Hype Cycle for Connected, Electric and Autonomous Vehicles, 2023

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Initiatives: Manufacturing and Transportation Sector Dynamics in IT

Connected, electric and autonomous vehicle technology is disrupting the automotive value chain in sustainability, revenue potential, safety, user experience and many others. This Hype Cycle advises automotive CIOs on the critical technologies to evaluate in this space.

Additional Perspectives

- Summary Translation: Hype Cycle for Connected, Electric and Autonomous Vehicles, 2023
  (12 October 2023)

More on This Topic

This is part of an in-depth collection of research. See the collection:

- 2023 Hype Cycles: Deglobalization, AI at the Cusp and Operational Sustainability

Analysis

What You Need to Know

The automotive sector is a major engine of innovation, and this can be seen in the pace of new technologies that make their way into this industry. Data-enabled services, electrification and smart cabins are a part of many technologies in this Hype Cycle. Most of these technologies continue to be in the Innovation Trigger and Peak of Inflated Expectations, showing they have a lot of potential to disrupt the automotive space, but yet have some way to go before reaching mainstream adoption.

Other technologies, like autonomous vehicles, hydrogen vehicles, vehicle-to-everything (V2X) communications and automotive cybersecurity, continue to be in the Trough of Disillusionment, as they do not yet benefit from regulations or disruptive players that can bring them into mainstream adoption.

The Hype Cycle

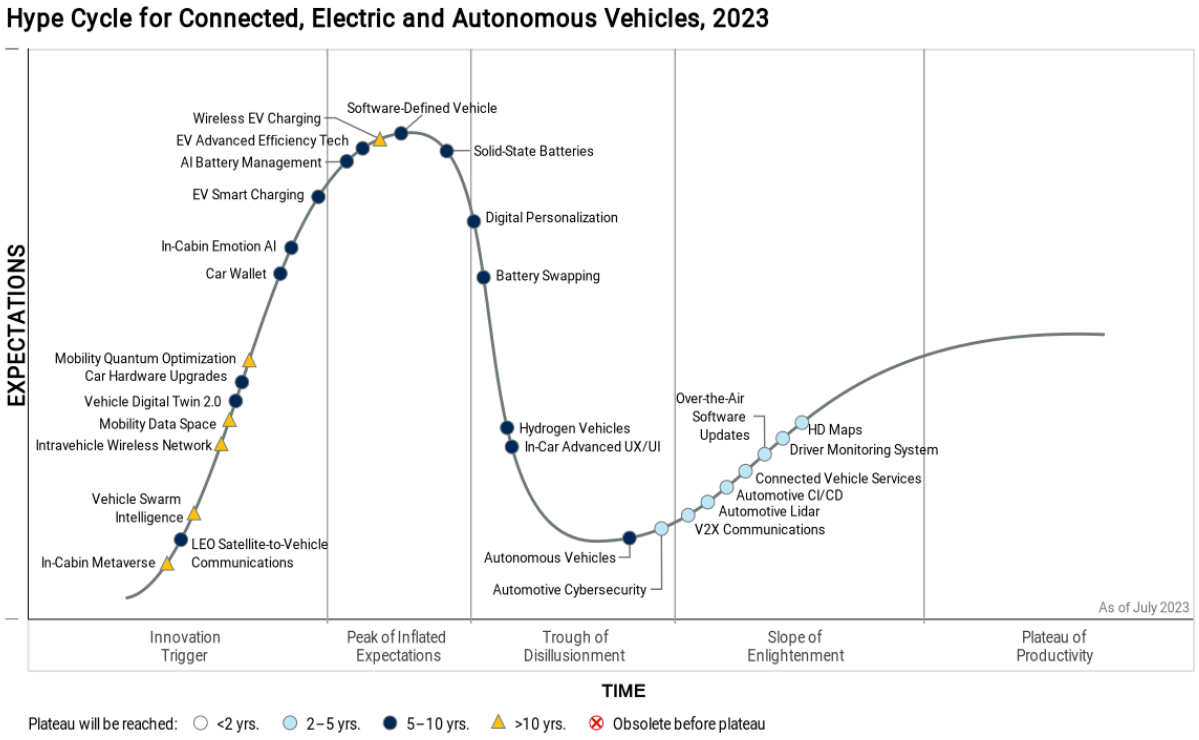
This Hype Cycle is dedicated to primarily vehicle technologies in the areas of connectivity, autonomy and electrification. Hence, it should not be seen as an exhaustive coverage of vehicle technology, nor the automotive value chain.

The technology evolution observed in this year's Hype Cycle has been influenced by the following trends:

- Electric vehicles (EVs) are a battleground between OEMs, which creates an immense pull effect for every innovation that can deliver a significant improvement in EV performance. This can be seen in several innovations featured on this Hype Cycle, like AI battery management, EV smart charging and solid-state batteries.
- Another major area of innovation is the maximization of the business benefit from data collected from, or sent to the vehicle. This is closely related to the rise in importance of software, which is foreseen to become the main revenue growth driver for OEMs by 2030. Low Earth orbit (LEO) satellite-to-vehicle communications, vehicle digital twin 2.0 and mobility data space — to name a few — show a lot of data-related innovation has yet to achieve mainstream status.
- The major importance of software as a revenue maker reinforces the need for better hardware. Car hardware upgrades will enable OEMs to maximize software revenue potential across the lifetime of each vehicle in operation.
- Vehicle user interfaces are one of the major enablers of software revenue generation, as better user experience leads to more purchases of digital features. Moreover, EV and autonomous vehicle proliferation means drivers will spend more time in the car without actually driving. In-cabin emotion AI and in-car advanced UX and UI show how the relationship between vehicles and occupants will evolve, enabling the vehicle to better anticipate occupant needs and delivering a more orchestrated cabin experience.
- The UN R155 regulation keeps driving greater OEM focus on automotive cybersecurity, together with China rolling out specific cybersecurity regulations by 2024. Regulatory pressure is progressively moving OEMs' approach to cybersecurity from reactive to proactive.

- Autonomous driving is always a highlight in automotive technology. However, the past 12 months have shown OEMs see limited commercial feasibility in Level 4 autonomy in the near future. Alternatively, Level 3 is already a reality in production vehicles, spearheaded by Honda and Mercedes to start with. This will be OEMs' main goal for autonomous vehicles within this decade.

Figure 1: Hype Cycle for Connected, Electric and Autonomous Vehicles, 2023



The Priority Matrix

Automotive cybersecurity should reach maturity within two to five years, as UN R155 will drive all new road vehicles to comply by 2024 in the jurisdictions where it is enforced. Moreover, China will enforce a regulatory cybersecurity framework also in 2024. These two milestones combined will push automotive cybersecurity to a level of advanced maturity and widespread adoption.

Automotive continuous integration/continuous delivery (CI/CD) is slated to achieve maturity in the same period. This innovation concept is disrupting the way that car software is developed. As most legacy OEMs transition to a centralized vehicle architecture within the next two to five years, this will enable them to spread the adoption of CI/CD.

Over-the-air software updates and V2X communications promise a high benefit when reaching maturity in the coming two to five years. V2X is seeing major adoption in China, and this is already triggering investment in terms of technology development. The European New Car Assessment Programme (Euro NCAP) will soon include V2X into its vehicle evaluation criteria. This will prompt automakers to adopt the technology, driving it to a state of advanced maturity. Over-the-air software updates are also becoming more popular. As more new vehicles transition to a centralized architecture, OEMs can remotely update many more vehicle features, which raises multiple monetization opportunities.

Table 1: Priority Matrix for Connected, Electric and Autonomous Vehicles, 2023

(Enlarged table in Appendix)

Benefit	*Years to Mainstream Adoption*			
↓	*Less Than 2 Years* ↓	*2 - 5 Years* ↓	*5 - 10 Years* ↓	*More Than 10 Years* ↓
Transformational		Automotive CI/CD Automotive Cybersecurity	Autonomous Vehicles Software-Defined Vehicle	Mobility Data Space Vehicle Swarm Intelligence
High		Automotive Lidar Connected Vehicle Services HD Maps Over-the-Air Software Updates V2X Communications	AI Battery Management Car Hardware Upgrades Digital Personalization EV Advanced Efficiency Tech EV Smart Charging In-Cabin Emotion AI In-Car Advanced UX/UI LEO Satellite-to-Vehicle Communications Solid-State Batteries Vehicle Digital Twin 2.0	In-Cabin Metaverse Mobility Quantum Optimization
Moderate		Driver Monitoring System	Battery Swapping Car Wallet	Intravehicle Wireless Network Wireless EV Charging
Low			Hydrogen Vehicles	

Source: Gartner (July 2023)

On the Rise

In-Cabin Metaverse

Analysis By: Pedro Pacheco

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

Gartner defines a metaverse as “a collective virtual shared space, created by the convergence of virtually enhanced physical and digital reality. A metaverse is persistent, providing enhanced immersive experiences.” In the connected, autonomous and electric (CAE) vehicle, the metaverse will play a role in onboard entertainment, the enablement of additional services and the creation of new monetization opportunities.

Why This Is Important

The metaverse will allow people to augment and enhance not only digital, but also typically physical activities. Its application in the field of CAE vehicles will create new onboard features in terms of entertainment and productivity. The metaverse will be a place where users and companies will be able to deliver, co-create, share and sometimes sell digital experiences and personalization features. Moreover, the metaverse will improve remote collaboration and customer service.

Business Impact

The metaverse can translate into a major revenue opportunity for CAE vehicle manufacturers in a broad range of digital services and features. These could include immersive in-cabin experiences for entertainment or productivity, sales of digital personalization features, sales of digital assets related to vehicles, or even the creation of metaverse marketplaces where those digital assets are sold.

Drivers

- The foreseen widespread adoption of electric and autonomous vehicles raises new opportunities for digital features offering occupants with more entertainment or productivity enhancement. As electric vehicles require drivers to wait for them to charge, autonomous vehicles free vehicle users from the burden of driving. This opens opportunities, for instance, for in-cabin remote collaboration for work purposes or remote leisure activities with family or friends.
- The car is also commonly referred to as the “third space,” after home and work. For that matter, as we progressively walk toward a metaverse-rich society, cars will be forced to go the same way.
- The revenue model of automakers is transforming. The mechanical simplicity of electric vehicles will reduce revenue opportunities in the area of after-sales, something that automakers will try to compensate with through the sale of digital services and digital features. Automakers will be looking to prioritize new monetization opportunities, and the metaverse can provide a channel to achieve that. This means they can create their own non-fungible token (NFT) market or create a broad range of digital assets that can be transacted as NFTs. For instance, vehicles will offer a growing number of digital personalization possibilities. These options of personalization can be turned into NFTs for sale in a marketplace.
- Virtual reality, augmented reality, digital twins or blockchain are technologies growingly present within connected vehicles. This works as a future driver for metaverse adoption, as these are also, coincidentally, foundational technologies for metaverse.

Obstacles

- The adoption of metaverse technologies is nascent and fragmented. Furthermore, this is a time for learning, exploring and preparing for a metaverse with limited implementation. The financial and reputational risks of early investments are not fully known, and caution is advised.
- Current manifestations of metaverses are siloed, app-based, noninteroperable experiences that do not satisfy the decentralized and interoperable vision of the metaverse. This current, walled-garden approach also strongly limits users’ control of experiences.
- Several of the drivers previously mentioned will only come to fruition in the long term. As such, this creates a situation where the technologies enabling true value-adding metaverse use cases are still nascent, besides requiring levels of cellular connectivity and hardware performance far above what is available today.

User Recommendations

- Have one single metaverse strategy. Meaning, whatever you plan for CAE must be part and parcel of a complete, companywide metaverse strategy.
- Optimize your digital capabilities and level of data maturity. A company that doesn't master digital technology nor data will never be successful in the metaverse, so you need to start by building the foundation for future metaverse success.
- Define the CAE use cases where you see metaverse delivering disruptive value. Start implementing these use cases with present-day technology. Building a technology roadmap that will take you from "as is" tech to the metaverse as technology itself evolves.
- Be careful when investing in a specific metaverse, as it is still too early to determine which metaverse space will be viable in the long term.
- Develop your capabilities in the cornerstone technologies for metaverse, like immersive technologies, advanced computing power and fast cellular connectivity.

Sample Vendors

Magic Leap; Meta; Microsoft; Unity; Varjo

Gartner Recommended Reading

Emerging Technologies: The Future of the Metaverse

Quick Answer: What Is a Metaverse?

Emerging Technologies: Critical Insights on Metaverse

LEO Satellite-to-Vehicle Communications

Analysis By: Bill Ray

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Satellites in low Earth orbit (LEO) may be used to provide high-bandwidth, low-latency communications to moving vehicles. Flat-panel antennas, built into the fabric of a car or truck, can deliver line-of-sight communications to orbit, sidestepping terrestrial networks to provide a direct link from vehicle vendor to end user.

Why This Is Important

Vehicles of all kinds increasingly need reliable connectivity. Such connectivity is used to update software, upsell additional features and services, track telematic data for preventative maintenance, and maintain the relationship between the vendor and the end user or driver. Cellular networks have limited coverage, and moving between countries can raise complications. By contrast, satellites can provide global connectivity whenever a view of the sky is available.

Business Impact

Satellites can provide global communications for connected cars, without the need for terrestrial cellular networks. This direct link cements the relationship between the vehicle vendor, which may also operate the satellites, and the end customer, avoiding any intermediary, such as a terrestrial network operator. International coverage and shipping are simplified, because vendors don't need to make multiple agreements or worry about vehicles moving within economic blocks, such as the European Union.

Drivers

Companies building LEO satellite constellations are keen to provide automotive connectivity, as their business requires scale to be economically viable. Automotive vendors are exploring the potential of LEO satellites for a combination or reasons:

- International roaming complicates the use of cellular networks, particularly where vehicles may be sold across country borders and permanently moved to a different country.
- Cellular connectivity can be expensive, and automotive vendors do not like being beholden to cellular operators that could change pricing or coverage with minimal warning.
- Cellular technologies are evolving at an accelerated pace. Automotive vendors are concerned that terrestrial networks might decide to refarm radio spectrum to new technologies, requiring in-field hardware upgrades to avoid connectivity loss.

- Terrestrial network coverage is far from ubiquitous, with rural areas often providing limited — or zero — network coverage.
- Satellite connectivity can provide a route for additional services, such as infotainment products and navigation services, which could provide additional revenue streams.
- Satellite networks can provide broadcast capabilities, allowing a mass update of vehicles in a single transmission. By contrast, terrestrial networks require individual downloads.

Obstacles

While LEO satellites offer many advantages, the business model is far from certain, given the following factors:

- It costs billions of dollars to build and maintain an LEO satellite constellation. Thus, some market instability is likely as the industry matures.
- Data services provided by satellites are more expensive than the same services delivered by terrestrial networks, as satellite operators must recover the high capital cost of building a constellation.
- The cost of ground equipment (the antenna that must be fitted to every car) remains above $500. The antenna is also more easily installed during vehicle design and production.
- Connectivity will still be limited to line of sight, so vehicles in tunnels will be cut off. Coverage in urban canyons (between skyscrapers) will depend on the number of satellites deployed, with only the largest megaconstellations able to provide ubiquitous urban coverage.
- Aftermarket accessories, such as roof racks or metallic paint, could interfere with the satellite connection.

User Recommendations

- Explore cooperative or partnership arrangements to provide competitive services against companies that can leverage sibling relationships (such as Tesla/Starlink and Geely).
- Look for partnerships with constellations that aren't owned by companies with an interest in automotive, such as Amazon Project Kuiper or Hanwha Systems.
- Evaluate hybrid services, using terrestrial networks where possible and switching to satellite where necessary.
- Conduct a cost-benefit analysis to work out at what price it would make sense to integrate a phased-array antenna into the roof of every vehicle.

Sample Vendors

Geely Space; Hanwha Systems; SpaceX

Gartner Recommended Reading

Forecast Analysis: Enterprise and Automotive IoT, Worldwide

Tool: Connected Vehicle Use-Case Opportunity Assessment

Vehicle Swarm Intelligence

Analysis By: Pedro Pacheco

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

Vehicle swarm intelligence mimics behavior from the animal kingdom to achieve collective outcomes vastly superior to the autonomous decisions that each individual member of a swarm can make. Vehicle swarm intelligence at scale requires advanced AI concepts like agent-based modeling and orchestration management. Such capabilities when applied to autonomous vehicles (AVs), can largely reduce the effort on data collection, simulation and machine learning training of AV decision rules.

Why This Is Important

Training AVs to operate efficiently in the real world is very complex. They require a detailed digital twin of roads and their surroundings, but ever-changing ambient conditions make this a hard task. Furthermore, AVs need to be trained on the decision-making process for every possible situation they encounter on the road, which is even harder. Swarm intelligence can dramatically accelerate data collection and decision training by allowing AV collective decision making.

Business Impact

Swarm intelligence can heavily accelerate the timeline to AV commercial viability. For instance, AV companies starting a robotaxi service in a new city spend a considerable amount of investment and time to train AV technology in tackling all obstacles to a high degree of safety. Swarm intelligence can cut down on that testing process and, therefore, allow an economically scalable deployment of the technology.

Drivers

- The current high costs of AV technology and the required length of deployment time make it a major motivator for the deployment of swarm intelligence. It would allow for a level of insight into crowdsourcing that could radically shortcut the timeline for AV widespread adoption.
- The fact that some companies — such as Tesla or Mobileye — have already started to use swarm data collection is a motivation for other companies to follow suit. It can drive a more widespread adoption of swarm data collection. Also, it will evolve the concept of swarm intelligence by adding infrastructure data, such as road cameras, and extracting insights from that data that will be shared across all relevant vehicles. For instance, Bosch believes almost all automakers will use this capability by 2027.
- The creation of mobility open data ecosystems, like the project currently being led by the International Dataspace Association in Germany, can be the stepping stone for a future platform of AV swarm intelligence.
- The constant progress in the area of AI creates new opportunities for the jump in swarm data collection, federated learning and swarm intelligence. AI data annotation processes are becoming increasingly automated. New forms of AI — like generative AI — allow for more efficient machine learning.
- Advances in distributed computing or mesh computing will make it easier to harness the capabilities of each AV's high-performance computer, allowing each to work collaboratively to build a platform of swarm intelligence.
- Swarm intelligence is being developed in other areas like defense. The U.S. Department of Defense has already demonstrated swarm intelligence capabilities through microdrones that could perform collective decision making, adaptive formation flying and even self-healing abilities.

Obstacles

- Most automakers are still to adopt swarm data collection. Even if this changes with time, it still represents an obstacle because automakers need to deploy swarm data collection before enabling swarm intelligence.
- The step from swarm data collection to swarm intelligence hasn't yet happened and requires a higher level of machine learning. Today this step is manual, which hinders the impact of swarm action from a cost and time perspective.
- Collaboration between automakers is lacking. Those already setting up swarm data collection are not yet building common platforms with other automakers or AV players. This lack of collaboration leads to a slower adoption of the technology.
- Poor data collection at infrastructure level. Even if not part of swarm intelligence, it is still essential to enhance the collective data visibility of the vehicles, which leads to main data blind spots.

User Recommendations

- Establish capabilities to achieve swarm data collection and processing from a vast fleet of vehicles — you require this capability prior to enabling vehicle swarm intelligence.
- Form partnerships to create broad, cross-company swarm data collection ecosystems. This is a major task that can only be overcome through collaboration.
- Create capabilities, together with your partners, to move from swarm data collection to swarm intelligence — meaning, direct and automated determination of insights from swarm data and subsequent sharing of those insights with the rest of the ecosystem. Make use of every vehicle's advanced computing abilities (distributed computing) to minimize data exchange with the cloud.
- Tap into the most advanced AI labs from tech vendors and universities to acquire AI tech that allows vehicles to deliver on-edge self-learning and consecutively share new insights with other vehicles.

Sample Vendors

Bosch; Mobileye; Tesla; Woven by Toyota

Gartner Recommended Reading

Top Strategic Technology Trends for 2022: Autonomic Systems

Intravehicle Wireless Network

Analysis By: Pedro Pacheco, Mike Ramsey

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Intravehicle wireless network pertains to the use of wireless technologies to exchange data and commands within the vehicle's electronic architecture. Specifically, this technology is intended to replace cabling to carry information. It is not related to Wi-Fi for occupant use; rather, it allows for vehicle systems to communicate with each other without a wire connection.

Why This Is Important

Intravehicle wireless networks can lower manufacturing costs by reducing wire harness complexity. In addition, wire harness reduction reduces vehicle weight, which improves driving range, particularly for electric vehicles. Moreover, the steep increase in technology embedded in the vehicle provides an additional incentive for wireless networks to prevent further increase in wire harness complexity.

Business Impact

The automotive sector is under pressure to increase automation content in order to reduce costs. The wire harness is one of the most complex parts of vehicle assembly, so the introduction of wireless connections would enable a direct cost reduction. Furthermore, the reduction of in-vehicle cabling also enables weight reduction, which benefits driving range or vehicle performance.

Drivers

- The arrival and growth of new OEMs in the area of electric vehicles (EVs) has been an important influence in the development of wireless technology. The startups face strong pressure to increase the level of factory automation to lower costs.
- There is a second trend of harmonizing the vehicle communication network, simplifying the vehicle architecture and enabling the move to a centralized high-performance compute vehicle architecture which supports the introduction of wireless technology.
- EVs require weight reduction to maximize driving range.
- Some tech vendors, such as Renesas Electronics and Visteon, have already launched wireless battery management systems which not only reduce weight but also reduce the size of battery packs.
- Several tech vendors in the area of consumer electronics and smart homes have developed high-quality wireless technology for infotainment and are now trying to expand into the automotive sector.

Obstacles

- There isn't currently any approved standard or protocol for intravehicle wireless communication. IEEE 802.15.4 is often proposed as a physical layer, along with Bluetooth, but the application layer remains uncertain. This absence increases the adoption cost and inherent adoption risk, which makes OEMs reluctant to move forward with the technology.
- While adopting a wireless network for entertainment applications may be relatively easy, going beyond that presents many more obstacles. However, investing in an intravehicle wireless network will only offer a good ROI once a substantial part of the wire harness can be replaced by wireless, or if it enables other key advantages like reduction in EV battery size.
- Using wireless communication for more critical applications — such as safety — still raises reliability concerns because of the signal interference risk vehicles are exposed to. This, in turn, creates a problem of trust in the technology among OEMs and customers.

User Recommendations

For OEMs:

- Incorporate this technology into your roadmaps and analyze vendor proposals by beginning with infotainment applications and progressively moving into more critical areas.
- Track academic research in order to tap into a technology breakthrough as early as possible.
- Partner with other OEMs and tech vendors in order to arrive at standardization of intravehicle wireless communication networks. For instance, General Motors (GM) is already preparing to incorporate Visteon's wireless battery management technology into their EVs.

For tech vendors:

- Propose the technology to OEMs if you already have expertise in robust short-range wireless communication networks by reassuring OEMs about the reliability of your solution in the realm of automotive applications.
- Present a quantifiable ROI that considers the advantages this solution brings in terms of vehicle design and manufacturing.

Mobility Data Space

Analysis By: Pedro Pacheco

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

A federated and sovereign open data ecosystem that securely and efficiently exchanges data across national and transnational mobility ecosystems, including many vehicle types, the infrastructure they use, pedestrians, travelers, and even ambient conditions like weather and air quality. It aims to increase transportation efficiency at the national/transnational level by deploying use cases that create business opportunities for a multitude of providers involved.

Why This Is Important

Data exchange creates a transparent and sovereign platform where members can easily access data across a national/transnational mobility ecosystem with high levels of privacy and security by default. This could be helpful to deliver the highest safety and efficiency in mobility. The number of connected personal devices and connected vehicles is already high, but the ability to exchange data among them and the infrastructure is reduced due to the lack of a common data architecture.

Business Impact

This is a disruptive innovation in mobility as it could unlock the potential of data. A mobility data space would provide data-focused vehicle makers, mobility providers and infrastructure operators with the opportunity to continuously optimize vehicle operation and adjacent services, which would unlock major digital revenue generation opportunities. Moreover, an open data space can bring major societal and economic benefits by reducing accidents, emissions and congestion.

Drivers

- The number of connected vehicles (on- and off-road) keeps increasing fast, which means a broad platform upon which to build a mobility data space.
- The direction of connected vehicle data regulation is toward simplifying the sharing with third parties within the limits of privacy. Right-to-repair efforts in the U.S. are starting to push automakers to share vehicle data directly with third parties and to allow them to download software directly to vehicles, circumventing automakers. In Europe, the EU's Data Act will also prompt automakers to be more forthcoming in sharing data with third parties (see How Must Connected Device Manufacturers Prepare for the New EU Data Act?). This means vehicle makers will be encouraged to collaborate with third parties, as they may not be able to control the connected services market merely by sticking to a strategy that tries to limit third parties' access to vehicle data. This collaboration environment favors mobility data spaces.
- The International Data Spaces Association (IDSA) is playing a key role in creating a mobility data space in Europe, gathering the collaboration of several major names in the mobility world, including many main automakers. ERTICO even advocates the creation of a " common European mobility data space." These initiatives are generating momentum that can achieve the large scale a mobility data space needs to create a disruptive impact.
- Similarly to the German mobility data space, the EONA-X association also intends to create a mobility data space in France, looking at improving the overall efficiency of the entire mobility ecosystem.

Obstacles

- A mobility data space must achieve a large scale and coverage across a multitude of vehicle makers, mobility providers, infrastructure operators and potentially even governments. However, it's hard to convince such a large number of stakeholders to adhere because each entity has its own interests which sometimes generate competitive distrust.
- A large number of organizations still have a relatively basic level in what comes to extracting value from data because they don't have enough data maturity to achieve the expected monetization. Among these are their ability to collect the necessary data at the needed cadence. This creates obstacles at the moment these organizations need to join and leverage a mobility data space.
- Some organizations and interest groups fear such a widespread data exchange may pose considerable challenges to privacy, which could create a negative perception of vehicle users.

User Recommendations

For car companies:

- Embrace and support the growth of a transnational mobility data space. Use it as a data source to develop disruptive business and operational models that will deliver great potential for monetizable connected services both for car buyers and governments.
- Focus on improving customer convenience by using adjacent parts of the mobility ecosystem at the beginning and end of car journeys.

For mobility/transportation providers:

- Join mobility data spaces as a way to better understand user needs and provide them with better service.

For governments:

- Support the creation of a mobility data space in your jurisdiction by establishing regulations about how data can be used and where it can be stored.

Sample Vendors

EONA-X association; International Data Spaces Association (IDSA)

Gartner Recommended Reading

Quick Answer: Will Catena-X Disrupt the Automotive Value Chain?

Top Automotive Trends for 2023

2023 CIO and Technology Executive Agenda: An Automotive Perspective

How Must Connected Device Manufacturers Prepare for the New EU Data Act?

Car Hardware Upgrades

Analysis By: Pedro Pacheco

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

Hardware upgrades to vehicles on the road, especially in areas of computing and sensing, support the roll out of a steady flow of new digital features and services to deliver a recurring revenue stream across the vehicle lifetime. The hardware built into the vehicle from the factory will not be enough to enable high-performance digital features throughout the vehicle life, so OEMs may design the vehicle architecture to enable easy hardware upgrades.

Why This Is Important

To achieve high revenue from the sale of car digital features/services, OEMs will have to leverage the vehicle's useful life as much as possible. On average, a passenger car's useful life is around 12 years in the U.S. and Europe. This number will increase further, given the greater longevity of electric vehicle (EV) powertrains. However, it is not possible for a vehicle's factory-installed hardware to enable an up-to-date user experience for 12 years, which hampers OEMs' digital revenue ambitions.

Business Impact

The ability to easily update vehicle hardware at a competitive price for the end customer will allow OEMs to keep selling new digital features/services throughout the life of a car. The widespread adoption of battery electric vehicles (BEVs) will bring a major long-term drop in revenue from new car sales and after-sales. Hardware updates will be pivotal in helping OEMs recover this lost revenue through enabling widespread adoption of the latest digital features/services in the car.

Drivers

- In the next decade, automakers will suffer major revenue losses from traditional sources due to BEV proliferation. BEV powertrains are much simpler than internal combustion engines and have far less maintenance needs. EVs will last longer and, in turn, drivers will keep their cars for longer. This implies a reduction in new car sales.
- In addition, the reduced maintenance needs of BEVs mean a reduction in conventional after-sales revenue — the “cash cow” of many OEMs. As such, they need to generate revenue from other sources and sales of car digital features and services are seen as the main candidate.
- No software-driven device in the world has ever kept up-to-date in terms of hardware performance for 12 years because semiconductor performance evolves at a fast pace. This limitation creates the need for upgradable hardware in software-defined vehicles.
- Software-defined vehicles feature a simplified electronic architecture, where a large number of microprocessors is replaced by a very small count of high-performance computers. Such simplification and centralization will proceed for the following generation of vehicles. This simplification makes it easier to upgrade hardware capabilities for crucial parts of the vehicle architecture by replacing a simple module.

Obstacles

- Most OEMs are still trying to develop a successful strategy for digital monetization. Hence, they struggle to find features/services that customers want to buy. This roadblock is holding them back from moving into the next stage, which is hardware upgrades.
- Hardware upgrades require vehicles with a centralized high-performance computing architecture. However, cars for sale today do not offer that.
- End customers will not pay for hardware updates unless they see the value. If OEMs can't offer digital features that entice customers, they will also not be enticed to buy hardware updates.
- Semiconductor technology evolves at a fast pace, hence there is an element of challenge when developing the latest-generation hardware that must be compatible with a 12-year old vehicle architecture.

User Recommendations

For OEMs:

- Develop all your upcoming software-defined vehicles with the capability to easily update performance-critical hardware. This upgrade needs to be simple enough to be done by the vehicle driver. This is essential because end customers will not pay for an update if that is too expensive.
- Plan hardware updates ahead of the vehicle launch, and make them an integral part of product and software life cycle management.
- Make the hardware upgrade enticing for the vehicle owner. This means spreading the cost of the hardware update across future digital features enabled by this update, and having a roadmap of future digital features/services that the customer can only access through that update. You must also do active marketing promotion of new hardware updates to keep customers informed.

For tech vendors:

- Develop a hardware roadmap for OEMs that features a number of cost-competitive hardware updates across at least a 12-year span for a particular vehicle model family.

Gartner Recommended Reading

Market Trends: Software-Defined Vehicles Will Disrupt the Automotive Supply Chain

Life Cycle Management of Software-Defined Vehicles: Step 1 — Software Bill of Materials

Vehicle Digital Twin 2.0

Analysis By: Jonathan Davenport

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

A vehicle digital twin 2.0 takes connected car platforms to the next level by creating a virtual representation of both the physical vehicle and its software. Simulations can be run to gain visibility into vehicle behavior by mixing real-time connected car performance and usage data, with physical and virtual datasets. Using vehicle digital twin 2.0 to simulate the impact of new code and understand how the entire vehicle will operate ensures that updates don't have unintended consequences on the overall performance of the vehicle.

Why This Is Important

A vehicle digital twin 2.0 is needed to ensure that any over-the-air (OTA) software or firmware update and changes to parameters do not negatively impact customer satisfaction and, ultimately, that functional safety levels are maintained. Automakers want to move away from a revenue stream based on selling low-margin capital items to selling software-enabled services, from which much higher gross margins can be derived.

Business Impact

Vehicle digital twin 2.0 will provide the ability to confidently deploy rich application updates, even to safety critical systems deep in the vehicle and as a result deliver customized value-added services to the customer. Automakers can generate income from multiple owners over a vehicle's life, either through one-off purchases or subscriptions. Likewise, digital personalization of vehicles is enabled, which is especially important for shared mobility services vehicles to underpin customer retention.

Drivers

- Customer requirements are changing based on experiences of having continuous improvement derived from consumer electronics, which is forcing automakers to rethink their approach to deploying software updates to vehicles. Competitive pressures from Tesla and other newer carmakers are accelerating the need to adopt digital twins as an enabling part of software updating technology.
- Continuous improvement to products, especially for AI-based applications such as autonomous driving, will lead to large-scale data collection to both identify product weaknesses and train algorithms, which require vehicle digital twin 2.0 to support testing and simulation in the cloud.
- As more functionality within the vehicle is controlled using software, vehicle digital twin 2.0 will be required to quickly identify changes made to the vehicle's software. These changes may include legitimate vehicle owners making repairs. Equally though, they could be as a result of malicious cyber criminals or the use of counterfeit software that raises revenue assurance issues for automakers. The deployment of preventative measures and/or rolling back of software to "safe" positions will also be required.
- Investments in service-oriented software that can be more easily updated and maintained will mean that automakers require not only an "as built" understanding of the software running on the vehicle, but also ongoing insights about "as maintained" software versions.
- As automakers separate hardware and software development life cycles, they will need a vehicle digital twin 2.0 to store, analyze and simulate high-frequency real-time vehicle performance data as part of a broader CI/CD software development approach. Software simulation, where full hardware-in-the-loop (HIL) or software-in-the-loop (SIL) testing and validation are performed using a digital twin in the cloud, will enable automakers to confidently deliver new or improved functionality to vehicles.

Obstacles

- To utilize the vehicle digital twin 2.0 effectively, different parts of the automakers organization, such as IT, R&D, product and engineering, will need to collaborate to find the optimal hardware for IT to operate in the cloud, and for R&D and engineering to incorporate into vehicles.
- The cost of transporting and storing large volumes of data in the vehicle digital twin 2.0 will be expensive.
- A digital twin that doesn't represent an accurate model could amount to wasted effort, time and energy and will not provide the required insight.
- Many automakers lack the in-house skills and expertise to fully utilize a vehicle digital twin 2.0.
- Building a business case that explains the benefits of collecting, storing and analyzing larger quantities of data will be hard for traditional automakers to quantify the benefits and show a strong return on investment.
- Risks associated with collecting data from the vehicles that contravene privacy legislations, such as the California Privacy Rights Act (CPRA or CCPA 2.0) and the GDPR, could lead to debilitating fines.

User Recommendations

- Build a compelling business case for making the investment in a vehicle digital twin 2.0 by clearly articulating the income from quality software updates, along with estimates of costs saved from recalls had inappropriate updates been deployed.
- Reduce the risk of customer confusion and associated litigation by publishing digital ethics policies that clearly state what data will be collected from the vehicle and for what purpose.
- Ensure revenue from software-defined vehicles is maximized by utilizing a vehicle digital twin 2.0 to monitor for use of counterfeit software and firmware in individual vehicles.
- Undertake deep dives to understand what is causing problems within vehicles by leveraging the vehicle digital twin 2.0 to collect higher frequency data from a subset of a vehicle fleet.
- Increase customer satisfaction by simulating the behavior of software, and how it interacts with other software and hardware in the vehicle prior to deployment.

Sample Vendors

Amazon Web Services (AWS); AVL; Fujitsu; Google; Siemens; T-Systems International

Gartner Recommended Reading

Software-Defined Vehicles' Impacts on the Role of the CIO

Market Trend: Connected and Autonomous Vehicle Data Enhances Software Life Cycle Management Transformation

Life Cycle Management of Software-Defined Vehicles: Step 1 — Software Bill of Materials

Life Cycle Management of Software-Defined Vehicles: Step 2 — Vehicle Software Register

Life Cycle Management of Software-Defined Vehicles: Step 3 — Vehicle Digital Twin 2.0

Mobility Quantum Optimization

Analysis By: Pedro Pacheco

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Quantum computing (QC) is a type of nonclassical computing that operates on the quantum state of subatomic particles to address problems with vast combinatorial complexity. One of the many areas where quantum computing offers potential for polynomial improvement is optimization. In mobility, this capability can be used to optimize traffic, as well as highly complex operational ecosystems.

Why This Is Important

QC uses quantum mechanical principles, including superposition and entanglement, to effect extreme scale parallelism in computationally explosive problems. One of the early impact areas with potential for polynomial speedup is optimization where annealing algorithms have shown early promising results. Quantum systems designed to address optimization at scale have the potential to solve major transport optimization problems not addressed by classical computers.

Business Impact

The United Nations expects that 68% of the world's population will live in urban cities by 2050. Transit authorities have been looking to optimize urban mobility by improving routing and reducing commute times and traffic congestion while seeking a better quality of life for residents. Quantum systems designed to solve optimization problems at scale and specialized quantum-emulation classical technologies can potentially optimize the combined efficiency of transportation in a large ecosystem.

Drivers

Quantum computing has a strong potential in transportation as it allows companies to explore annealing-based solutions to problems that were previously seen as unsolvable or too time-consuming:

- QC's ability to model and forecast complex ecosystems, like traffic environment and urban planning, is a point of attraction for several organizations, as it could bring substantial improvements in increasing the efficiency with which people and goods are transported. Volkswagen has already started to test the technology in traffic optimization, using a QC from D-Wave. Ford is working with Microsoft on a use case that utilizes QC to optimize vehicle navigation route guidance. Besides making use of swarming effect information, the model uses QC to run frequent optimizations that take into consideration thousands of other vehicles on the road.
- Several transportation providers feature highly complex operations, like in the case of airlines or railway companies. Some of these companies see quantum annealing systems and classical quantum emulation alternatives as a tool that can unlock opportunities in terms of planning and running these operational processes, including running complex "what if" scenarios for better disruption preparedness. For instance, these are among the reasons why Delta Air Lines is partnering with IBM to explore quantum applications.
- Vehicle design also entails several processes of optimization, and some of them are already evaluating QC as a way to unlock significant additional improvements, be it in several parameters of vehicle performance or cost. As an example, Airbus launched the Quantum Computing Challenge back in 2019 as a way to accelerate cooperation with academia and startups in this area, with the aim of introducing QC for commercial applications.

Obstacles

The obstacles pertain to usage practicality and the complexity of using a computer in a totally different way for problem solving:

- **Decoherence.** QC is extremely sensitive to decoherence, a process where the surrounding environment (like magnetic and electric fields and heat sources) destabilizes qubits, leading to information loss and diverse results.
- **Shortage of QC programming skills.** QC programming languages are different from other existing languages, which entails the need to hire or train specific expertise.
- **Complexity of mapping business problems** and refactoring them into quantum applications. None of the existing classical applications and algorithms used in classical systems work in a quantum context.
- **Immaturity of the quantum ecosystems,** scale of systems and limited vendor maturity creates challenges in enterprise ability to develop sustainable optimization solution roadmaps.

User Recommendations

QC becomes more commercially accessible but is still in an early phase. Transportation CIOs must plan QC initiatives with a future mindset:

- Modernize optimization algorithms and leverage classical technologies, including accelerators and quantum emulation accelerators. Apply logical constraints to problems to optimize complexity.
- Identify inflection points where quantum alternatives become better than classical advantage. Most optimization problems may not need a quantum approach.
- Develop a long-term technology adoption plan focused on quantum ecosystem selection and choice. Roll out use cases in line with the evolution of QC technology. Focus on a five-year horizon to deploy real-time applications where calculation speed is essential.
- Set up a QC internal innovation and exploration team, with a strong executive sponsor, clear innovation processes and cross-functional support. Nurture QC expertise to achieve a major QC unit in the long run.
- Leverage QC-as-a-service providers as a start.

Sample Vendors

Alibaba Cloud; D-Wave; Fujitsu Group; Gurobi Optimization; IBM; Microsoft; NVIDIA; Rigetti Computing

Gartner Recommended Reading

Innovation Insight for Quantum Computing for the Automotive Industry

Quantum Computing Planning for Technology General Managers

Car Wallet

Analysis By: Mike Ramsey

Benefit Rating: Moderate

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Car wallet is a generic term applied to the ability of a vehicle to make or accept payments. The wallet could have a single or multiple forms of payment and can make or receive payments from a wide variety of users, retailers or service providers. A car wallet could be connected to an individual or even have its own account when multiple drivers are using the vehicle, such as in a shared vehicle circumstance.

Why This Is Important

An embedded payment system in a vehicle is a progression from existing payment technologies like toll pass devices. It facilitates mobile payments for services, such as EV charging, parking or tolls, or goods like food. The payment capability also makes it possible for the vehicle itself to be paid by users, keeping a digital account in the vehicle. Today, automakers have several avenues to enable making payments through the vehicle; however, most are limited in capability and scope.

Business Impact

Enabling vehicles to pay and be paid is a convenience and safety feature primarily; however, it also could enable a transition to a vehicle miles traveled tax. While it would not dramatically change the industry, it could be a very useful feature for car and business owners as well as governments and provide differentiation for automakers. A vehicle with its own account and card could keep a balance and make a payment independent of the user of the vehicle at that moment.

Drivers

- Technology has improved in vehicles as has the prevalence of embedded connectivity, which is a requirement for a car wallet.
- Biometric identification via fingerprint or video will enable secure transactions.
- Proliferation of the Plug and Charge standard (ISO 15118) for EV chargers could help establish vehicle payment systems. It allows users to plug in a charging cord and have the payment handled automatically by identifying the vehicle and its owner, as well as payment.
- Any large effort by a government to mandate or influence widespread use of this technology, for instance to collect tolls, pay monthly vehicle-mile-traveled fees or registration, could create a breakthrough effect for this technology that would expand its usage significantly.
- Growth of electric vehicle sales, which will necessitate a move to a vehicle-miles-travel taxation system rather than gas taxes, could expand the viability of car wallets.
- Expansion of Google's and Amazon's footprint in vehicle multimedia systems could significantly increase vehicle payment capability because of those companies' significant ecosystems, though it may not impact the ability to make payments to a vehicle.

Obstacles

- Tolling systems are designed for a specific purpose and work well; however, to expand a payment system to many more users, such as retailers and parking lots, will require a simple API that is flexible.
- If no vendors accept this type of payment and it requires a lot of integration to work, then there is little incentive for the car companies to install digital wallets in vehicles.
- Automakers span across many countries and creating a single payment method will be challenging for both the automaker and the retailers.
- If a car wallet isn't installed in millions of vehicles, then retailers won't make the effort to connect their systems to it.
- Dominance of the existing large credit card/payment providers that already have brand awareness and market presence may be threatened by the advent of an alternative payment solution.
- Fragmentation in different markets could also limit the appeal and spread of the payment technology.

User Recommendations

- Explore the different vendors for car payment and determine which has the easiest path to integration with existing point-of-sale systems for retailers.
- Investigate biometric authentication and tokenization tools to make in-vehicle transactions easier.
- Determine whether it makes sense to partner with large tech providers to offer ecosystem access to expand the number of retailers and service providers that already have connections.
- Use the adoption of Plug and Charge for EVs as a means to enable car wallet capabilities.
- Ensure that the vehicle can store payment capability, including the necessary security measures.
- Work with the existing large credit providers, such as Visa and Mastercard, to enable closer integration between their technology and the vehicle's technology while leveraging their brand and market presence.
- Make sure that technology is capable of very accurate localization.

Sample Vendors

Amazon; BlackBerry; IBM; Sheeva.AI; SiriusXM; ZF Car eWallet

Gartner Recommended Reading

'Right to Repair' Initiative Could Have Significant Impacts on the Connected Car Ecosystem

The Future of Data-Driven Transportation Ecosystems

Infographic: Artificial Intelligence Use Case Prism for Automotive Enterprises

Quick Answer: What Is the Market Size for Connected Car Data

In-Cabin Emotion AI

Analysis By: Pedro Pacheco

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Embryonic

Definition:

In-cabin emotion artificial intelligence (AI) collects information on an occupant's state of being through several different sensors, like computer vision, infrared camera, natural language processing, electroencephalogram (EEG) scan or heart rate measurement. The assessment of each occupant's state can allow the vehicle to adapt different features and processes to improve onboard experience, improve driver alertness and even assess occupant health.

Why This Is Important

The increase in the number of cabin sensors to assess occupants' conditions will open up new opportunities for emotion AI. For instance, the European Union (EU) mandates that all newly homologated cars from 2022 must be equipped with a driver-monitoring system (DMS) that uses a camera to monitor the driver. This means carmakers can add capabilities to the existing system with software as the computer vision camera is already present. Most new cars are using AI voice assistants that could incorporate emotion AI through speech recognition.

Business Impact

The concept of emotion AI will enable original equipment manufacturers (OEMs) to develop cars that are much better at delivering experiences to occupants' expectations. Moreover, emotion AI will be an enabler toward improving the vehicle's human-machine interface (HMI), allowing drivers to control more complex features. Finally, emotion AI can also improve safety, health and well-being by enabling onboard sensors to detect driver drowsiness or intoxication, and assess the health condition of occupants.

Drivers

- Emotion AI has found good traction in areas of application like market research and call centers. This has allowed the technology to further mature for better responding to automotive-specific needs.
- The number of in-cabin sensors is increasing — as shown by the EU's driver-monitoring-system regulation. This makes it less costly to implement emotion AI in a vehicle since the necessary sensors will already be there.
- Vehicles will display a growing technological complexity that offers a wealth of features and functionalities to occupants. Traditional HMIs — heavily based on large touchscreens — won't be sufficient to help users deal with all the complexity. This is where emotion AI comes in by being able to better understand occupants' needs. In addition, emotion AI will enhance onboard AI assistants by providing them with emotional capability. These combined aspects will have the ability to greatly enhance onboard experience.
- Emotion AI offers opportunities in improving driver attentiveness and in assessing occupants' health conditions.

Obstacles

- Consumers have growing concerns about privacy and may perceive emotion reading as an invasion of privacy. This makes OEMs skeptical about using emotion AI or, alternatively, forcing them not to present the technology as emotion reading.
- Despite the capabilities of emotion AI, it is hard for OEMs to associate an occupant emotion to a particular situation and, similarly, to determine what action should be taken by the vehicle. This means additional contextual data must be added for emotion AI insights to be actionable.
- Even though AI can be used through different sensors, only computer vision has made progress in what comes to car interiors.
- Cultural bias is a challenge, as individuals from different cultures and geographies express emotions differently. This means the more use you make from emotion AI, the more precise its emotion recognition needs to be; however, cultural bias makes this a challenge.
- Some emotions are harder to detect than others. Happiness and joy are usually easy to infer, but irony presents greater difficulty, as you need excellent voice analytics to identify it. In several cases, you need to combine different forms of detection, facial detection and voice analysis.

User Recommendations

For OEMs:

- In addition to the DMS, embed emotion AI capabilities on the voice assistant. This will expand the range of insights you can extract from emotion AI.
- Add additional cabin sensors and data orchestration to have more contextual information on why an occupant displays a certain emotion.
- Develop a consumer-oriented value proposition for emotion AI, which can get around the issue of consumers thinking their cars are reading their minds.
- Work toward a more advanced level of cabin experience orchestration and intelligence, which will put you in a far better position to leverage the potential of emotion AI toward more tangible user benefits.

For tech providers or automotive suppliers:

- Take the regulatory framework for DMS as an opportunity to implement emotion AI and, through that, expand the capabilities of your solution.
- Incorporate opt-in emotion AI in voice assistants as a way to strengthen the value of this user interface.
- Expand your emotion AI solutions by adding data collection capabilities that enable you to determine contextual information of why the user displays a certain emotion.

Sample Vendors

Affectiva; Amazon Web Services; audEERING; Cipia; Eyeris Technologies

Gartner Recommended Reading

AI Multisensory Tech in Automotive HMIs, Part 4: Emotion AI

Competitive Landscape: Emotion AI Technologies, Worldwide

EV Smart Charging

Analysis By: Pedro Pacheco

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Advanced technologies pertaining to electric vehicle (EV) smart charging are enabled by charger connectivity to the cloud and vehicle. This covers topics including vehicle-to-grid (V2G), plug and charge, vehicle digital services, and enablement of features and functions via the charger's operating system. The aim is to improve end-user convenience and the profitability of charging operations.

Why This Is Important

Charging an EV is a crucial part of vehicle ownership. The technology embedded in the charger can enable superior user experience and convenience, while creating revenue opportunities for automakers, charge point operators (CPOs) and vehicle users under the form of digitally enabled services.

Business Impact

Smart charging will allow automakers to convert their customers into full electrification through a smoother charging experience, also enhancing charger profitability. EV charging itself is a business that can be explored as a source of new revenue. Moreover, smart charging will be an enabler of new business and operational models that could translate into new digital services enabled by the EV charger's operating system (OS). Online booking and loyalty programs are just a few examples.

Drivers

- New automotive entrants trigger disruptive innovation that pushes incumbents to abandon their status quo. For instance, Tesla developed its proprietary version of “plug and charge” 10 years ago and is offering several energy services that complement charging like, for instance, Tesla Autobidder.
- ISO 15118, the standard for V2G communication interface for bidirectional charging, is becoming widespread in both EVs and chargers. This standard opens the way for bidirectional energy and “plug and charge,” an operational model where an EV user can easily plug their car into the charger and tap their smartphone to effect payment and start charging.
- The Open Charge Point Protocol (OCPP) — the most popular EV charger protocol — allows advanced interoperability between charger and OS and keeps expanding its capabilities. This allows EV chargers to expand their digital capabilities.
- Some companies are combining digital, energy and EV charging ecosystems to develop innovative business models. For instance, energy retailer, Good Energy, and e-mobility provider, Zapmap, have partnered to offer free charging by leveraging momentary excess renewable electricity generation.
- Several EV charging OS vendors are pure-play software firms that go farther on what software can achieve. As OS vendors acquire a greater market share of the total EV charger software market, the balance of power between charger makers and OS vendors will be redefined. This means charger makers will focus more on hardware and, at the same time, will build hardware that will enable the most competitive OS.
- As more utilities look to EV charging as a buffer for variations in energy consumption and to address flexibility needs to counter intermittency the need for more smart and connected EV chargers will increase.
- It is likely that governments will eventually target EV charging as a way to recover the revenue lost from fuel taxation. This heightens the need to extract data from chargers, supporting the concept of smart charging.

Obstacles

- Most automakers are reluctant to invest directly in EV charging due to the vast capital demanded in relation to the financial benefit they expect. Consequently, they don't adopt the EV charging technology needed to build a strong business momentum for themselves.
- Many CPOs are too focused on quickly recovering their investment into charging infrastructure and, for that matter, shy away from investing in smart charging.
- EV charging technology evolves at a slower pace than EV tech, due to longer product life cycles and because usually, charger makers don't have the scale of R&D capabilities that automakers have.
- Regulation is often an obstacle to the adoption of smart charging technology. For instance, Germany and some U.S. states have mandated the adoption of card payment terminals in public chargers, which indirectly discourages CPOs from adopting "plug and charge."
- CPOs must validate potential locations' access to grid connections. Capital, permitting and hosting constraints from the utility provider often hold back the rollout of new sites.

User Recommendations

- Examine how EV drivers use their cars and the location of charging infrastructure to determine all the open opportunities to deliver more user value. Factor accessibility into your EV charging strategy in order to develop an EV smart charging tech roadmap that will enable user value.
- Invest in charging technology that will enable new business models delivering greater convenience and price competitiveness to end customers. Such models will define who will be the winners in the EV charging market. Focus particularly on composable charger capabilities like scalable charging power and other software-defined features.
- Partner with charger makers and charger OS vendors that provide you the ability to deploy these new business models. However, in order to achieve so, you must have ambitious financial targets that motivate the commitment of these companies.

Sample Vendors

ChargePoint; Efacec; EVBox; EVgo Services; go-e; Tritium; Wallbox Chargers

Gartner Recommended Reading

Guide to New Business Models in the Electric Vehicle Ecosystem

Market Guide for Turnkey Electric Vehicle Charging Solutions

Forecast Analysis: Electric Vehicle Shipments, Worldwide

At the Peak

AI Battery Management

Analysis By: Pedro Pacheco

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Definition:

Artificial intelligence (AI) applies advanced analysis and logic-based techniques, including machine learning, to interpret events, support and automate decisions, and take actions. Regarding battery management, AI optimizes performance based on parameters such as driving needs, temperature and durability. An AI-optimized battery management system can assist with reaching ideal results even when dealing with opposing performance requirements, such as extending battery life and fast charging.

Why This Is Important

The battery management system (BMS) controls and optimizes battery operation (charge, discharge, operation temperature and other parameters). AI can improve battery durability and deliver more energy throughout its lifetime. In addition, an AI-optimized BMS allows manufacturers to better understand real-life battery operation and efficiently feed that data back into development. For instance, Bosch Group claims its “battery in the cloud” technology can improve battery durability by up to 20%.

Business Impact

The automotive industry invests billions of dollars in battery development to address the main obstacles to EV widespread adoption. Bringing to market new battery chemistries is also very time-consuming, with developments often taking longer than regulations allow. As such, an AI-optimized BMS allows automakers to make the most out of the current lithium-ion chemistries until the next battery chemistry leap is ready to reach the market.

Drivers

- EV makers face immense pressure to convince a growing number of customers to adopt the technology, but the price is still an issue — along with driving range, charging speed and durability. This means OEMs need new technology to overcome these challenges.

- The next battery chemistry leap is still more than three years away — even for leading OEMs. But regulatory and competitive pressures mean they can't afford to wait for new battery breakthroughs to improve the performance of battery electric vehicles (BEVs).
- Battery-related fires are a concern, having led China to issue specific regulations (see China Announces New EV Safety Standards, electrive.com) on the matter. This raises the need for greater intelligence at a battery-management level to detect thermal runaway events.
- Automotive and battery makers aim to collect data insights from real-world battery operation to gain a more precise understanding of usage conditions and battery wear and tear — something that feeds into the concept of real-time digital twin of the battery. These insights will be used to improve new battery designs and to optimize the operation of batteries currently in operation. However, current battery systems don't yet have enough sophistication to enable such advanced real-time digital twins. Nevertheless, this is a technology trend already being actively researched, as exemplified by the EU-funded Project Helios (see Digital Twins Are Just the Right Battery Technology at the Right Time, HELIOS).

Obstacles

- AI models require time and usage to be improved in order to present benefits across a wide range of conditions, so the benefit derived by AI BMS may take some years to unfold.
- Many existing vehicle electronic architectures don't yet allow the type of fluid data collection and exchange that are necessary to heavily leverage the advantages of AI battery management.
- The focus of automakers has been primarily to launch as many new EVs as possible in order to comply with regulations. Hence, due to the novelty of EVs, battery durability is still not a main OEM priority. However, OEMs will focus more on this area once customers start having bad experiences related to battery durability.
- It will take several years until fully new EV platforms come to market and that will be the timing for them to incorporate AI battery management systems.

User Recommendations

For OEMs and battery makers:

- There is a growing number of vendors on the market offering AI BMS and their technology is evolving. Hence, keep evaluating new solutions as they arrive at the market.
- OEMs must evolve to a centralized high-performance computing vehicle architecture in order to realize a number of benefits, including leveraging the capabilities of AI BMS.
- The battery is the best component to start the implementation of the vehicle digital twin 2.0. AI BMS is a crucial component for that implementation.
- In order to best leverage all the advantages brought by AI BMS, OEMs must work together with vehicle R&D, after-sales and battery suppliers to achieve so.

For technology providers:

- Invest in AI BMS development if your company possesses formidable AI capabilities, as this will become one of the most important in-vehicle AI applications.
- Companies providing battery-related solutions must explore AI BMS solutions as this is a major opportunity but still a nascent market.

Sample Vendors

Bosch Group; Eatron Technologies; Infineon Technologies; Intellegens; NXP Semiconductors; Stem

Gartner Recommended Reading

Quick Answer: How Will Proposed European Legislation Impact Circular Economy for Batteries?

Emerging Technologies: Venture Capital Growth Insights for Battery Technologies, 2020

Forecast Analysis: Electric Vehicle Shipments, Worldwide

EV Advanced Efficiency Tech

Analysis By: Pedro Pacheco

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Electric vehicle (EV) advanced efficiency tech consists of a range of software and hardware technologies aimed at improving the driving range of battery electric vehicles (BEVs). These entail: (1) advanced battery tech for higher energy density, (2) technology to reduce electrical losses and (3) technologies for thermal efficiency, among others.

Why This Is Important

Driving range is an obstacle to purchasing an EV. Even the longest-range EVs are limited compared with internal combustion cars when operating in more demanding conditions involving speed, low temperature or towing. Improving range and efficiency is vital to the successful transition to new technology. The charging network will also remain a weak point throughout the decade in most developed nations, further emphasizing the need for greater driving range.

Business Impact

Improving the range and efficiency of EVs could help countries meet their ambitious targets to stop selling internal combustion engine vehicles. Several countries have set a date for ending sales of passenger cars equipped with internal combustion engines (ICE), like in the case of the U.K. (2030). In addition, major automotive markets (like China, EU and U.S.) have set a demanding corporate average fuel efficiency (CAFE) roadmap for automakers.

Drivers

- **Advancement in battery energy density.** This could mean optimizing the current lithium-ion (Li-Ion) chemistry or new chemistries like solid state. For Li-Ion optimization, companies are reducing internal electrical resistance and developing more-advanced battery management systems, for instance.
- **Greater electrical efficiency.** The usage of higher operating voltages in the BEV's high-voltage circuit and a more energy-efficient inverter (transitioning from silicon carbide [SiC] to gallium nitride [GaN]) can improve the overall vehicle efficiency. OEMs are even raising the voltage of the low-voltage circuit from 12v to 48v for the same reason.
- **Aerodynamics.** This proves to be an important asset in what comes to motorway driving. A very low drag coefficient (Cd) will make a difference.
- **Lightweighting.** Several technical solutions can be used to achieve this purpose. From a technology perspective, reduction of the wire harness through wireless technology can also help achieve weight reduction. The same can be achieved by simplifying the configuration of the vehicle cabin or by adopting structural batteries that don't require a specific casing.
- **Thermal management.** Keeping the battery always at the ideal operational temperature range is important to maximize range. However, technology that makes better use of sources of heat will be able to reduce the burden on the battery and, hence, achieve greater energy savings. Also this entails minimizing the usage of climate control. This is achieved, for instance, by heating up elements of the cabin in touch with the occupant's body like seats, seatbelt and floor.
- **Photovoltaic (PV) panels.** The progressive increase in PV panels' energy efficiency opens opportunities for automotive applications. In fact, the first production-ready solar-powered cars have started arriving in the market (Sono Motors and Lightyear One). This opens the way for PV panels to be used as a range extender that, hence will improve overall EV energy efficiency.

Obstacles

- Batteries need to be larger to produce more range, but that means they are heavier, which reduces efficiency. As such, BEVs, on average, need to haul a lot more weight than ICEs, which makes it increasingly harder to compete with ICE engine vehicles. A leap in battery chemistry is needed in order to allow much higher energy density. However, there is uncertainty as to when this breakthrough will occur.
- Greater energy efficiency often entails higher costs in terms of technology and lightweight materials. However, consumers' willingness to pay is a natural market barrier.
- The price of some raw materials used for batteries, such as lithium, nickel and cobalt, will hinder the approach of simply installing larger batteries, as their price may become prohibitive.
- Some raw materials, such as cobalt and carbon fiber, aimed at improving driving range pose challenges in terms of sustainability.

User Recommendations

- Focus on the development of BEV-dedicated physical vehicle platforms as insisting on mixed BEV/ICE platforms leads to too much of a compromise in several BEV performance parameters.
- Transition to a high-voltage powertrain architecture (800v and above) in tandem with GaN inverters as a way to improve electrical efficiency. This will not only improve efficiency but also enable faster charging.
- Keep developing the current Li-Ion chemistry while working on solid-state batteries. For instance, the move to structural batteries, new cell designs and new anode chemistries can improve energy density and allow faster charging even without transitioning to a solid-state technology.
- Take steps to incorporate PV technology as a way to enhance driving range.
- Reduce vehicle weight by using wireless tech for wire harnesses and adopting a centralized high performance compute architecture.

Sample Vendors

CATL; Infineon; JTEKT; Kyocera; Panasonic Group; Northvolt; SK; Samsung SDI; LG Chem

Gartner Recommended Reading

Forecast Analysis: Electric Vehicle Shipments, Worldwide

Market Guide for Turnkey Electric Vehicle Charging Solutions

Guide to New Business Models in the Electric Vehicle Ecosystem

Software-Defined Vehicle

Analysis By: Jonathan Davenport

Benefit Rating: Transformational

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

The software-defined architecture enables automakers to deliver over-the-air updates that improve or add new capabilities through the entire vehicle. Service-oriented software will run on high-performance computers with a high-speed communication backbone linking sensors and actuators controlled by domain or zonal electronic control units (ECUs). Cloud-native software provides a modern way to build, deploy and manage applications, and decouples hardware and software development life cycles.

Why This Is Important

Traditional automakers are facing two challenges: delivering profitable connected-vehicle services and responding to the new market entrants who continue to gain ground, both in terms of market share and the levels of technical innovation. In response, automakers are changing their vehicle's E/E architecture and their engineering organization to enable software to be used to deliver new or improved functionality over a vehicle's life cycle.

Business Impact

Redesigning the E/E architecture of the vehicle breaks the link between hardware and software development life cycles. Automakers will be able to deliver over-the-air (OTA) software and firmware updates even to safety-critical systems and have the flexibility to add new functionality. This will enable automakers to deliver the full direct and indirect monetization potential of connected vehicles by saving money by fixing warranty, and recall issues with software and making money from content sales and features sold on a subscription basis.

Drivers

- Automakers want to complement the low-margin revenue they get for selling capital items to selling software-enabled services which deliver much higher gross margins. For example, Stellantis targets ~€20 billion in incremental annual revenue, with 40% gross margin by 2030, driven by software-enabled vehicles.
- Cloud-native, service-oriented, containerized applications are being developed that allow automakers to standardize software solutions across all their vehicle models and brands.
- The use of Android Automotive as the dominant vehicle infotainment operating system is advancing. A wide range of traditional automakers such as General Motors, Ford and Honda are also buying Google Automotive Services — which includes Google's Play Store, Maps and other content such as YouTube. Other companies are working with partners — such as Harman in the case of VW — to build their own App store.
- The ability to run the same or similar applications across multiple car brands will help drive third-party developers to write solutions for vehicles, while having standardized vehicle data signals will help companies to utilize connected vehicle data across different OEM brands much more easily.
- Availability of powerful semiconductor processors enable the E/E architecture to be redesigned, reducing the number of ECUs used within a vehicle dramatically and replacing them with high-performance computers and domain or zonal controllers.

Obstacles

- Automotive corporate culture is a major roadblock to digital transformation. Change is hard because the innovation process is typically a top-down, systems-engineering waterfall approach aimed at incremental improvements and functional safety.
- Engaging the best talent — especially in the software sector — is a difficult task for legacy car companies, due to limited reward and organizational strategy.
- Automotive executives can see the changes in the market, but are trapped inside the restrictions of their current business and operating models, hence making it hard to adapt to market disruptions.
- Automakers still put more priority on product engineering than software development.
- Providing regular software updates to safety critical components injects new risks into vehicles and opens the door to cybersecurity challenges and new bugs.
- There are technical issues in implementing this central compute architecture in vehicles, primarily power consumption, which negatively impacts battery life for electric vehicles.

User Recommendations

Automakers must:

- Build up first-class in-house software expertise by offering talent a pay package that matches or exceeds those offered by digital giants.
- Embrace agile continuous software deployment by creating a culture of empowered innovation, making a firm break from traditional waterfall deployment methodologies.
- Outperform the competition by showcasing a customer-first mindset that is prepared to disrupt traditional business models to offer excellent in-vehicle experiences/services.
- Specify vehicle hardware with enough performance to enable future application use cases.
- Establish close partnerships with chip vendors to implement innovative hardware architecture in future vehicles.

Technology service providers should:

- Create strong software-focused partnerships by educating automakers on how to transition from a waterfall development approach to an agile way of working.
- Maximize the value of hardware portfolios by pivoting toward the development of low-cost, reliable sensors and chips, optimized for automotive applications, and divesting noncore assets.

Sample Vendors

Amazon; Aptiv; BlackBerry; Continental; Elektrobit; EPAM; IBM

Gartner Recommended Reading

Software-Defined Vehicles' Impacts on the Role of the CIO

Market Trends: Software-Defined Vehicles Will Disrupt the Automotive Supply Chain

Life Cycle Management of Software-Defined Vehicles: Step 2 — Vehicle Software Register

Life Cycle Management of Software-Defined Vehicles: Step 3 — Vehicle Digital Twin 2.0

Market Trend: Connected and Autonomous Vehicle Data Enhances Software Life Cycle Management Transformation

Wireless EV Charging

Analysis By: Lauren Wheatley, Pedro Pacheco

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Wireless electric vehicle (EV) charging is based on inductive charging that uses the electromagnetic field (EMF) to transfer energy. Induction chargers use an induction coil to create an alternating EMF from a charging base station. An induction coil in the vehicle converts EMF into an electrical current to charge the battery. In addition to stationary charging of parked vehicles, the technology can potentially enable dynamic charging for vehicles as they drive.

Why This Is Important

The technology is based on an application of magnetic induction, which uses a changing magnetic flux to create a current that transfers electricity from an energy source to a battery. The efficient transfer of power for wireless EV charging (on par with conductive charging), both statically and in motion, can facilitate EV adoption by improving charging convenience and potentially addressing drivers' range anxiety.

Business Impact

Wireless EV charging is mostly based on a car parked over a charging mat installed in public or private parking spots. However, applications also include installing long strips of inductive charging plates on roads that charge vehicles as they drive over them to enable dynamic EV charging.

Drivers

Although still an emerging technology with a number of technical issues to resolve (like size and scale) wireless charging offers several advantages for users:

- Despite different user experiences, when compared to conventional internal combustion engine (ICE) refueling, inductive charging makes charging mobile devices and EVs more convenient. Rather than having to connect a power cable, the device can be placed on or close to a charging plate. In the case of dynamic electric vehicle charging (DEVC), the vehicle can drive over a charging path embedded in the road pavement.
- The ability to charge high-value, high-use vehicles like buses and trucks without taking them offline.
- In addition wireless charging is now being prototyped and tested within new vehicle designs.

Obstacles

- Wireless charging is significantly more expensive than cable charging. Economies of scale will reduce the cost gap but may not be enough to drive adoption.
- Static wireless charging doesn't offer much greater convenience over cable charging, since the vehicle must be parked with precision in relation to the charging pad.
- Static wireless charging installation and maintenance on public car parks would be more expensive than cable chargers since the charging pad would have to be installed under the surface.
- Dynamic wireless charging will be very hard to implement at scale — it needs the simultaneous buy-in from a large number of vehicle makers and infrastructure providers.
- Wireless charging is much slower than cable charging, which makes dynamic wireless charging impractical, especially on motorways; either you cover a large distance with wireless charging or the vehicles would have to drive very slowly. This is even more hindering for larger vehicles due to higher power requirements.

User Recommendations

- Deploy strategies to reduce cost as it is a major roadblock for this technology.
- Prioritize overnight charging for fleets for static dynamic charging as it minimizes the situation where users can forget to plug the vehicle at the end of the day.
- Study the combination of static wireless charging with robotic technology in order to serve more vehicles with a lower number of charging pads.
- Focus on dynamic wireless charging only once you see a broad platform of support emerging among automakers and road infrastructure providers.

Sample Vendors

Continental; Electreon; ENRX; Hevo; InductEV; WiTricity

Gartner Recommended Reading

Top Automotive Trends for 2023

Emerging Tech Impact Radar: Electrified Vehicles, 2022

Solid-State Batteries

Analysis By: Pedro Pacheco

Benefit Rating: High

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Definition:

Solid-state lithium-ion (Li-ion) batteries replace the traditional organic solvent electrolyte with a solid one. Moving to a solid-state electrolyte has several advantages, including increased energy density, removing unneeded components, such as separators, and removing safety risks in the conventional battery design. This promises to enable greater driving range and shorter charging time for electric vehicles (EVs).

Why This Is Important

Solid-state Li-ion batteries could store two to three times as much energy as liquid electrolyte batteries used today, and mitigate the fire hazards seen in traditional Li-ion cells. This is critical to occupant and public safety. Some companies have claimed a reduction in charge times by 75% or more. Together, these advances could be a major step forward for EVs, heavily mitigating the main consumer purchase objections: range and charging time.

Business Impact

Several major regions, such as China, the EU and U.S., have put in place aggressive policies to incentivize widespread adoption of zero-emission vehicles, making this the top priority for automakers. Solid-state batteries will allow OEMs to accelerate EV adoption by addressing consumers' main objections to purchase. As such, this technology is a key enabler to OEMs' compliance in lowering the average CO_2 emissions of the vehicles they sell.

Drivers

- Regulatory pressure is the main driver. The EU mandates stringent average CO_2 targets for the sales of each OEM under the penalty of heavy fines. This is added to generous incentive schemes in several EU countries. China actually preceded the EU in the adoption of sales targets for what they call “new energy vehicles,” — battery electric cars, plug-in hybrids and fuel cell, as well as incentives to the purchase of these vehicles. Moreover, the U.S. is also ramping up support for EVs. Besides a host of state incentives and President Biden’s Bipartisan Infrastructure Law to support charger installation, the new Corporate Average Fuel Economy (CAFE) standards for 2024 through 2026 will push for a pronounced increase in fuel economy that supports widespread electrification. Moreover, the EU, U.K. and several U.S. states have regulated the phase-out of internal combustion passenger cars between 2030 and 2035. This regulatory pressure is pushing OEMs to put better EVs on the market from a customer standpoint, as the current technologies still show visible limitations in terms of driving range and charging time. This situation is a great opportunity for the widespread adoption of solid-state batteries.
- There is a major competitive pressure for established automakers to catch up with newcomers, like Tesla or Lucid Motors, in overall EV performance and battery tech is crucial to do so.
- Most of the main OEMs are already investing in solid-state technology, including Toyota, Volkswagen and General Motors. Even if automakers’ investment into solid-state technology is still a fraction of their total EV program budget, the successive announcements of new investments and partnerships generate market frenzy that stimulates further awareness and investment.
- Solid-state technology is known to be intrinsically safer than liquid electrolyte by minimizing the risk of thermal runaway that can lead to fire and even explosion. This will help reduce the inherent liability of OEMs in this kind of occurrence, as well as enabling EVs to raise their credibility among consumers and public opinion.

Obstacles

- It remains to be seen whether solid-state batteries can overcome their life span and manufacturing limitations, while offering the promised advantages in driving range and charging time. Last decade, some companies made bullish comments about launching EVs equipped with solid-state batteries by mid this decade. However, these launch dates keep being pushed into the second half of this decade or potentially even into 2030.
- Even after market launch, solid-state batteries will command a price premium that will limit them to more premium vehicle segments, which are associated with lower volumes. This is something that may change as volumes progressively increase.
- Li-ion batteries with liquid electrolyte still have margin for improvement in terms of chemistry and cell configuration. Several passenger cars already offer an homologated driving range above 600 km (373 miles), with a tendency to increase even further. This means the initial generation of solid-state batteries may only offer reduced advantages over conventional Li-ion batteries despite a higher foreseeable price.

User Recommendations

- Ramp up investment in solid state, either by developing the technology internally or partnering with another company. But for the latter, it's important to access proofs of concept that can give you concrete evidence of the solution's strength.
- Don't push back on liquid electrolyte investment in detriment of solid state. These still have a considerable roadmap for future development. Even after market launch, solid state will need some time before it shows to be clearly better than conventional Li-ion. For instance, some OEMs are already launching conventional Li-ion batteries with silicon anode, which is delivering major gains in terms of energy density and charging speed.
- Exercise care in accelerating time to market of solid-state technology — be particularly realistic in terms of production scale-up time. Claiming first-mover advantage is appetizing from a prestige standpoint and as a display for investors. However, make sure the solid-state technology you deploy delivers tangible benefits to customers with limited downsides, also allowing high production volumes competitively.

Sample Vendors

Basquevolt; Bolloré Group; CATL; Hydro-Québec; Panasonic Group; ProLogium Technology; QuantumScape; Sion Power; Solid Power; Toyota

Gartner Recommended Reading

Emerging Technologies: Venture Capital Growth Insights for Power and Energy Components and Electronics, 2020

Guide to New Business Models in the Electric Vehicle Ecosystem

Cool Vendors in Technology Innovation Through Power and Energy Electronics

Sliding into the Trough

Digital Personalization

Analysis By: Jonathan Davenport

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Definition:

Connected car technology enables drivers to benefit from personalized experiences. Personalization will occur seamlessly inside/outside the vehicle, with contextual support and advice, and with social and functional applications. Occupants will benefit from the ability to adapt to a range of vehicle digital settings, like adjusting seat and mirror positions, creating a totally new mask for the digital cockpit, or changing the rear light or front light patterns.

Why This Is Important

Digital personalization moves the industry away from limiting a vehicle's specification to preexisting options selected at point of purchase, to enabling the delivery of customizable software-defined experiences that match the tastes of different users through the vehicle's life. Personalization could span from customizing interior lighting to unlocking brand new functionality in the car, such as autonomous driving features to meet specific requirements, which might vary by different times of day or journey types being undertaken.

Business Impact

Digital personalization will help automakers shift their business model to source an increasing proportion of revenue from digital features and services. Vehicle manufacturing will become much more standardized and modular. Even factors considered as static physical attributes, such as vehicle color, will be controlled digitally. Cloud-based customer profiles will help mobility companies provide a consistent customer experience across their fleets to support long-term customer retention.

Drivers

- Automakers want to receive more revenue through personalized, digitally enabled services, and benefit from improved customer experience and higher gross margins on these digital products. They will accomplish this by providing the ability to lock/unlock connected car features, based on the driver's cloud-based customer profile.
- The volume of connected vehicles is increasing. By the end of 2023, Gartner forecasts there will be 429 million connected vehicles, providing access to a rich set of customer data to gather insights about preferences and, more importantly, behavior.
- Cloud-based customer profile technology, underpinning personalized services, is already being adopted. For example, using the BMW ID, individual preferences can be set in any current BMW vehicle quickly and automatically. Likewise, Volkswagen Group and Tesla are also investing in driver profiles too.
- Customers want and expect quality and effortless personalized experiences. However, shared and standardized core-vehicle designs and self-driving systems will mean that vehicle performance will no longer be a differentiating factor between automotive OEMs. Therefore, digital personalization will be increasingly important for automaker differentiation.
- The rise of Android Automotive, as the mainstream infotainment and digital cockpit operating system, will help automakers deliver quality in-vehicle experiences that are better than smartphone-mirroring services, like Apple CarPlay.
- Digital personalization of mobility service use cases, such as car sharing, will extend beyond different digital keys. This would enable functions such as limiting speed to providing a consistent digital personalization experience among different OEM vehicles within a mobility service provider's fleet.

Obstacles

- Current vehicle electronic and electrical (E/E) architectures inhibit the ability to unlock new digital services beyond the infotainment system, which is why automakers are investing in software-defined vehicles. However, while the concept is gaining momentum, the number of vehicles with this architecture is limited, which impacts the ability to deliver widespread digitally personalized services.
- Companies are cautious about how they store and use personal data, so that they comply with local regulatory requirements as a result of regulations such as the EU's General Data Protection Regulation (GDPR).

- To offer personalized services when more than one person uses the vehicle, customer profiles become important. However cloud-based customer profiles to deliver digital personalization is a nascent concept in the automotive industry today and requires cross-business collaboration to successfully deploy solutions.

User Recommendations

- Prioritize the delivery of digital personalization use cases by undertaking research to assess the true customer and broader business value that each might deliver.
- Analyze the use cases that deploy AI to analyze personal information to provide a personalization service delivery. Ensure that customers are clearly informed about what data is being collected, for what purpose and that the personalized services will deliver a high-enough value to entice them to share their data.
- Design a single cloud-based customer profile that can be easily created, maintained and transferred between vehicles. This single profile should be used across all enterprise systems, including financing, insurance, and marketing.
- Address customers' security and privacy concerns by ensuring that connected vehicle personalization systems protect personal data, both from theft and misuse. Embed transparency and privacy protections in the customer experience to increase trustworthiness and, potentially, digital revenue.

Sample Vendors

Eyeware Tech; ForgeRock; Google; HELLA; Samsung Electronics (HARMAN International)

Gartner Recommended Reading

Software-Defined Vehicles' Impacts on the Role of the CIO

Market Trend: Connected and Autonomous Vehicle Data Enhances Software Life Cycle Management Transformation

Life Cycle Management of Software-Defined Vehicles: Step 2 — Vehicle Software Register

Top Automotive Trends for 2023

Battery Swapping

Analysis By: Pedro Pacheco

Benefit Rating: Moderate

Market Penetration: Less than 1% of target audience

Maturity: Adolescent

Definition:

Battery swapping refers to the technology that uses robotics automation to quickly and efficiently replace an electric vehicle's battery for another one that is fully charged. The purpose of swapping is to reduce the time it takes to restore energy to a vehicle.

Why This Is Important

Driving range is a primary customer objection to battery electric vehicles (BEV), and battery charging takes a long time when compared to refueling an internal combustion engine (ICE) vehicle. Battery swapping allows a BEV driver to have a fully charged battery in about three minutes.

Business Impact

Widespread battery swapping could help address the problem of slow battery charging, and therefore, address range anxiety, which is a major customer objection to BEV adoption. Battery swapping stations can, sometimes, charge the batteries at off-peak times, which would reduce the cost of electricity. Furthermore, the batteries stored at the battery swapping station have the potential to be used in the future for electric grid stabilization.

Drivers

- Battery charging times are still quite slow when compared with the benchmark of refueling an internal combustion engine vehicle. This charging time is particularly slow if the driver wants to charge the battery above 80%. There are constant advances in terms of vehicle architecture and charging technology to reduce this duration, but it will take substantial time before full battery charging gets anywhere close to the refueling time drivers enjoy from ICEs.

- Real-world BEV driving range is still below customer expectations, especially when driving on motorways or under low temperatures. This means more frequent charging and the subsequent waiting times can be frustrating for customers accustomed to ICEs.

- The Chinese government has introduced policies to support battery swapping. In June 2019, the National Development and Reform Commission (NDRC), the Ministry of Ecology and Environment (MEE) and the Ministry of Commerce (MOFCOM) jointly issued the implementation plan for Promoting the Renewal and Upgrading of Key Consumer Products and Smooth Resource Recycling (2019-2020), which encourages OEMs to offer BEVs with battery swapping options (see Overview on Battery Swapping and Battery-as-a-Service [BaaS] in China, GIZ).

- On 6 May 2021, China's State Administration for Market Regulation (SAMR) approved the National Standard for Battery Swap Safety Requirements for Electric Vehicles (GB/T 40032-2021; see China's Battery Swap National Standard Drafted by Firms Including NIO to Go Into Effect Nov 1, CnEVPost). This standard is the first mandatory standard governing the development of battery swapping in the BEV industry in China. This is a major step forward as it allows, for instance, a swapping station to use batteries from several different OEMs. The standard was drafted by companies including NIO, Beijing Electric Vehicle Co. Ltd. and Geely Auto Group. It specifies safety requirements, test methods and inspection rules for battery-swappable electric vehicles.

Obstacles

- The vast majority of OEMs don't yet intend to offer battery swapping at all. Additionally, big names in the BEV space, such as Tesla and Renault-Nissan-Mitsubishi Alliance, have tried battery swapping and abandoned it, discouraging other OEMs from adopting this tech. Consequently, only a very small percentage of BEVs sold to date offer this technology and this is not foreseen to change in the coming two years.
- Except for China, there is a lack of standards and regulations enforcing the adoption of battery swapping. Since OEMs are not aligned in terms of battery configuration, battery swapping stations can't cater to different vehicle models at the same time.
- Battery charging times are dropping fast due to major OEM investment in battery tech, vehicle architecture and charger technology. This implies that the slow speed of adoption for battery swapping can make this technology redundant at some point.
- Drivers who reject vehicle leasing, also reject the notion of having to pay a recurring fee for a battery they never own — something that is contrary to the concept of battery swapping.

User Recommendations

- Focus battery-swapping efforts on China as it is the only country in the world with regulations and standards supporting this technology.
- Prioritize offering battery swapping for heavy-duty vehicles. They have far larger batteries than passenger cars and operational needs imply that these vehicles need to be used far more often. These factors favor battery swapping, in comparison to traditional charging.
- Promote the widespread adoption of battery swapping in two- and three-wheelers, since several of these manufacturers have agreed to adopt interchangeable batteries, putting them far ahead of automakers.
- Diversify your investment in BEV battery recharging technologies. It's not yet clear whether battery swapping can become a mainstream technology, which means you should have other options in mind.
- Drive battery form factor harmonization, as battery makers who supply several different OEMs are in a better position to achieve this and, consequently, can become major drivers of battery swapping.

Sample Vendors

Ample; Aulton New Energy Automotive Technology; BAIC Group; CATL; Changan Automobile; Dongfeng Motor; Geely Auto Group; Gogoro; NIO; Sinopec Group

Hydrogen Vehicles

Analysis By: Pedro Pacheco

Benefit Rating: Low

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Hydrogen vehicles use hydrogen as a fuel to power internal combustion engines or fuel cells. A fuel cell is a device that converts chemical potential energy into electrical energy. Fuel cells require hydrogen combined with oxygen in the air and produce water, heat and electricity.

Why This Is Important

Regulation in major markets like China, EU and the U.S. will lead to the progressive phase-out of internal combustion engines (ICEs). Battery electric vehicles (BEVs) still present limitations in terms of charging speed and, in some cases, driving range. These give an opportunity to hydrogen vehicles, as refueling takes less than five minutes and their driving range can easily go beyond 600 km (373 miles). In addition, fuel cell vehicles could actually clean the air as they drive by.

Business Impact

The business impact of hydrogen hinges heavily on public incentives — EU's $5.2 billion fund for hydrogen projects, for instance — and the pace of BEV technology. Hydrogen still has a chance if incentives can enable an economically-sustainable, price-competitive green-hydrogen distribution network before BEVs can address their weaknesses, even after incentives are discontinued. However, this is a narrow window of opportunity, given there is a lot more investment on BEVs than hydrogen.

Drivers

- Both the EU and China have put together regulations and incentives promoting hydrogen vehicles, even if those incentives are on par with BEVs. In addition, the EU is also financially supporting the production of green hydrogen — something that will accelerate the creation of a hydrogen distribution network.
- Hydrogen is seen by some governments as a cornerstone of their overall energy strategy. For instance, the EU predicts hydrogen's part of the energy mix will grow from 2% to 13-14% by 2050. It describes hydrogen as "a technology which can bridge the gap between electricity production from renewable energy and the goal of decarbonizing a large share of the EU's energy consumption by 2050." Looking at the energy ecosystem holistically, hydrogen can be used for renewable energy storage (without the negative environmental impact of batteries), heating and energy to power land, sea and air transportation, as well as industrial processes. Under this holistic perspective, it makes sense that hydrogen is also used to power road vehicles.
- Europe's need for greater energy security provides a new opportunity for hydrogen, especially as a replacement for natural gas.
- The oil and gas industry is a major proponent of hydrogen since the production and distribution of hydrogen share several similarities with those from other existing hydrocarbon fuels. As such, these companies have a vested interest in developing hydrogen refueling infrastructure if or when they get strong signs of interest vehicle manufacturers.

Obstacles

- Production and distribution of green hydrogen are far from cost-effective.
- The main OEMs advocating for hydrogen (General Motors, Hyundai and Toyota) are now investing more in BEVs than in hydrogen.
- Fuel cell vehicles present much lower well-to-wheel efficiency (from fuel production to vehicle use) than BEVs (30% to 40% against 80% to 90%). This is now even more of an issue after the sharp increase in energy prices.
- The business case for hydrogen is very weak when there is an absence of incentives and regulations.
- BEV technology moves at a faster pace due to the higher number of companies committed to it. For instance, a Mercedes EQS already offers a worldwide harmonized light vehicles test procedure (WLTP) driving range of 770 km (478 miles) — more than any production hydrogen car. The rise in charging power and new battery tech, such as solid-state, will bring charge time below 15 minutes.
- It is hard for fuel cell's cost reduction roadmap to be more aggressive than BEV's as there are many more companies investing in the latter.

User Recommendations

- Focus on the development of hydrogen powertrains mostly for larger vehicles used for long-haul applications, given that BEV technology is already way ahead for passenger cars and urban trucks.
- Develop a whole business model rather than just vehicles or infrastructure in isolation. Just as Tesla did by setting up their own charging network, gigafactories, dealer network and online sales, proponents of hydrogen technology must tackle all hurdles that make the usage of hydrogen vehicles expensive, inconvenient and inefficient. In many cases, this will mean establishing partnerships with a broad number of companies in order to produce a strong impact on the whole energy and transportation ecosystem.
- Focus on B2B use cases where companies need hydrogen for other purposes besides transportation.
- Influence regulations to make sure these recognize and benefit fuel cells' ability to purify the air while in operation.

Sample Vendors

Ballard Power; General Motors; Honda Motor Company; Hyundai; Toyota

Gartner Recommended Reading

Technology Innovation and Global Regulations Drive New Interest in Alternative Fuel Trucks

Utilities Technology Trends 2022: Green Hydrogen Can Help Displace Fossil Fuels and Stabilize Energy Markets

Apply Technology to Reduce Greenhouse Gas Emissions in Logistics

In-Car Advanced UX/UI

Analysis By: Pedro Pacheco

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

In-car advanced user experience (UX) and user interface (UI) technologies are used to enable interaction between the vehicle and its occupants beyond touchscreens. Widespread vehicle connectivity is triggering a growing number of new features. This requires more advanced technologies like augmented reality, mixed reality, emotion AI, AI voice assistants, and gesture control that enable more efficient and safer exchange of large amounts of information between humans and machines.

Why This Is Important

In-car UX must efficiently handle ever-more connected digital features in a way that allows for safer driving. However, today's car UX focuses excessively on large touchscreens. A study from the American Automobile Association (AAA) Foundation for Traffic Safety found that drivers using the touchscreen and voice activation technologies are visually and mentally distracted for more than 40 seconds, which creates a major accident risk. Hence, new UX/UI tech is needed to address this problem.

Business Impact

Advanced UX/UI tech is needed to achieve a successful implementation of infotainment vehicle functions while minimizing today's major dependency on large touchscreens, which generate excessive driver distraction. The usage of more advanced UX/UI tech will allow occupants to exchange information more easily with the vehicle's infotainment system. This, in turn, will make it easier for OEMs to successfully monetize a growing number of in-car features and services.

Drivers

- Fast growth in the number of connected cars is increasing the number of features and functions that need to be controlled by the driver. Today's most common vehicle human-machine interfaces (HMIs) still exchange most of the information through large touch displays. This can often be dangerously distracting for the driver, which calls for the use of more advanced UI technologies like mixed reality, augmented reality, smart surfaces or smell sensors.
- Occupants will have a growing number of functions and features to control. Similarly, this justifies more advanced UI tech that relays information through different senses to avoid overwhelming the user. This can be done through an advanced voice assistant or smart touch surfaces, for instance.
- The widespread adoption of autonomous and electric vehicles will increase the amount of time the driver spends inside the car without driving. This generates new use cases for many new digital features which, in turn, ask for a more advanced UI.
- OpenAI GPT's far greater conversational capabilities are expected to generate a major growth in vehicles running GPT-powered voice assistants. This, in turn, will reduce dependence on touchscreens and will open the way for the creation of a real in-car AI personal assistant.
- EU and U.S. regulations supporting the adoption of driver monitoring systems mean it will become cheaper to implement in-cabin emotion AI by using the same camera. This would enable a better assessment and anticipation of occupant needs. Operating in tandem with a more evolved voice assistant, this gives the vehicle far greater situational awareness to orchestrate a growing number of features toward a better user experience.
- Designers from some premium brands have already stated the long-term future of car interiors won't focus on large screens but more on having technology more easily available to occupants. This position supports the need for the next level in terms of UX/UI technologies.

Obstacles

- OEMs are mostly focused on increasing the number and size of screens onboard. This is a major trend that takes place mainly because it's easier to add more screen area than alternative technologies. As such, this is an intermediate step before OEMs move into more advanced technologies based on a broader range of sensors and interfaces.
- Besides large touchscreens, some other UI technologies are still not mature enough to assume a major role in the vehicle UI.
- The price of alternative technologies is often high, considering they cannot replace large touchscreens but just complement them. Consequently, OEMs often tend to stick to touchscreens rather than going beyond that.

User Recommendations

- Tackle the safety risk that touchscreens represent for drivers. Consider this as a crucial factor in the sourcing and selection of your UI technology.
- Develop a holistic approach to vehicle UI. Invest in technologies like augmented reality, mixed reality, virtual reality, smell sensors, smell generators, voice assistants and smart surfaces, which allow for information exchange between the car and occupants by using different human senses.
- Plan your vehicle UI roadmap with a focus on the increase in the amount of time drivers have for leisure and work activities while on the route. As electric vehicle (EV) drivers will spend a significant amount of time charging, autonomous vehicle users will be freed from the need to drive.
- Identify other functions that a UI sensor can bring because this increases ROI. For instance, a driver monitoring system installed in the rear-view mirror can also assess for forgotten objects, children or animals in the cabin.

Sample Vendors

Amazon Web Services (AWS); Continental; DENSO; GestureTek Health; HARMAN International; Tanvas; Ultraleap

Gartner Recommended Reading

AI Multisensory Tech in Automotive HMIs

AI Multisensory Tech in Automotive HMIs, Part 1: Smell

AI Multisensory Tech in Automotive HMIs, Part 2: Visual Immersion

AI Multisensory Tech in Automotive HMIs, Part 3: Smart Surfaces

Automotive Cybersecurity

Analysis By: Mike Ramsey

Benefit Rating: Transformational

Market Penetration: 5% to 20% of target audience

Maturity: Emerging

Definition:

Automotive cybersecurity is a holistic approach to protecting a vehicle from any type of cyberthreat. Automotive cybersecurity aims to protect all vehicle hardware, software and information related to vehicles and their users and customers.

Why This Is Important

As cars become more defined by software, and updated through cellular connections, they become an attractive attack surface for cybercriminals. There are an increasing number of incidents involving the theft of vehicles through the keyless entry, and some using app-based API attacks. In addition, the United Nations Regulation No. 155 (UN R155) cyber regulation mandates compliance in over 60 countries.

Business Impact

Automotive companies are creating more secure electronic control units (ECUs), telematics control units (TCUs) and other data connections into vehicles, and spinning up vehicle security operations centers (VSOC) to monitor and respond to breaches in their fleet. Compliance with new regulations will require a more structured response to security. Security breaches could be quite significant, leading to costly plant shutdowns, ransom attacks, intellectual property theft and even physical harm to drivers.

Drivers

- Regulations, such as the UN R155 as well as standards being adopted for security, such as ISO/SAE 21434, will lead to a significant expansion of security in vehicles as well as organizational changes to address security.
- Rising numbers of ransomware attacks in the automotive industry on enterprises will increase the focus on security and lead to a number of implementations.
- Attacks on vehicles have been rare, but are rising as the scale of connectivity rises.
- Efforts to consolidate security operations along with efforts to produce revenue or catch other issues in the fleet could help to pave the way for more investments by reducing the burden of the expense.
- Greater numbers of vehicles on a security platform should lower the overall cost and could lead to other, complementary business opportunities.
- Governments and consumer groups will continue to demand greater security to prevent dangerous, costly and inconvenient cyberattacks.
- Greater ability to update vehicles will also lead to more dangerous opportunities for hackers to affect the vehicle's core safety systems.

Obstacles

- Security efforts can be costly, and it is difficult to recover the investment in the expense from consumers, who expect the coverage but don't want to pay for it.
- There are many different potential ways to protect vehicles, and none will protect from every different method of attack. Hackers are creating new ways of breaking into vehicles.
- Car makers are adding more ways to connect and control vehicles as features, but these same features lead to a greater number of vulnerabilities that could be difficult to address.

User Recommendations

- Adopt the frameworks for secure-by-design monitoring and updating set out in UN R155 as well as by third-party cybersecurity frameworks such as National Institute of Standards and Technology (NIST) and Auto-ISAC.
- Create a strategy to secure ECUs and semiconductor chips such as microcontroller units (MCUs), application processors and memory chips used in ECUs, data storage, sensors and actuators, in-vehicle network, and the data gateway.
- Check vehicles in operation for attacks and plan a way to respond to those attacks with patches.
- Establish and maintain a software bill of materials to understand where all software was created and in what vehicles it exists.
- Work with legal and public relations to have an action plan in case of a ransomware attack or other type of attack, and know what your public response will be ahead of time.
- Update vehicles to secure software where new vulnerabilities have been discovered.

Sample Vendors

Argus Cyber Security; AUTOCRYPT; C2A Security; Green Hills Software; GuardKnox; Irdeto; Karamba Security; Thales; Upstream Security; VicOne

Gartner Recommended Reading

How to Protect Connected Vehicle Monetization From Commercial Hackers

Automotive Insight: Vehicle Cybersecurity Ecosystem Creates Partnership Opportunities

How to Develop a Security Vision and Strategy for Cyber-Physical Systems

How Automotive CIOs Can Lead a Successful Cybersecurity Implementation and Comply With WP.29 UN R155

3 Steps to Implementing a Vehicle Security Operations Center

Autonomous Vehicles

Analysis By: Jonathan Davenport

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Autonomous vehicles use various onboard sensing and localization technologies, such as lidar, radar, cameras, global navigation satellite system (GNSS) and map data, in combination with AI-based decision making, to drive without human supervision or intervention. Autonomous vehicle technology is being applied to passenger vehicles, buses and trucks, as well as for specific use cases such as mining and agricultural tractors.

Why This Is Important

Autonomous vehicles have the potential to change transportation economics, cutting operational costs and increasing vehicle utilization. In urban areas, inexpensive fares and high-quality service may reduce the need for private car ownership. Road safety will also increase, as AI systems will never be distracted, drive drunk or speed. Autonomous features on privately owned vehicles will enable productivity and recreational activities to be undertaken, while the vehicle handles the driving operations.

Business Impact

Autonomous vehicles have the potential to disrupt established automotive business models. Self-driving systems will stimulate demand for onboard computation, radically increasing the semiconductor content of vehicles. After the office and home, vehicles will become a living space (like airplanes) where digital content is both created and consumed. Over time, it is likely that fleet operators will retrain and redeploy commercial drivers to other, higher-value-adding roles within the company.

Drivers

- The formalization of regulations and standards for autonomous vehicles will aid implementation. Automated lane-keeping system (ALKS) technology has been approved by the United Nations Economic Commission for Europe (UNECE). This is the first binding international regulation for SAE Level 3 vehicle automation, with a maximum operational speed of 37 mph. To take advantage of the new regulatory landscape, automakers are beginning to announce Level 3 solutions. Honda is the first company to announce a commercially available ALKS equipped vehicle, though only 100 will be produced.
- Other companies are quickly following, with Mercedes-Benz being the first automotive manufacturer worldwide to secure internationally valid system approval and has launched in Germany. Its Level 3 solution has secured approval from the state of Nevada and an application to enable cars to drive autonomously in California has also been made.
- In China Changan, Great Wall Motor and Xpeng have announced Level 3 systems. Other global automakers are following suit. Hyundai's new Genesis G90 and the Kia EV9 vehicles will come equipped with a Level 3 Highway Driving Pilot (HDP) function.
- This signals that the autonomous vehicle market is most likely to evolve gradually from ADAS systems to higher levels of autonomy on passenger vehicles, rather than seeing a robotaxi-based revolution. This will require flexible vehicle operational design domains (ODDs). Progress is being made by companies like Mobileye who's perception system was developed on the roads of Israel, but required minimal retraining to perform well in diverse cities like Munich and Detroit.
- The most compelling business case for autonomous vehicles relates to self-driving trucks. Driver pay is one of the largest operating costs for fleets associated with a commercial truck, plus goods can be transported much faster to their destination because breaks are no longer necessary. The Aurora Driver product is now at a "feature complete" stage, with a plan to launch a "middle-mile" driverless truck service at the end of 2024.

Obstacles

- Designing an AI system that is capable of driving a vehicle is hugely complex. As a result, the cost of bringing a commercial autonomous vehicle to market has been greater than companies could have previously envisioned, requiring significant investments to be made.
- When autonomous vehicles are commercially deployed, autonomous vehicle developers, not the human occupants, will be liable for the autonomous operations of the vehicle. This raises important issues, should a vehicle be involved in an accident, and the need for associated insurance.
- Challenges increasingly include regulatory, legal and societal considerations, such as permits for operation and the effects of human interactions.

Analyst Notes:

- Volvo's EX90 vehicles are being deployed with hardware-ready for unsupervised autonomous driving (including a lidar from Luminar), despite the self-driving software not being ready for deployment. Volvo plans to deploy an over-the-air software to move capability from Level 2 ADAS system to Level 3 in the future.
- Despite continued improvements in Level 4 autonomous vehicle perception algorithms and broader self-driving systems used for mobility use cases (such as robotaxis), driverless operations have not scaled to different cities quickly. Waymo — one of the early leaders of operations without a safety driver — has struggled to expand outside of Arizona.
- Slow progress saw Ford and VW pull their investments in Argo AI at the end of 2022, causing the joint venture's operation to close. VW had invested approximately 2 billion Euros in the company.
- Likewise Pony.ai's permit to test driverless vehicles in California was suspended after an accident and in San Francisco, Cruise's autonomous operations led to traffic disruptions — local transit officials cited 92 unique incidents between 29th May and 31st December 2022.

User Recommendations

Governments must:

- Craft national legislation to ensure that autonomous vehicles can safely coexist with a traditional vehicle fleet as well as a framework for their approval and registration.
- Work closely with autonomous vehicle developers to ensure that first responders can safely respond to road traffic and other emergencies and self-driving vehicles don't obstruct or hinder activities.

Autonomous mobility operators should:

- Support consumer confidence in autonomous vehicle technology by remaining focused on safety and an accident-free road environment.

Traditional fleet operators looking to adopt autonomous technology into their fleets should:

- Minimize the disruptive impact on driving jobs (bus, taxi and truck drivers) by developing policies and programs to train and migrate these employees to other roles.

Automotive manufacturers should:

- Instigate a plan for how higher levels of autonomy can be deployed to vehicles being designed and manufactured to future-proof vehicle purchases and enable future functions-as-a-service revenue streams.

Sample Vendors

Aurora; AutoX; Baidu; Cruise; Mobileye; NVIDIA; Oxbotica; Pony.ai; Waymo; Zoox

Gartner Recommended Reading

Emerging Tech Impact Radar: Autonomous Vehicles, 2022

Lessons From Mining: 4 Autonomous Thing Benefit Zones for Manufacturers

Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide

Tech Providers 2025: Product Leaders Must Strategize to Win in the Evolving Robotaxi Ecosystem

Climbing the Slope

Automotive Lidar

Analysis By: Gaurav Gupta

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Definition:

Lidar (light detection and ranging) is an optical remote-sensing technique for scanning surfaces from a distance with laser light (nonvisible). Lidar systems use an active optical sensor that transmits laser beams, and calculates ranges and the precise position of the target. Measurements are combined into a point cloud dataset, which is registered to a 3D-coordinate system.

Why This Is Important

Most leaders in the automotive industry consider lidar one of the core technologies to enable autonomous driving. It provides outstanding localization and object recognition capabilities for vehicles. While advances are being made through improving the range, frame rate, resolution and cost, the technology still is expensive compared with other safety sensors, including radar and cameras, and has technical challenges.

Business Impact

Lidar is a key component for enabling autonomous driving and improving advanced driver assistance systems (ADAS). Lidar provides superior information to onboard computers and can be used to create maps and identify objects. While there is some debate on whether lidar is an absolute requirement for autonomous vehicle applications, it is used by many companies for advanced safety systems that are not fully autonomous. A few companies are also using lidar for redundancy to camera/radar systems.

Drivers

- Adoption of lidar technologies for high-volume applications will bring economies of scale. Lowering the cost of production and making it easier to adopt the technology is a key for adoption in passenger vehicles. Mercedes-Benz and Volvo have agreed to significant production plans for putting lidar onto consumer vehicles' ADAS.

- Proliferation of other applications (such as drones for aerial mapping, which provides details on topography, vegetation and infrastructure) will also drive adoption. Additionally, extension of lidar use beyond passenger vehicles, such as in mining, building and agriculture, will provide scale, which will help bring costs down.
- Technology improvement will help deliver scale by enabling lower hardware price points. Solid-state lidars have already become more popular than mechanical scanning lidars as they have no moving parts and offer better performance and reliability.
- Some specific technology advancements include vertical-cavity surface-emitting lasers (VCSELs), which are low-power laser sources and offer significantly better endurance and lifetime expectancy than a regular diode laser. Another advancement is Spectrum-Scan lidar, which delivers range, precision and dependability due to the employment of a signal-processing technique called random-modulation continuous wave. This has greater benefits than more conventional ranging and detecting techniques.

Obstacles

- There are design challenges, such as thermal management of heat sinks (laser light beams are produced by high currents), board layout to minimize parasitic components, and electrical component reliability in the system as it requires high power due to the high pulse speed and energy.
- Improvement in other sensor technologies, such as 4D radar, can limit applications for lidar.
- The slow start of production for fully autonomous vehicles could limit the market size for lidar and cause consolidation in the industry, limiting the investment in new technologies and factories.
- Most lidar companies are unaware of challenges in manufacturing at scale as they focus on low-volume R&D products.
- Lidar often suffers from durability problems and may not hold up well in consumer applications.

User Recommendations

- Find lidar solutions that have a clear path to cost reductions, such as those that use technology similar to consumer electronics and/or keep pace with technological innovation in sensors.
- Prioritize vendors that offer perception algorithms/software capabilities with the hardware to ease and optimize analysis.
- Analyze the financial viability of your lidar provider by evaluating their current partners and engagements.
- Ensure your lidar provider isn't involved in any legal cases, such as patent infringement issues, which is often seen with emerging technology startups.

Sample Vendors

AEye; Aurora; Ibeo Automotive Systems; Innoviz; Luminar; Ouster; Quanergy Systems; Valeo

Gartner Recommended Reading

Emerging Tech: Synthetic Data Will Drive Future Autonomous Vehicles

Emerging Tech: The Future of Autonomous Vehicles

Emerging Tech Impact Radar: Autonomous Vehicles, 2022

Predicts 2023: Automotive and Smart Mobility

Emerging Tech Impact Radar: Sensing Technologies and Applications

V2X Communications

Analysis By: Jonathan Davenport

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Emerging

Definition:

Traditionally vehicle-to-everything (V2X) communications supported the wireless transmission of data directly between vehicles and other road users or infrastructure. However, messages are increasingly being transmitted over the standard cellular network leading to vehicle-to-network-to-everything (V2N2X) communication. Vehicles send messages to and receive messages from other vehicles (V2V), external infrastructure (V2I), pedestrians (V2P), the home (V2H) and the power grid (V2G).

Why This Is Important

V2X has two primary uses: safety and traffic optimization. The ability for vehicles to send messages to other vehicles, for example, that a vehicle is stationary or had to perform an emergency stop, enables new forward collision warnings to be sent. Combined with V2P and V2C messages, this will improve driving performance, which will have a tremendous impact on public safety if implemented on a large, interoperable scale. V2I functionality also could be used for innovative traffic management systems and help improve traffic flow.

Business Impact

Automakers can market V2V communication as a safety feature, which will provide drivers with warnings of hazardous road conditions, collisions and changes in traffic patterns. V2P and V2C communication should lead to a reduction in accidents involving vulnerable road users. For governments, V2I communication will enable improved traffic flow by harnessing innovative traffic management systems. However, governments have allocated (expensive) radio spectrum to V2X applications.

Drivers

- Direct V2V safety messages have always been seen as important for low-latency communications, however, interoperability of messages between automakers has been slow to scale. Now with the use of multiaccess edge compute (MEC), such as AWS Wavelength, latency of V2N2X messages can be almost on par with direct messages. For example, companies like Vodafone Group have found that round-trip time (RTT) between the base station and MEC infrastructure could be as low as 10 milliseconds.
- By the end of 2023, Gartner forecasts there will be 429 million connected vehicles, this provides a large installed base over which V2N2X messages can be communicated.
- Automakers that wish to comply with the Euro New Car Assessment Programme (NCAP) 2025 Roadmap and get a five-star safety rating will need to implement V2X by 2024. Car manufacturers want to ensure their vehicles score well in Euro NCAP's test program, which is an important data source for consumers.
- For autonomous vehicles, V2V communication technology provides additional safety input that cannot be captured by conventional vehicle sensors, allowing the vehicle to adjust its driving strategy and initiate emergency maneuvers to ensure the safety of passengers and other traffic participants.
- While V2X is not essential for autonomous driving, significant benefits will be delivered to autonomous vehicles if they can communicate with the infrastructure around them. Active sensors in autonomous vehicles, such as camera, radar and lidar, can be supplemented with additional insights from V2X, especially non-line-of-sight data points, effectively allowing vision beyond the sensor range and enabling vehicles to see around obstructions.
- V2I communication will help keep vehicles moving, thus minimizing the time spent idling at junctions and traffic signals. Passenger journey times should improve, as should fuel efficiency, which leads to potential environmental benefits.
- V2G will allow electric vehicles to help balance peak network loads by either ceasing to charge or by selling electricity back to the grid.

Obstacles

- Direct V2X is an emerging technology that is being extensively tested, but it is not yet widely deployed.
- Dedicated short-range communications (DSRC) and cellular (4G or 5G) C-V2X technologies aren't compatible. The future technological evolution of V2X has yet to gain global consensus. Momentum had been building for C-V2X; however, Volkswagen's decision to use DSRC added further confusion as to which technology will "win" in Europe.
- V2X technology is most useful when there is a large installed base of vehicles, but the rollout of the technology has been slow and limited to disparate geographic regions.
- Automakers continue to lack direction from a regulatory standpoint.
- Direct willingness of consumers to pay for the technology is extremely limited.
- Early cellular-based vehicle-to-network-to-infrastructure solutions are also emerging, which communicate over the standard cellular network — bypassing the need for direct low-latency communications. Audi has started using green light optimized speed advisory (GLOSA) data, which reports traffic signal status.

User Recommendations

Automakers should:

- Lobby governments to push for a regional V2X standard.
- Prepare to utilize different communication technology, depending on regulatory mandates and local market adoption trends.
- Examine how use cases that do not rely on low-latency messages can be delivered using vehicle-to-network-to-everything.

Governments should:

- Help improve road safety by consulting on regulatory mandates that will help drive adoption.

- Guide policy decision making by undertaking research into DSRC and cellular solution investment costs for roadside units and highway infrastructure.

Communications service providers should:

- Lobby governments and automakers to push for the cellular standard.
- Ideate possible revenue models that could be used to generate income from low-latency-based use cases.
- Ensure that revenue is generated when spectrum assets are used for V2V communications, even when messages do not travel across the cellular network.

Sample Vendors

!important Safety Technologies USA; Autotalks; Ericsson; HARMAN International; Panasonic; Qualcomm Technologies; u-blox; Vodafone Group; Volkswagen

Gartner Recommended Reading

Emerging Tech Impact Radar: Autonomous Vehicles, 2022

Emerging Tech Impact Radar: Sensing Technologies and Applications

Forecast Analysis: Automotive Semiconductors, Worldwide, 2021-2031

Automotive Insight: Vehicle Cybersecurity Ecosystem Creates Partnership Opportunities

Automotive CI/CD

Analysis By: Jonathan Davenport

Benefit Rating: Transformational

Market Penetration: Less than 1% of target audience

Maturity: Emerging

Definition:

Automotive continuous integration/continuous delivery (CI/CD) describes the ability to create, test and then deliver new software versions quickly and frequently when all relevant tests have passed. Proactive software updates are usually delivered using over the air (OTA) software updates. For example, how car makers promptly deliver bug fixes and new features to customers.

Why This Is Important

Automotive CI/CD will allow automakers to create major revenue opportunities by delivering functions-as-a-service, and also reduce expenditure on software-based warranty and recalls. Incremental code changes are made frequently and reliably to enable ongoing improvements to be made to vehicle code. Updates are delivered OTA to fix bugs, respond to cyberattacks, and enable owners to unlock new functionality over a product's lifetime.

Business Impact

Automotive CI/CD will provide the ability to:

- Fix issues on vehicles without having to visit a repair shop. For automakers, this has the potential to deliver significant cost savings for warranty and recalls.
- Undertake remote maintenance that will reduce breakdowns with associated improvement in customer satisfaction and brand loyalty.
- Develop and deploy new and improved software to vehicles, which unlocks potential for additional revenue streams.

Drivers

- The technique of automotive CI/CD is nascent; but competitive pressure from companies like Tesla is driving the market forward. For example, Ford has started using Red Hat's OpenShift Pipelines to standardize its CI/CD pipeline — helping it build, test and deploy applications across clouds. As a result, Ford has been able to use automation to cut the delivery time of applications, while having fewer code errors which has enabled it to release functionality to customers more often.
- Most other automakers are already deploying some form of OTAs and are gradually increasing their frequency.
- Future software-defined vehicle architectures like Volkswagen's ID family of electric vehicles, support easier updates with fewer control units and modern software technology.
- New market entrants working with a "greenfield" vehicle electronic and electrical (E/E) architecture, following an agile software development process, will deliver proactive software deployment much quicker than traditional OEMs, which work with a wide range of legacy systems.
- In contrast to traditional waterfall development approaches, developers, quality assurance (QA) engineers and operations managers work together on one platform. As a result of different teams working independently of one another, they can deploy their changes whenever they are ready and not on any coordinated schedule. This allows frequent feedback collected at the build, test and production stages.
- More regular software updates to vehicles can be deployed. Once the software is integrated and developed, and the code has passed all necessary tests, auto companies can choose to deploy the code on a batched basis and push it into production.
- OEMs' revenue models are changing with the electrification of their vehicle model range. As a result, after-sales revenue will drop dramatically and product life cycles will extend. This is pushing automakers to find new revenue sources, of which software-enabled services is one of most attractive alternatives.

Obstacles

- Automakers have begun to alter internal processes to shift to regular updates and upgrades; however, progress remains fairly slow because it requires time for organizational changes to stabilize and talent to be recruited.
- Automakers are set up to produce physical products, not to develop software, which usually requires an agile organization and development process.
- The potential negative impact of making changes to mission-critical safety software applications is something that many in the industry are extremely nervous about.
- Low investment and immature deployments of cybersecurity solutions compound the industry's risk aversion.
- Traditional vehicles that rely on distributed engine control units (ECUs) running embedded software are often not possible to update because compute power is limited and memory has already been consumed by the software at the start of production.

User Recommendations

- Excel at in-house software development by bringing together all IT functions into a single team and then focus on recruiting top software engineering talent.
- Embrace cultural change by investing in change management initiatives and bringing in senior leaders from outside the traditional automotive industry to shake things up.
- Work in an agile software development environment by focusing on releasing and delivering capabilities to customers in contrast to the traditional project-oriented workflow.
- Ensure the highest levels of simulated safety by using digital twin technology to test software across each vehicle model variant prior to deployment.
- Align all participants that are delivering components of a vehicle's software stack by preparing contracts for services in advance, which allows for proactive software deployment.

Sample Vendors

Aptiv; Elektrobit; Ford; General Motors; Mercedes-Benz Group; Stellantis; Tesla; Toyota; Volkswagen

Gartner Recommended Reading

Software-Defined Vehicles' Impacts on the Role of the CIO

Market Trend: Connected and Autonomous Vehicle Data Enhances Software Life Cycle Management Transformation

Life Cycle Management of Software-Defined Vehicles: Step 1 — Software Bill of Materials

Life Cycle Management of Software-Defined Vehicles: Step 2 — Vehicle Software Register

Life Cycle Management of Software-Defined Vehicles: Step 3 — Vehicle Digital Twin 2.0

Connected Vehicle Services

Analysis By: Mike Ramsey

Benefit Rating: High

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

In-vehicle services are enabled by a wireless connection between automobiles and the cloud. These services can include in-vehicle Wi-Fi, theft prevention and recovery, preventive maintenance, retail purchase tie-ins, parking location and payment services, event booking, driver health monitoring, dynamic navigation map updates, advanced driving systems, digital or human concierge services, and more.

Why This Is Important

Connected vehicle services in the car may be a key differentiator for automakers and can form a new source of revenue for third-party service providers. Most automakers have begun offering functions as a service, disconnecting capabilities from the options purchased when the car was new. These services could be enabled at the time of the sale or afterward. There is a significant effort behind digital services in the industry that will lead to recurring revenue.

Business Impact

Connected vehicle services are at the heart of a shift in business models in the automotive industry. Digital services or capabilities in cars will shift the focus away from the sale of a vehicle and toward these aftermarket services, which typically are higher margin than the sale of the car itself. In addition, aftermarket digital services enable car makers and other service providers to have a relationship with second and third owners of vehicles.

Drivers

- A steady increase in the number of connected vehicles is likely the most important influence in the development of in-vehicle services. A constant data connection is the first-level requirement for the services, and the onset of 5G may improve service delivery.
- New electrical and compute architectures in vehicles that enable configurable vehicles.
- The creation of an application ecosystem for the vehicle through a common platform.
- Automakers shifting their business models toward services and giving those services the emphasis they need to grow.
- A willingness for car companies to agree on common standards and to allow third-party developers to creatively solve problems or offer services, also leading to improved service development.
- Consumer acceptance for paying for services rather than purchasing capability through options upfront.
- New entrants in this space, primarily the electric vehicle (EV) startups, offer digital services and upgrades that put pressure on the rest of the industry to adapt.
- The ability for second or third owners to add or subtract digital features using connectivity, which could lead to an expansion in services.

Obstacles

- The business model for providing services has always been challenging because of competing capabilities from smartphones, and that will remain a challenge.
- It may take some time to create an ecosystem that enables third-party technology companies and service providers to easily integrate with these systems.
- Consumers may be angry about or unwilling to accept additional fees for capabilities that they feel should be standard on vehicles, or that could be provided by smartphones.
- Right-to-repair legislation, as well as the European Data Act, could interfere with automakers' ability to control the types of services delivered to vehicles by opening up service delivery to third parties that are outside the automakers' control.

Analysts Notes: Connected services may see a leap forward soon as automakers roll out new software-defined architectures. For instance, the Ultifi platform developed by General Motors is designed to make end-to-end upgradability easier in vehicles, thus enabling a broader range of services. As it stands, the ambition of the automakers to generate revenue from services has surpassed their ability to deliver services that consumers actually would be willing to pay extra for.

User Recommendations

- Explore new developer interfaces that make it simpler to build applications for in-vehicle services.
- Assess value creation in terms of the entire product, not just the revenue generated from data sales or transactions from the connected services themselves.
- Create cloud-based customer profiles that facilitate delivering services to the vehicle and the consumer.
- Deliver services that are differentiated from smartphone applications and are not considered something that should be standard in a vehicle. Charging for something people expect to be permanent in the car will be unpopular.
- Explore car wallet applications to make payment from the vehicle easier.

Sample Vendors

Amazon; Google; HARMAN International; HERE Technologies; IBM; Microsoft; TomTom

Gartner Recommended Reading

Framework for Monetizing Over-the-Air Software Updates

Tool: Connected Vehicle Use-Case Opportunity Assessment

Software-Defined Vehicles' Impacts on the Role of the CIO

Over-the-Air Software Updates

Analysis By: Mike Ramsey

Benefit Rating: High

Market Penetration: 20% to 50% of target audience

Maturity: Early mainstream

Definition:

Over-the-air (OTA) software updates refer to methods of using wireless communication to distribute new software or firmware updates and/or configuration settings to automobiles' various computing systems, including infotainment systems and electronic control units.

Why This Is Important

OTA software or firmware updates are foundational to many of the big changes affecting the automotive industry. They enable automakers to repair or upgrade vehicles without a service visit and without making physical changes to the vehicle. This means that cars continue to gain capability over time, automakers create a lasting connection to consumers, and warranty and repair costs are lowered while limiting inconvenience to customers.

Business Impact

OTA updates are expected to have the following effects on the automotive industry:

- Reduce maintenance and warranty costs.
- Improve product differentiation and consumer satisfaction during the vehicle ownership phase and provide new revenue opportunities by adding new capabilities.
- Establish an ongoing relationship with consumers by enabling services and downloadable content.

- Create customer satisfaction and higher levels of safety by making repairs and recalls through digital means.

Drivers

- Proliferating connectivity in automobiles combined with new electrical and compute architectures is enabling OTA to be delivered deeper into the vehicle. A few years prior, embedded connectivity in vehicles was not common and the use of OTA to deliver repairs or upgrades was even less common.

- For automakers, the shifting business model priorities from a vehicle-centric business model to a customer-centric model, where new revenue streams are generated on an ongoing basis rather than from a single sale, will support an even greater adoption.

- Most major automakers now offer capabilities that can be added after the sale of the vehicle through purchase or as a commitment at the time of sale.

- OTA will benefit from wider adoption of embedded 4G and, eventually, 5G connectivities. OTA offers the ability to repair and upgrade vehicles at a low cost relative to dealership visits and ensures that all vehicles actually receive the fix. It also creates an aftermarket opportunity to continuously improve and monetize vehicles over a long duration.

Obstacles

- Vehicle architectures are still largely set up on a distributed compute architecture, which makes updating OTA firmware challenging.

- The technology is limited by connectivity to vehicles, and data security and software validation concerns by the automakers.

- Most automakers are not equipped to do regular OTA updates on a large number of different models as this capability is largely available with solution providers. Combining agile software development with the system engineering approach is challenging for most automakers and suppliers. In addition, there could be resistance from dealers as OTA updates represent a potential loss of their service business.

- The need to pay for a connection to the vehicle is also a concern. If consumers do not subscribe to a data connection, then the automaker must pay telecommunications companies for that data connection to the vehicle, creating a burden on automakers.
- Most automakers have failed to offer the right value to their consumers that would encourage them to pay for new software or services.

Analyst Notes: Updates are becoming more frequent and many automakers now have created marketplaces where features can be bought and downloaded. The next stage in the evolution of this technology will be third-party applications that can be downloaded through an automaker's store to change the features or capabilities in a car.

User Recommendations

- Stop using a simple ROI equation for introducing OTA as these updates must be done to facilitate and implement many advanced technologies and new business models.
- Ensure that teams are set up to create and test new software on a constant basis by working with engineering and business partners rather than just reacting to problems that exist on the vehicles.
- Invest in a new system to develop software that puts an emphasis on continuous deployment, rather than multiyear deployment cycles.
- Emphasize cybersecurity by using software that can operate within a network-based security monitoring system. Automakers must determine whether it is more advantageous to build their own OTA infrastructure solution, partner with a provider for a solution or use a hybrid approach.
- Seek vendors that can execute OTA updates securely and efficiently to minimize network demand and limit the cost of downloads.

Sample Vendors

Airbiquity; Aptiv; Aurora Labs; BlackBerry; Bosch; Continental; HERE Technologies; Samsung; Sibros Technologies; Wind River

Gartner Recommended Reading

Market Trends: Software-Defined Vehicles Will Disrupt the Automotive Supply Chain

Life Cycle Management of Software-Defined Vehicles: Step 2 — Vehicle Software Register

Software-Defined Vehicles' Impacts on the Role of the CIO

Market Trend: Connected and Autonomous Vehicle Data Enhances Software Life Cycle Management Transformation

Auto Industry Insight: How to Create Messaging for the Chief Software Officer

Driver Monitoring System

Analysis By: Jonathan Davenport

Benefit Rating: Moderate

Market Penetration: 5% to 20% of target audience

Maturity: Early mainstream

Definition:

A driver monitoring system (DMS) is an in-vehicle system that employs sensing technologies and analytics to monitor head and body pose, eye state, attention, drowsiness, emotions, and impairment. This system can also be used to identify drivers and to monitor other occupants. DMSs are primarily used to prevent accidents caused by fatigue or distraction, and also to ensure effective handovers between the vehicle and the human in Level 3 autonomous driving situations.

Why This Is Important

From July 2022, automakers in the EU applying for type approval had to have driver drowsiness and attention monitoring/distraction technology. The intention of the regulation is to reduce motor vehicle accidents caused by driver fatigue or distraction. Driver alertness is a crucial factor in a significant proportion of accidents according to research studies, such as those conducted by The Royal Society for the Prevention of Accidents (RoSPA). DMSs are also being deployed into aftermarket video telematics solutions.

Business Impact

Impacts delivered include:

- Automakers and fleet operators can help reduce the volume of road traffic incidents caused by distraction.
- Overreliance on advanced driver assistance system (ADAS) features will be prevented by ensuring that the driver continues to supervise the operation of the vehicle.
- Smoother vehicle-human handovers will be delivered using DMS technology when the vehicle is operating autonomously.
- In-vehicle service delivery can be refined by capturing occupant emotion AI data.
- DMS can identify babies left behind in vehicles and, in mobility use cases, left luggage and spills.

Drivers

- The European Commission's new general safety regulations (GSR) mandated driver drowsiness and attention monitoring/distraction recognition for all new vehicles applying for type approval from July 2022. Euro NCAP is also pushing for the use of DMS in vehicles.
- Alerts from the DMS can be used by fleet managers to educate drivers on safe behaviors while behind the wheel. For example, DMSs can identify and capture evidence of drivers who light a cigarette or are picking up their mobile phone while driving.
- DMS will play an important role in the adoption of Level 2 hands-free driving by ensuring that the driver is monitoring the road and is ready to take over control. Likewise, for Level 3 autonomous vehicles, the DMS will need to collect information to verify the driver is able to resume manual control, if necessary. Current U.N. Regulation No. 157 regulatory approval for automated lane-keeping system (ALKS) technology will accelerate commercial deployments.
- The ability to use a DMS cabin camera for facial recognition enables biometric authentication of drivers. DMS-based driver identification can be used to offer personalized services, such as adjusting seat and mirror positions. The tension of seat belts can also be adjusted based on the size, gender or age of occupants. This feature also has the potential to increase vehicle security and underpin use cases like authentication for in-car payments.
- ADAS features such as lane-keeping solutions can be improved by monitoring head and eye movement to gauge driver intention, for example, if the driver intends to change lanes without using an indicator signal.
- Incorporation of in-cabin camera technology enables automakers to offer multimodal user interfaces with gestures or gaze in combination with voice. For example, location-specific questions, such as "What is that?" made to a voice-based virtual assistant, can be linked to a driver's gaze to provide contextually aware answers.
- DMS can also be used to monitor the quality of occupant experience (emotion AI) to detect forgotten objects on board and the presence of children or animals left behind in vehicles, which can be dangerous on hot days.

Obstacles

- Privacy concerns about being monitored in the vehicle exist, though most solutions only process data at the edge and do not store personal information. Some radar-based systems have been developed to overcome the concern of identification of the occupants.
- DMS can be used to get a distracted driver's attention back on the road or to suggest the driver take a break when tired. However, current solutions still mostly rely on the driver to act on the system's warnings, which can impact efficacy.
- False positives can annoy vehicle owners and lead to DMSs being switched off. Similarly, false negatives also hamper the effectiveness of DMS.
- Outside of Europe, the lack of regulatory pressure has historically led to a very low investment from OEMs, similar to what happened with many other safety technologies.
- The systems are an added expense, and when not mandated it's not clear if consumers want or would be willing to pay more for this feature.

User Recommendations

Automotive manufacturers must:

- Deliver a safer and more pleasant driving experience by improving the level of integration between DMS and broader ADASs.
- Leverage a DMS to support a smooth machine-human handover for Level 3 autonomous applications. This is particularly important when calculating the period of time necessary to perform a handover based on the activity the driver is engaged in.
- Create new capabilities where the DMS enables a more premium cabin experience.

Mobility fleet operators must:

- Drive customer retention by utilizing the ability to recognize occupants (not just the person who made the booking) and use this to undertake digital personalization of the vehicle's environment.
- Use DMS to also assess the level of cleanliness of the cabin, and to detect and inform customers about objects forgotten inside the vehicle.

Insurers and corporate fleet operators must:

- Improve safety by leveraging DMS-based telematics solutions to educate people about safe driving practices and reduce the risk of accidents.

Sample Vendors

Continental; Cipia; Nauto; Seeing Machines; Smart Eye Group; Vayyar

Gartner Recommended Reading

Invest in 3 Critical Semiconductor Enablers for a Successful Driver Monitoring System Product Portfolio

Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide

AI Multisensory Tech in Automotive HMIs, Part 4: Emotion AI

Market Insight: IoT-Based Digital Personalization, Part 2 — Architecture for Automotive Customer Retention

Market Trends: Machine Vision Will Be the Game Changer Across Markets

HD Maps

Analysis By: Jonathan Davenport

Benefit Rating: High

Market Penetration: 1% to 5% of target audience

Maturity: Adolescent

Definition:

High-definition (HD) maps are developed as a layer on top of traditional navigation maps to provide autonomous vehicles with data to localize themselves and plan maneuvers. HD maps are designed to be read by a computer. These maps provide a centimeter-level accuracy of 3D road geometry, boundaries and permitted traffic routes, along with semantic information about the environment, such as speed limits, the position of traffic lights and road signs.

Why This Is Important

HD maps provide autonomous vehicles with environmental knowledge to help navigate road infrastructure by giving measurements to objects in the environment. Lacking an HD map can be likened to how a human driver feels in an unfamiliar city — stress levels rise; they don't know which lane to use, which traffic lights to watch, what the speed limit is, and so on. By providing these sorts of data, the HD map removes a burden from the autonomous vehicle's perception system.

Business Impact

There are a number of reasons why HD maps are so important for companies developing advanced driver assistance and autonomous driving systems:

- HD maps provide an additional data feed to enable autonomous vehicles to make better informed decisions and operate more smoothly.
- Vehicle sensor suites can capture data to triangulate a vehicle's position on an HD map, providing centimeter-level accurate localization.
- HD maps provide driving style data. For example, while it may be safe and within the speed limit to drive around a corner at a certain speed, the HD map can provide reference speed information to ensure passengers feel comfortable.

Drivers

- HD maps are becoming easier to incorporate into vehicles. Historically, HD maps required very large onboard storage, with file sizes exceeding 100TB. However, companies such as DeepMap (which NVIDIA acquired in June 2021) and Mobileye have spearheaded a revolutionary approach that creates lighter-weight HD maps that contain the essential information autonomous vehicles need to drive and localize themselves.
- There is also a trend toward simplifying the construction and maintenance of HD maps, which has been a bottleneck to map expansion in the past. Vendors are creating solutions that enable a road to be mapped using a standard autonomous vehicle's sensor suite, to capture the data points about the road's surroundings, including buildings, street furniture and road curvature. These data points are uploaded to the cloud over the cellular network and kept fresh by the distribution of delta updates over the air.
- In the long run, it is likely that HD maps will be standardized across manufacturers and become a commodity. Activities for standardization are happening now, including with the Navigation Data Standard (NDS) Association, but are not yet complete.
- The opportunity for HD maps extends beyond autonomous vehicles. Broader autonomous things like robots, drones, ships and industrial equipment will require rich information about their operational design domain (ODD), which extends the reach for map developer's solutions.
- The growth in consumer deliveries by robots is providing an early customer base for HD map vendors while the industry waits for autonomous vehicle deployments to scale.

Obstacles

- Traditional mapping companies use surveying vehicles to build a map. This approach is expensive and doesn't scale because roads need to be continually surveyed to maintain accuracy.
- Real-time kinetic (RTK) solutions improve the accuracy of global navigation satellite system (GNSS)-based localization by identifying satellite position errors. RTK could cannibalize the localization side of HD maps.
- Though the production of HD maps is becoming more scalable by leveraging fleetwide data collection, maps still require manual annotation, for example, so that the autonomous vehicle knows which set of traffic lights it should be watching.
- Companies that do not have access to large vehicle fleets will be at a disadvantage from the perspective of updating and extending HD maps.

User Recommendations

- Overcome the challenge of building and maintaining an HD map by collecting camera and other sensor data from third-party vehicle fleets equipped with advanced sensors.
- Work collaboratively with traditional mapping companies, IT services firms or startups to build and maintain an HD map in the autonomous fleet.
- Adapt to differing regional conditions by developing systems that can comply with different regulations, especially in China, where mapping is strictly regulated.
- Invest in storage and computing resources for automated processing of map input data to streamline and deliver updates over-the-air to vehicles.
- Design safe autonomous vehicles by ensuring they can work in situations in which the HD map is not correct due to changes in the environment, such as construction, road maintenance and accidents.
- Set the operational design domain (ODD) of vehicles to ensure they only operate in areas with an up-to-date HD map.

Sample Vendors

Civil Maps; HERE Technologies; Mobileye; MobilTech; NVIDIA; TomTom; Ushr

Gartner Recommended Reading

Cool Vendors in Autonomous Vehicle Systems

Vendor Rating: Intel

Market Trend: Connected and Autonomous Vehicle Data Enhances Software Life Cycle Management Transformation

Forecast Analysis: Autonomous Vehicle Net Additions, Internet of Things, Worldwide

Appendixes

See the previous Hype Cycle: Hype Cycle for Connected, Electric and Autonomous Vehicles, 2022

Hype Cycle Phases, Benefit Ratings and Maturity Levels

Table 2: Hype Cycle Phases

(Enlarged table in Appendix)

Phase	Definition
Innovation Trigger	A breakthrough, public demonstration, product launch or other event generates significant media and industry interest.
Peak of Inflated Expectations	During this phase of overenthusiasm and unrealistic projections, a flurry of well-publicized activity by technology leaders results in some successes, but more failures, as the innovation is pushed to its limits. The only enterprises making money are conference organizers and content publishers.
Trough of Disillusionment	Because the innovation does not live up to its overinflated expectations, it rapidly becomes unfashionable. Media interest wanes, except for a few cautionary tales.
Slope of Enlightenment	Focused experimentation and solid hard work by an increasingly diverse range of organizations lead to a true understanding of the innovation's applicability, risks and benefits. Commercial off-the-shelf methodologies and tools ease the development process.
Plateau of Productivity	The real-world benefits of the innovation are demonstrated and accepted. Tools and methodologies are increasingly stable as they enter their second and third generations. Growing numbers of organizations feel comfortable with the reduced level of risk; the rapid growth phase of adoption begins. Approximately 20% of the technology's target audience has adopted or is adopting the technology as it enters this phase.
Years to Mainstream Adoption	The time required for the innovation to reach the Plateau of Productivity.

Source: Gartner (July 2023)

Table 3: Benefit Ratings

Benefit Rating ↓	*Definition* ↓
Transformational	Enables new ways of doing business across industries that will result in major shifts in industry dynamics
High	Enables new ways of performing horizontal or vertical processes that will result in significantly increased revenue or cost savings for an enterprise
Moderate	Provides incremental improvements to established processes that will result in increased revenue or cost savings for an enterprise
Low	Slightly improves processes (for example, improved user experience) that will be difficult to translate into increased revenue or cost savings

Source: Gartner (July 2023)

Table 4: Maturity Levels

(Enlarged table in Appendix)

Maturity Levels	Status	Products/Vendors
Embryonic	In labs	None
Emerging	Commercialization by vendors Pilots and deployments by industry leaders	First generation High price Much customization
Adolescent	Maturing technology capabilities and process understanding Uptake beyond early adopters	Second generation Less customization
Early mainstream	Proven technology Vendors, technology and adoption rapidly evolving	Third generation More out-of-box methodologies
Mature mainstream	Robust technology Not much evolution in vendors or technology	Several dominant vendors
Legacy	Not appropriate for new developments Cost of migration constrains replacement	Maintenance revenue focus
Obsolete	Rarely used	Used/resale market only

Source: Gartner (July 2023)

Document Revision History

Hype Cycle for Connected, Electric and Autonomous Vehicles, 2022 - 19 July 2022

Hype Cycle for Connected, Electric and Autonomous Vehicles, 2021 - 7 July 2021

Hype Cycle for Connected Vehicles and Smart Mobility, 2020 - 17 July 2020

Hype Cycle for Connected Vehicles and Smart Mobility, 2019 - 31 July 2019

Hype Cycle for Connected Vehicles and Smart Mobility, 2018 - 18 July 2018

Hype Cycle for Connected Vehicles and Smart Mobility, 2017 - 28 July 2017

Hype Cycle for Connected Vehicles and Smart Mobility, 2015 - 21 July 2015

Hype Cycle for Vehicle-Centric Information and Communication Technology (Vehicle ICT), 2014 - 21 July 2014

Hype Cycle for Vehicle-Centric Information and Communication Technology (Vehicle ICT), 2013 - 31 July 2013

Hype Cycle for Vehicle-Centric Information and Communication Technology (Vehicle ICT), 2012 - 30 July 2012

Hype Cycle for Vehicle-Centric Information and Communication Technologies (Vehicle ICT), 2011 - 27 July 2011

Hype Cycle for Vehicle-Centric Information and Communication Technologies (Vehicle ICT), 2010 - 22 July 2010

Hype Cycle for Vehicle-Centric Information and Communication Technologies (Vehicle ICT), 2009 - 24 July 2009

Hype Cycle for Vehicle-Centric Information and Communication Technologies (Vehicle ICT), 2008 - 1 July 2008

Hype Cycle for Vehicle-Centric Information and Communication Technologies (Vehicle ICT), 2007 - 30 June 2007

Hype Cycle for Automotive Information and Communication Technologies, 2006 - 26 June 2006

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2023 CIO and Technology Executive Agenda: An Automotive Perspective

Guide to Connected Car Profitability

How to Become the Digital Automaker of the Future

How Auto Companies Can Bridge Cultural Barriers to Become Tech Companies

Guide to New Business Models in the Electric Vehicle Ecosystem

Framework for Monetizing Over-the-Air Software Updates

Tool: Connected Vehicle Use-Case Opportunity Assessment

Software-Defined Vehicles' Impacts on the Role of the CIO

4 Ways CIOs Can Enable Electric Vehicle Fleets

Table 1: Priority Matrix for Connected, Electric and Autonomous Vehicles, 2023

Benefit	*Years to Mainstream Adoption*			
↓	***Less Than 2 Years*** ↓	***2 - 5 Years*** ↓	***5 - 10 Years*** ↓	***More Than 10 Years*** ↓
Transformational		Automotive CI/CD Automotive Cybersecurity	Autonomous Vehicles Software-Defined Vehicle	Mobility Data Space Vehicle Swarm Intelligence
High		Automotive Lidar Connected Vehicle Services HD Maps Over-the-Air Software Updates V2X Communications	AI Battery Management Car Hardware Upgrades Digital Personalization EV Advanced Efficiency Tech EV Smart Charging In-Cabin Emotion AI In-Car Advanced UX/UI LEO Satellite-to-Vehicle Communications Solid-State Batteries Vehicle Digital Twin 2.0	In-Cabin Metaverse Mobility Quantum Optimization
Moderate		Driver Monitoring System	Battery Swapping Car Wallet	Intravehicle Wireless Network Wireless EV Charging
Low			Hydrogen Vehicles	

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