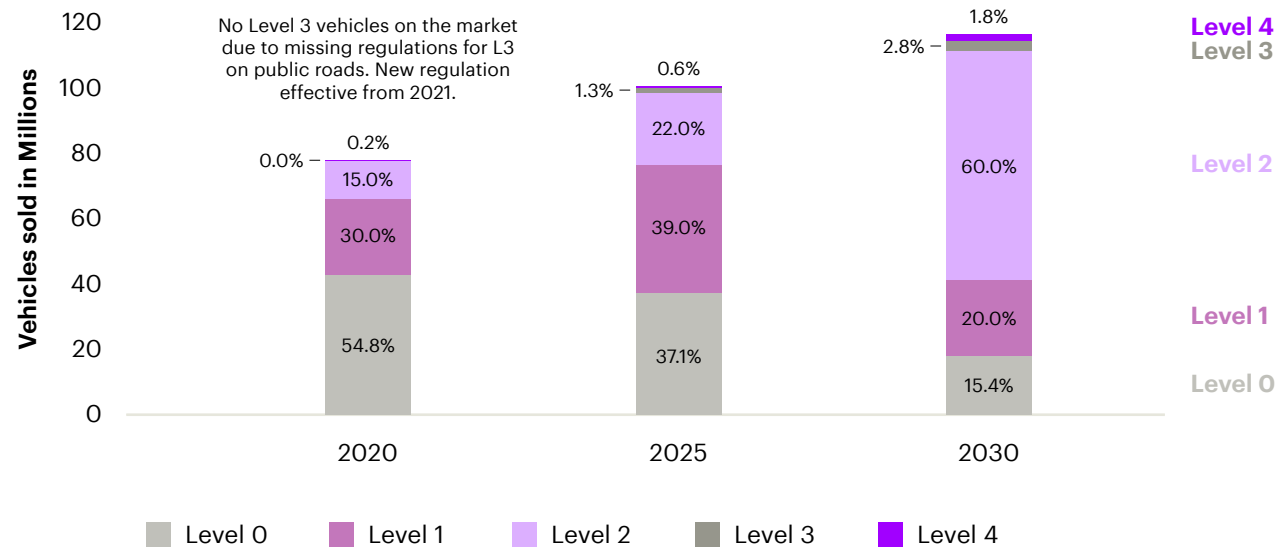
There will arguably be no access-based business model disruption in the foreseeable future. This forecast also applies to the market outlook for autonomous vehicles in terms of yearly new vehicle sales. While vehicle sales are likely to grow over the coming decades, it's anticipated that vehicles equipped with advanced driver assistance features (Level 2) will take the majority share.

Today, the market share of Level 2 vehicles is only about 15%. In the next generation, every fourth new vehicle sold will be capable of Level 2 driving. By 2030, Level 2 cars are expected to comprise 60% of the market. At the same time, Level 3 and Level 4 vehicles will only account for a cumulated share of about 5% of the total market by 2030 (Figure 2). This disparity in market share

Figure 2. Autonomous Vehicle market share

Market share Autonomous Vehicles | Yearly new vehicle sales

(Passenger cars + light commercial vehicles (under 6 tons))



Canalys (2021); LMC Automotive (2021); Gartner (2020); IDC Data (2020); UNECE (2020)

is because Level 3 functionality is largely restricted to the highest premium vehicle space, which is relatively small. Beyond 2030, the advanced technology will spread into lower market segments, helping commoditize the respective hardware and

software technologies. Volkswagen, for example, announced that it plans to equip its entire fleet with Level 3 technology in the future. But this will take time. In fact, Volkswagen targets the second half of the next decade.⁹

Because the AI hurdles are much higher than experts initially assumed, today we can only apply real automated features that fully take over the driving process in highly restricted, regulated situations. Nevertheless, this commercial space offers great business potential. We're already seeing driverless vehicles performing simple logistics tasks at walking speed in restricted and low-complexity areas like ports or company grounds—and it's likely that this field will significantly grow in the future. OEMs with trucks and light commercial vehicles in their portfolio are in a comfortable position, as most of the real driverless use cases will take place within the logistics and shipping segment.

“Standalone AI technology will not make real AD come true. Infrastructure is needed—otherwise it cannot be 100% safe and intelligent. Even L3 or L4 is very hard to be achieved in high degrees of complexity like high speed.”

Management Member, German Automotive Supplier¹⁰



Business models of the future

Although a major business model disruption is not likely any time in the near future, we expect to see access-based business models in the market relatively soon.

These offerings will probably be significantly less profitable and compete more with public transportation than individually owned cars, but in a consolidating market, deeply-pocketed tech players could conquer major domains such as mobility services in certain megacities. OEMs will have to stay alert to position themselves in a favorable spot—or form reliable partnerships within high potential market areas.

Incumbent OEMs' critical advantage in this marketplace rests on their deep knowledge in car production, broad experience in asset handling in the field and their profitable ownership-based business model. Areas with the most potential will likely reside in the private and commercial vehicle

space like driver assistance features for passenger cars (such as Level 2 traffic jam pilot) or automated driving features for specific logistics applications (such as Level 4 container handling).

It is highly likely the established, ownership-based automotive business model will remain intact, especially without eliminating the human factor.



Leveling the playing field: Level 5 is out of sight

Only a few years ago, even skeptical observers predicted a rise to Level 5 within a decade. However, currently most autonomous driving is barely beyond the advanced driver assistance (ADAS) stage—or Level 2 (adaptive cruise control with lane assist).¹¹ What’s more, the industry is struggling to reach Level 3 (autobahn pilot with no driver monitoring, the most challenging leap—Figure 3).

Those predictions only a few years ago completely overestimated the potential of the underlying technologies. Level 5 driving requires fully adaptive, AI-based systems.¹² But this “anytime, anyplace” driving is all but unachievable unless these systems can demonstrate something similar to humanlike reasoning—a goal out of reach with current technology. However, this situation is exactly what will level the playing field among uneven competitors.

Figure 3. AD Levels

Levels of driving automation

Description	Driver support features - You are driving (e.g. warning, emergency braking, lane keeping assist, traffic jam pilot)		Automated driving features - You are not driving (e.g. L3 highway pilot, L4 driverless taxi)		
SAE Levels	L1	L2	L3	L4	L5
Driver Responsibility	Driver has to drive when system requests to			Driver is able to drive	Driverless (no driver intervention in the car needed or possible)
Environmental Restrictions	Restricted to specific ODD* (not anywhere)				On-road (anywhere), driver-manageable
Level of Intelligence	Task-based AI** (Narrow)				General AI**

* Operational Design Domain: Operating conditions under which a given driving automation system or feature is specifically designed to function including geographic & environmental restrictions + traffic & roadway characteristics

** Artificial Intelligence

SAE (2021)

A futuristic car silhouette is centered in the image, surrounded by multiple horizontal blue light trails that create a sense of motion and depth. The car is dark, with some highlights on its body panels. The light trails are bright blue and have a slight wavy, rippling effect, suggesting a high-speed or digital environment.

The way ahead: Evolution over revolution

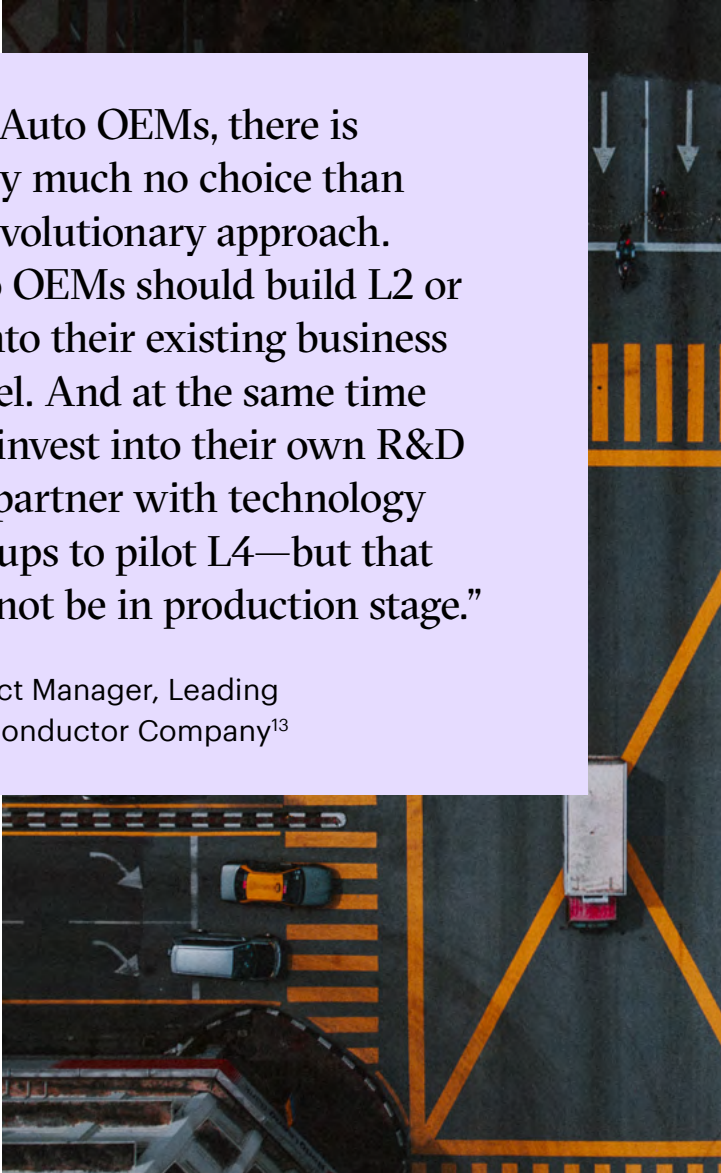
To thrive in the AD market, we recommend incumbent players take advantage of their greatest assets. They will also need to find opportunities to develop data-driven business models. Overcoming these twin challenges will require a fresh look at the entire market spectrum and loosening the bonds of simply doing things as they always have.

Jumping into the autonomous game may require an evolutionary approach rather than trying to revolutionize the entire industry. For example, it is highly inadvisable to leap immediately to a large scale robotaxi application (Level 4). Instead, it is much more feasible to start small by developing software-defined vehicles and viable Level 2 solutions with an incremental approach and applying them throughout an entire vehicle fleet. (See below: *practical recommendations, item 2.*) With this approach, OEMs will have access to a much more valuable data set of real-world edge cases. At the same time, they can mitigate risks by keeping the driver behind the wheel, staying within the ownership model and creating a safer environment.

The largest market potential, however, involves taking a sizeable piece of the cake by generating recurring revenues to cover development costs. But to compete, OEMs would need to put a large number of algorithm-equipped vehicles into the field. This, among other benefits, would help them to gather large amounts of real-world data from a diverse set of traffic scenarios.

Putting more vehicles on the road would in turn entail wresting control of the dataset that the vehicle fleet would generate, creating closed-loop processes. An OEM can then take the data it gathers in the field and circle it back over the air to train neural networks and advance the systems. Such a move would represent a more aggressive—but incremental—push toward Level 3. Trained networks would be distributed throughout the vehicle fleet enabling a broad database and constantly updated automated driving features.

We recommend OEMs avoid digging too deeply into the mobility services space of Level 4 ride hailing services as these can incur huge costs, including teleoperators, maintenance, vehicle observation, mapping, V2X and more. Further, these services can only be applied in restricted areas. They lack scale as any new area would require full additional mapping and network training costs.

An aerial photograph of a road intersection with yellow lane markings and a white truck. A purple rectangular text box is overlaid on the upper right portion of the image.

“For Auto OEMs, there is pretty much no choice than the evolutionary approach. Auto OEMs should build L2 or L3 into their existing business model. And at the same time also invest into their own R&D and partner with technology startups to pilot L4—but that will not be in production stage.”

Product Manager, Leading Semiconductor Company¹³

What's more, Level 4 ride hailing has little to no edge case collection, resulting in slow progress in network learning. Instead, OEMs seeking to explore driverless Level 4 options could focus on a commercial ownership model, applying use cases in gated and restricted areas.

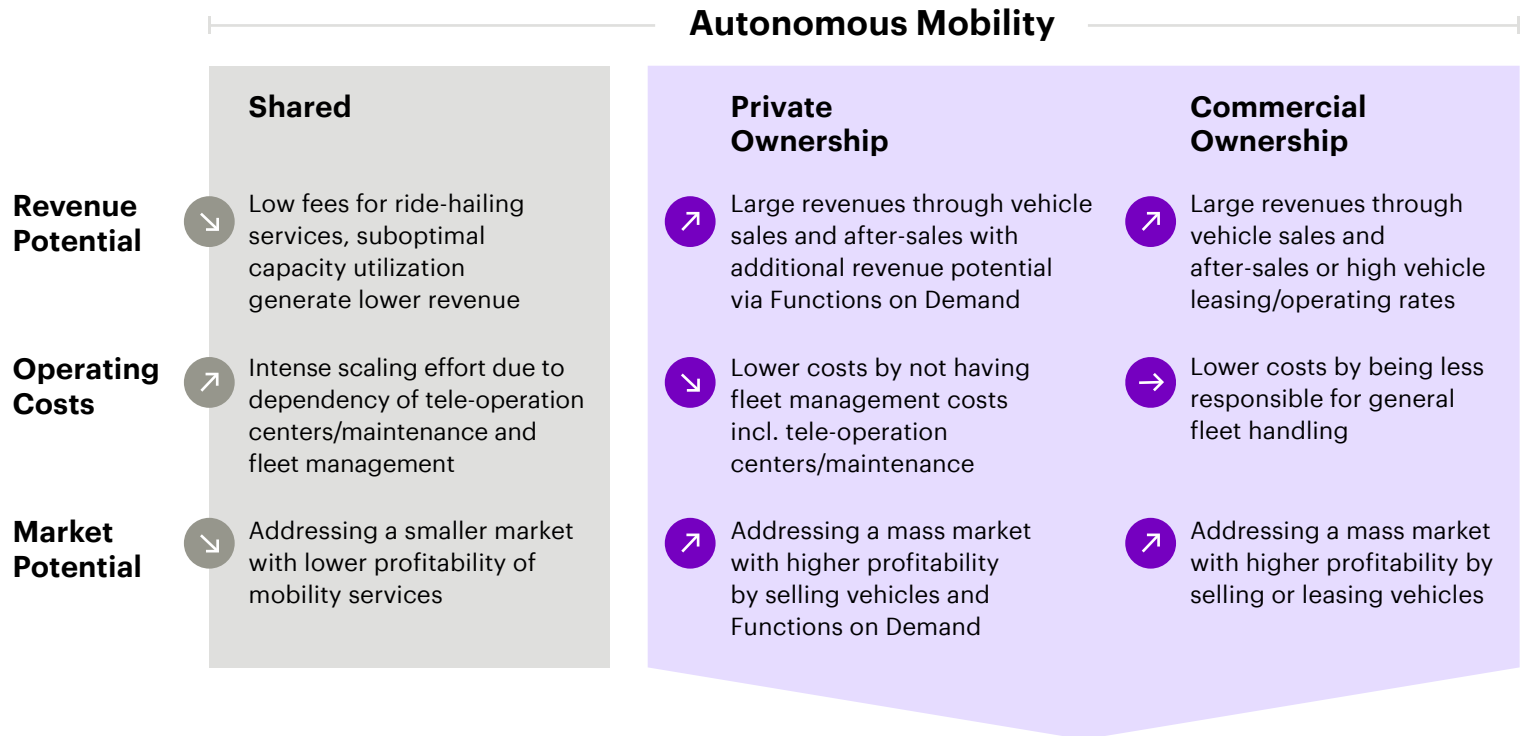
With this, they can participate in use cases operating in connected, mapped and simple environments without requiring any outstanding AI for reliable driverless performance. This would also create new aftersales revenue potential: specifically, OEMs could sell vehicle maintenance services to commercial customers.

Any new Level 4 capabilities an OEM gains in commercial applications could then be fed back to passenger cars. Specifically, companies could integrate Level 4 task-based features like automated valet parking and smart summon to generate new revenue streams (Figure 4).

OEMs can participate in use cases operating in connected, mapped and simple environments without requiring any outstanding AI or fully connected infrastructure for reliable driverless performance.

Figure 4. Business model recommendations

Business model recommendation for the Autonomous Driving option space



The way to go for OEM

“Private” and “Commercial” ownership business models with higher chance of profitability, no change of business models and large customer groups in B2C and B2B

Engholm et al. (2020): [Cost Analysis of Driverless Truck Operations](#)

Imperatives for incumbent OEMs

The automobile market is consolidating and will continue to do so. There will be major players in the field of AD, and OEMs will have to decide if they want to play the role of a hardware supplier or get in the race for data-driven business models.

Licensing the nuts and bolts of AD technology (namely the hardware and software) from tech players or providing hardware (the vehicles themselves) to these players will also be an option for OEMs, but losing the software and data element of their vehicles means losing the core of future vehicles. Instead, OEMs could focus on forming strategic partnerships and shared revenue plans while developing supplier/licensing business models.

The road toward software-defined vehicles will not end in a major business model disruption for incumbent OEMs, but a process disruption that

will turn current organizational and technological structures upside down. Manufacturers will have to transform themselves into software companies, building up data knowhow and enabling closed loop vehicle updating processes. Mastering this challenge can hardly be achieved alone. This is another reason for OEMs to form alliances and establish partnerships—so they can share development efforts and build up specific capabilities along their transformational journey.

Companies could integrate Level 4 task-based features like automated valet parking and smart summon to generate new revenue streams.

“[The] AD field is so complex that we need to have alliances, partnerships, consortium[s] and supplier infrastructure.”

Dr. Thomas Plocher, Ex Global Chief Engineer ADAS and Autonomous Driving, ZF¹³





Rebooting Autonomous Driving

Practical recommendations: what vehicle manufacturers need to get right

There are five essential, practical measures OEMs can take—and principles to observe—to start down the road toward autonomy:

01

Start investing iteratively in AI—Because L4 and L5 are not working as expected, manufacturers' ownership-based business model will remain intact. But there may be partial disruptions based on certain process innovations such as automated valet-parking or robotaxis. To protect against these blips, OEMs may need to invest in the technology early—but in careful stages. These early investments should stay focused on Level 2—L2 will be the biggest market for decades, and OEMs can lead the pack here, providing the most valuable real-world data. Monetize those features quickly and relentlessly to create an investment flow into the technology.

02

Get the preconditions right by becoming software-defined—Investing in AD means not only sinking money into AI research and data management. It also means transforming into a software-defined car manufacturer. In the past, OEMs focused their research on powertrain technologies. In the future, this money needs to flow into software stacks, including operating systems and developer ecosystems. The AD market will also require OEMs to embrace cloud and edge technologies. Cars need to become an endpoint in a wider cloud network that can seamlessly shift data and functions between edge and cloud platforms.



03

Use fleet analytics to develop relevant big data and edge cases—If OEMs succeed in transitioning their fleets into software-defined cars, they have a real opportunity and a potentially sustained competitive advantage. This advantage is grounded in the number of cars sold. For example, one of the top players, Volkswagen, sells more than 10 million cars a year. By comparison, Tesla sells only 500,000. If OEMs connect their cars to their backend, within a decade they can start harvesting data from a massive fleet in any corner of the world under any conditions.

04

Actively develop and define the AD market based on the insights from analytics, big data and edge cases. That requires a data-first mentality. Move away from the old “special equipment” logic. All cars need to be equipped with AD tech, whether configured and purchased by the owner or not. Data will need to be evaluated and monetized independently from the underlying hardware. This will not only help drive additional digital business models, but it will also help largely influence the stock evaluation.

05

Partnerships may help speed time to market and reliability—Collaboration with tech players, tier-one suppliers and/or service providers can not only increase the velocity of the race toward AD—it can also help OEMs save substantial development costs. Leveraging an ecosystem of partners will help accelerate speed to market for customer-relevant AD offerings.

While full AD may not be looming on the visible horizon just yet, smart OEMs can start their engines now to avoid major disruption and prepare to monetize AD's capabilities. This will require a fundamental transformation of OEM's products and processes.

Beginning with their strongest asset—the millions of drivers on the road—OEMs have an enormous advantage. The potential data they can harvest will serve as a highly prized asset they can leverage in partnerships and consortiums. However, doing so will require manufacturers to become more software-driven.

The AD market will likely develop in small increments—drivers are not seeking higher levels of autonomous driving. On the contrary, the consumer climate ranges from deep skepticism to outright opposition. Car manufacturers will have to work to actively develop the market, which is much easier by deploying driver-assistant systems with incrementally increasing capabilities.

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Figure 3:

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