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KEY TRENDS IN CONNECTED VEHICLE AND SMART MOBILITY: UNLOCKING VALUE WITH STRATEGIC INFRASTRUCTURE

EQUINIX WHITE PAPER

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EXECUTIVE SUMMARY

The auto industry has come a long way from Henry Ford's Model T, which ushered in the mass transportation era and drove to extinction many companies servicing the horse-drawn carriage trade. Today the global automotive sector faces its own seismic shift, driven by the rise of connected, autonomous, shared/subscription and electric (CASE) vehicles, which are at the heart of smart transportation. The need to focus on CASE vehicles (also known as CAVs, ACES or SAEV)[1] requires OEMs to revamp their business models or risk their own extinction. At the center of these new business models, massive amounts of data—often in real time from multiple sources—will need to be consolidated and insights derived and exchanged. This seismic shift in the industry will require a digital transformation.

This paper, developed by FTI Consulting and sponsored by Equinix, explores what the connected car future potentially looks like, identifies the evolving business models and illustrates how the technology architectures likely need to evolve to unlock value. Based on more than 20 structured, in-depth interviews with OEMs and auto ecosystem partners, as well as extensive secondary research, we see these key trends emerging:

- The next three years will see an explosive growth in connected cars; by 2020, we expect 98% of all new cars being sold to be connected. This will be driven by ubiquitous mobile networks plus government-required connectivity.
- The transition to autonomous vehicles will be gradual, as the benefits (in safety, congestion and parking, etc.) can only be realized after a reduction in the number of atypical cases that vehicle artificial intelligence (AI) must consider when it needs to anticipate the behavior of human-driven vehicles.
- More people will opt for Transportation as a Service (TaaS), especially in urban areas, where rides are shorter, streets are more congested, and people prefer not to waste time waiting in traffic or searching for parking.
- Electric vehicles (EVs) will become mainstream and increasingly will move toward platforms. Volkswagen, for example, is developing a "skateboard" that may even be offered to other OEMs. The goal is to build an EV in 10 to 16 hours versus 26 to 32 hours for combustion-engine vehicles.
- OEMs will make critical choices about their strategic focus and investments—increasingly on the electronics, user experiences and autonomous systems instead of, for example, entertainment services, where they cannot match the smart device's ease of use.
- OEM business models will need to evolve dramatically to cope with these changes. For example, within the B2C space, Pay as You Go, (PAYG) and Mobility as a Service (MaaS) will become commonplace, with associated data flows emerging as ecosystem partners need to collaborate around workflows to deliver new services.
- This will result in an explosion in demand for data and the associated digital infrastructure. For example, currently, 10 million connected BMW vehicles generate 600 MB of data per car per day (i.e., minimal levels of data.[2]

- For advanced connected cars, however, the data flow is estimated to explode to 1 GB per vehicle per day (or approximately 30 GB per vehicle per month).[3]
- This is forecast to further explode by 30 times to 1 TB of data per vehicle per month by 2025 as functionality increases.
- The traditional technology stack will simply not be able to support this avalanche of data. To meet the need, industry players will need the flexibility and agility of hybrid multicloud platforms and solutions.
- While the design decisions on how to enable CASE are now being made, a potentially helpful approach to unlocking value is through the lens of use cases and their timing:

  Predictive maintenance, for example, will have a more concentrated impact on the technology stack, mainly in the user interface and services portion of the stack around workload management and provisioning.

  Fleet management, on the other hand, will impact on the stack through the need for new functionality in the user interface, networking, and physical capacity (e.g., colocation) components of the stack.

  Today's internet and data networks are designed to distribute data from the core out to consumers who access data via smart devices. The rise of the internet of things (IoT), however, requires collection and processing of massive quantities of data from "connected" mobile assets at the digital edge. This presents challenges for traditional IT architectures, which are not distributed to the edge and struggle to manage large data streams.

  Autonomous vehicles will require a dramatic evolution of the stack to support new functionality with massive CPU and data requirements. For example, OEMs will have to design ways to off-load critical data and analytics through API gateways to third parties, eliminate vendor lock-in, ensure data integrity and enable real-time insights while ensuring data sovereignty compliance.

- OEMs are "on the CASE," each investing billions to deliver this new world. In many ways, this change is as profound as that famous shift from the horse-drawn carriage to the automobile.
- OEMs and other ecosystem members must plan for IT and technology infrastructure that will enable data aggregation, analytics and exchange in an efficient and cost-effective manner. Monolithic architecture will not work. The ecosystem must apply a distributed architecture for networks, data lakes and compute to address true MaaS and TaaS.

"The future of automotive is definitely in autonomous electrical vehicles, and we are not that far away from seeing them on public roads. Driverless cars will be used beyond commuting, and additional services, like mobile meeting rooms, will be built in."

Major Automotive OEM

NEW HORIZONS FOR CONNECTED CARS

Though the connected car has been around for over 20 years, until recently, its capabilities have been limited to emergency help, location tracking, partial remote diagnostics, and audio entertainment—all with limited revenue potential for OEMs and undifferentiated impact on user experience. Now advances in adjacent technologies—electrification, cloud infrastructure and mobility, vehicle communication protocols, edge processing/computing technologies, and artificial intelligence—have opened up new horizons, enabling the connected car to become a digital transportation, infotainment, retail, and communications hub. The vision of the connected car as a fully integrated experience as well as a mode of transportation is now within reach.

CONNECTED CARS ARE FAST TRACKED

While sales of traditional cars are decreasing, sales of connected cars are increasing, signaling changing consumer preferences. Connected car adoption is accelerating from 35% in 2015 to an expected 98% of all sold cars by 2020, (Figure 1) driven by ubiquitous mobile networks plus government-required connectivity (e.g., Europe's eCall initiative and China's electric vehicle signal polling). **Evolving V2X (Vehicle-to-Everything) technologies will enable vehicles to communicate with other vehicles, with pedestrians, and with the infrastructure managing roads, traffic and IT.** This communication will lead to safer, less-congested roadways with an enhanced driver experience. Note that the future here is not that far ahead: By 2025 V2X capabilities for vehicles and infrastructure will gain market momentum, with the deployments expected to start in as soon as 2020 (Figure 2).[4]

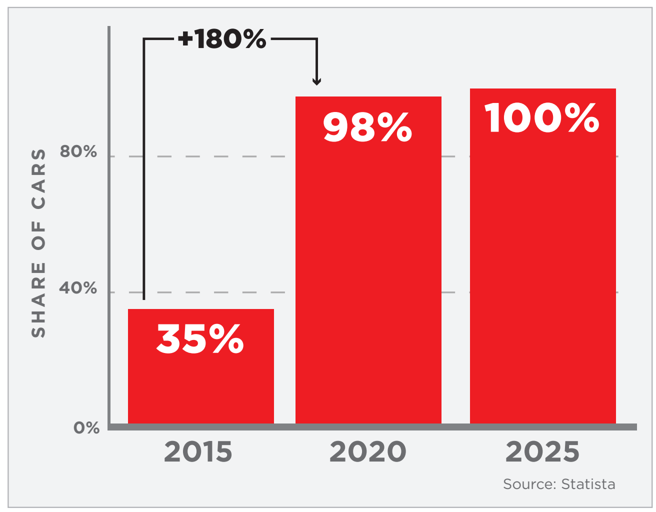

Figure 1. Number of connected cars
(% of cars sold)

As the points above illustrate, these changes are rapidly upon us. **5G will play a role for connected vehicles by bringing high-bandwidth connectivity** for over-the-air updates, advanced driver assistance systems (ADAS), high-definition (HD) and augmented and/or virtual reality (AR/VR) infotainment, and vehicle-to-cloud data transmission. Some industry participants believe 5G will make data transfers to and from the car less expensive. However, due to the pressure on profitability and failed expectations for incremental revenues from 4G roll-outs, telcos will likely prioritize higher-return, high-density areas and premium services. A fully connected car experience relies on ubiquitous connectivity and 100% coverage, and it is unlikely that both will become available on mobile networks outside urban areas. Therefore, we expect that 5G will be an important driver for in-car infotainment, but that core system data will continue to be processed within the car, and that a car itself will increasingly become the edge data center. Multiple wireless protocols (e.g., LTE, 5G, wifi and dedicated short range communications [DSRC]) will continue to be used to exchange select data with external environments; therefore, the supporting data center infrastructure would have to be able to handle a variety of interconnection points, protocols and data dimensions (Figure 3).

We don't expect OEMs to get involved in infotainment platforms in the near future. In several of our conversations with car OEMs, we learned that users' current preferences are to rely on mobile devices and their current subscription services for over-the-top (OTT) content. OEMs have struggled to bring entertainment services to the market and haven't been able to match smart devices' ease of use.

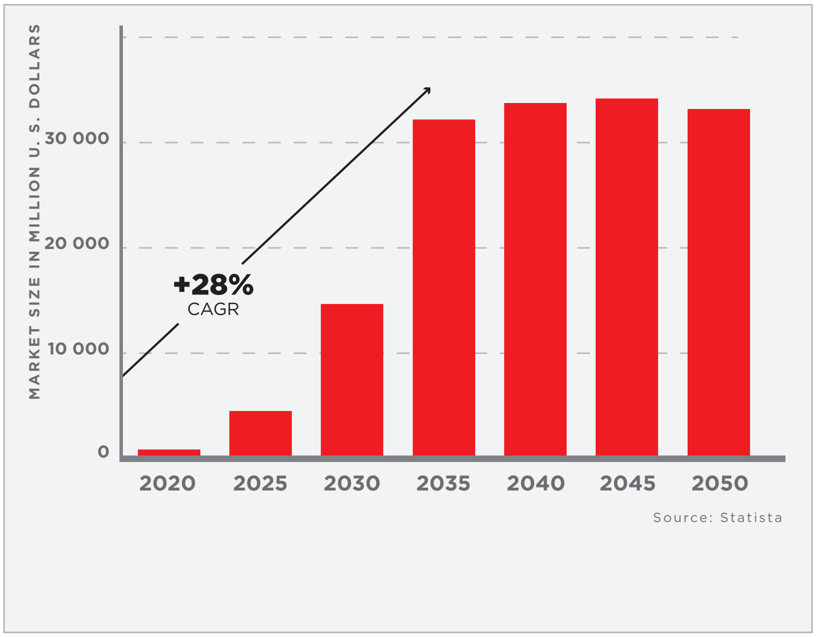

Figure 2. V2X market size ($M)

> "There is a school of thought that 5G will make data off-loading cheap, but it's not for now. An entertainment play is yet to be seen—Disney tried in-vehicle content before, and is now trying again with Audi's VR headsets, but the mass market is in smartphone-based services."

Automotive Robotics Manufacturer

V2V = Vehicle to vehicle **V2I** = Vehicle to infrastructure **V2C** = Vehicle to cloud

IN-CAR:

70%–90% of data

TYPE OF DATA:
high volume, high velocity, high variety, includes personally identifiable information about the user: e.g., core car systems performance and driving behavior

V2V:

2.5%–5% of data

TYPE OF DATA:
low volume, high velocity, low variety, not specific to the user: e.g., car positioning, vehicle speed, vehicle type

V2I:

2.5%–5% of data*

TYPE OF DATA:
low volume, high velocity, low variety, not specific to the user: e.g., vehicle speed, registration number, road conditions

V2C:

5%–20% of data

TYPE OF DATA: high to medium volume, low velocity, high variety, may include personally identifiable information about the user: e.g., AI and HD map updates

* Excluding data that forwards to the cloud

Figure 3. How do you see V2X data exchange in the future? [FTI market research]
Estimated (100%) data quantity per car per day varies considerably from 4 TB upward to c. 10 TB and 20 TB.

AUTONOMOUS VEHICLES: A GRADUAL TRANSITION

Low levels of car automation (e.g., Levels 1–3) are already in place, offering capabilities such as parking assistance, autonomous emergency braking, lane tracking/entering and adaptive cruise control. Fully autonomous Levels 4 and 5 will give the drivers back time from daily commuting and transform driving into opportunities to work, enjoy entertainment and socialize with fellow passengers.

Automotive experts anticipate that the transition to autonomous will be gradual, as the benefits (in safety, congestion and parking, etc.) can only be realized after the reduction of “corner cases”—those outside of normal operating parameters—that vehicle AI must consider when it needs to anticipate the behavior of human-driven vehicles. Adoption is likely to start with closed environments—for instance airports, campuses, and dedicated traffic lanes—and expand to selected public roads. **Collaboration across many digital supply chain partners will be required to test out these scenarios.**

Autonomous technology continues to evolve. Hardware is relatively mature and includes radar, lidar, sonar, inertial measurement units (IMUs), cameras, high-performance/low-power chips, and long-lasting batteries. Software for data transmission and car guidance is still evolving. Real-time HD maps are not available as they require high-speed connectivity. Larger server capacity for storage and algorithms to interpret image data and the ever-changing driving environment are under development.

Comparing regions, the U.S. legislative environment and road infrastructure are the most supportive of autonomous driving, while continental Europe lags because of limited testing activity and older road infrastructure. According to a study by KPMG, Autonomous Vehicles Readiness Index, the U.S. has been ranked above all European countries (excluding the Netherlands) for a combination of four success factors for autonomous driving: policy and legislation, technology and innovation, infrastructure, and consumer acceptance.[5] California, Nevada and Arizona now allow for driverless testing of autonomous cars with remote monitoring only. California has been a preferred choice for autonomous vehicle testing (with 1M+ autonomous miles driven from 2014 through 2017 by 20 companies).[6] Autonomous vehicle testing in Europe has been moving more slowly and is more regulated (with tests being conducted on private roads and/or in low-speed areas).[7]

Regulations to support testing and development of autonomous cars are in place in many geographies, with permits required for testing self-driving cars on public roads almost everywhere. In the U.S., 33 states have authorized autonomous cars on public roads. Within Europe, the U.K., Sweden, Germany and the Netherlands, regulations have been passed to allow vehicle testing.[8]

China, despite having prominent autonomous OEMs such as Baidu and JingChi, has had a slow start, but in 2018 announced plans to designate significant areas across cities, mountains, and highways for self-driving vehicle testing starting in 2019.

Autonomous vehicles may change value distribution across the automotive ecosystem. Traditionally, OEMs prefer to have technology in-house; however, tech giants may be better positioned to provide some technologies. Should OEMs compete or collaborate? The software critical to driver safety will still likely be controlled by OEMs, through either the internally developed stack or acquisitions. This is reflected in the current level of investments by automakers (Table 1). However, the remaining systems will require multiple autotech players to collaborate on architecture and security frameworks. A key question is whether OEMs will be able to retain control over car data.

> “For autonomous vehicles, what is most critical is the latency of V2I connectivity, and we don’t think that even 5G will make it fast enough for critical systems; therefore, in-vehicle networking will have to support real-time data exchanges as well as provide redundancy.”
>
> Major Automotive OEM

Table 1. OEM and supplier investment in CASE vehicle technology, partnerships and alliances

Company	Approx. investments, $	Year	Description
Volkswagen	**$50 BN**	2019–2023	Announced investments of $34 BN in electrification and $16 BN in autonomous driving and mobility services
Intel	**$15.3 BN**	2017	Acquisition of Israeli chipmaker Mobileye
Bosch	**$4.5 BN**	2019–2022	Announced investments in autonomous driving technology
BMW/Daimler/Audi	**$3.1 BN**	2015	Acquisition of Nokia's HERE Mapping Technology & Location Services
Hyundai	**$1.7 BN**	2016–2018	AI R&D in autonomous driving
Ford	**$1 BN**	2017–2022	Investment in ArgoAI
Toyota	**$1 BN**	2015–2020	Announced investment in Toyota Research Institute
Uber	**$680 M**	2016	Acquisition of autonomous truck driving company Otto
GM	**$581 M**	2016	Acquisition of Cruise Automation
Uber & Volvo	**$300 M**	2019–2022	Alliance to develop autonomous vehicles
Intel	**$250 M**	2016–2018	Announced investments in autonomous driving program

Source: Jon Walker, The Self-Driving Car Timeline—Predictions from the Top 11 Global Automakers
https://emerj.com/ai-adoption-timelines/self-driving-car-timeline-themselves-top-11-automakers/

SHARED/SUBSCRIPTION MODELS MONETIZE DATA

Car ownership is declining, partly because ride-sharing services such as Uber, Lyft, SnappCar, Didi, Juno, and BlaBlaCar are changing perceptions of car ownership, convenience and car use. The cost per mile can shrink significantly as a result of these services. This trend is expected to continue as more people opt for TaaS, especially in urban areas, where rides are shorter, streets are more congested, and people prefer not to waste time waiting in traffic or searching for parking.

Revenue is expected to move away from vehicle sales to services, underpinned by data collected by cars. As a result, we expect new monetization models to rise, including advertising-funded ride-hailing, data monetization through personalized use cases (e.g., insurance, EV charging plans) and anonymized cases (e.g., traffic optimization, parking optimization and path planning). The shift to Anything as a Service (XaaS) will extend the autotech ecosystem beyond driving-related services and create business models across industries (e.g., route optimization based on sales promotions by stores, an alignment of travel paths of car riding, sale or purchase of priority routes and delivery pods). OEMs' ability to collect data and share it while protecting users' privacy and providing an enhanced user experience is one of the significant catalysts for overall growth. For instance, Jaguar has teamed with Shell to offer in-car, automated payments via Apple and Android Pay at Shell stations.[9]

ELECTRIC VEHICLES REPLACE INTERNAL COMBUSTION ENGINE CARS

In contrast with the connectedness and autonomy trends, the driving forces for electric vehicle (EV) adoption extend beyond technology. Both U.S. and European Union legislators have gradually increased fuel efficiency targets since the end of the 1990s, and there is some talk of outlawing internal combustion engines). For instance, Norway is aiming to ban sales of traditionally powered vehicles by 2025: India, Ireland, Israel, Germany and the Netherlands target 2030.[10]

EV technology advances are bringing cleaner, more responsive and quieter cars. These cars are also more intelligent, having been designed with a "software first" approach. OEMs are signaling the strategic relevance of these companies promoting them from Tier 2 or 3 to Tier 1 suppliers.

Optimized driving and maintenance will be increasingly dependent on high-speed interconnectivity between systems via an in-car backbone.

Recent demos from the Ethernet Alliance supported Ethernet at 400 Gbps connectivity for ultra-low latency and set the road map for over 1 TBps beyond 2020.[11] In addition, EV charging stations will serve as hubs to collect and transmit data. These stations will need connectivity to serve as backups to edge communications, and therefore will need to be factored into next-generation infrastructure planning.

> "OEMs will want to collect and keep the car-related data to themselves in the hope of monetizing it in the B2B market, but so far the industry's capabilities to turn data into insight are limited."
>
> Major Automotive OEM

BUSINESS MODELS TO MONETIZE CASE

It is clear that CASE is already beginning to impact on how OEMs operate and generate revenue. As non-digital native companies, OEMs face challenges around moving from a stand-alone product to a platform mindset. Increasing the speed of innovation and harvesting data in the platform environment clashes with decades of rigid workflows, stable supply chains, and longer-term R&D and manufacturing planning.
Table 2 shows the potential for OEMs to adopt one of these business models as they evolve to CASE:

Table 2. Connected car business models: Potential to monetize value by market players [FTI market research]

			Potential to monetize by			
Revenue opportunities for connected cars	**Key enablers of growth**	**Market growth outlook**	**Traditional OEMs**	**New OEMs**	**Mobility platforms**	**OTT and service providers**
Vehicle sales	Car ownership, retail/ distribution channels	Low	High	High	Low	Low
Mobility as a Service (MaaS)	Tech platform, scale, strong end-user relationships	High	Med	Med	High	Low
Subscription services: Vehicle related	Access to data repair/road assistance partners	Medium	Med	Med	Med	High
B2B data sales	Quality data (richness and actuality), interoperability, compliance with regulation	High	Med-to-High	High	High	High
Subscription services: User related	Media content, strong UX, interoperability across devices, strong relationships with end users	High	Low-to-Med	Med	Med	High
Advertising	Connectivity, location-based analytics, user analytics	High	Low	Med	High	High

BUSINESS MODELS FOCUSED ON B2C

Pay as You Go (PAYG) and Mobility as a Service (MaaS)

The consumer shift from vehicle ownership to vehicle usage has given rise to new business models in vehicle sharing, ride hailing and carpooling. Current models (e.g., Uber, Lyft) offer simple demand-to-supply matching, plus analytics to optimize price. The number of interconnected players and the amount of data shared are relatively limited; however, the vision is that MaaS will extend to multiple modes of travel (e.g., on-demand public transport, bike sharing) and will be integrated with smart city infrastructure, offering additional services such as premium pricing for dedicated lanes and bundled subscriptions for door-to-door mobility.

Advertising model

A free-for-users advertising-based model (widely used by social media platforms, online publishers and app developers) can be a variation on PAYG MaaS. The ad model bundles data from user profiles and locations, provides touchpads for browsing and shopping during the journey, and offers options to optimize the route around seller promotions or shopping stops. It can also be targeted to rides in select city areas or journey times to fit with the target demographics or advertisers' footprints (e.g., WaiveCar).

Subscription services (Vehicle and user related)

OEMs have had limited success with subscription services. They have lacked breakthroughs in their own R&D and face strong competition from technology, media and entertainment companies. As cars become increasingly software-defined, however, introducing customized plans for vehicle maintenance and over-the-air updates, assisted driving, in-drive concierge services, and fuel and energy management offers a path to OEMs to keep the car relevant to customers through its life cycle and offer revenue to market opportunities. This transition will have a direct impact on OEMs' IT infrastructure, requiring a scalable, secure and interconnected platform to process data and develop meaningful insights from millions of connected vehicles.

BUSINESS MODELS FOCUSED ON B2B

B2B sales of data (anonymized and/or shared with user consent) may also become a new revenue stream for OEMs and drive the development of a wider AutoTech ecosystem. Car users may benefit from new insurance policies, training of self-driving AI, and optimizing of city infrastructure as data is shared in this manner. Anything related to car performance and safety is unlikely to be shared by OEMs, **but generalized and aggregated data will become a valuable asset for monetization**. To get there, clarity and a mutual understanding on data ownership must first be reached, given that the components and systems will come from multiple suppliers. Getting explicit user consent for data sharing in the initial car sale agreement is an emerging practice, but the amount of data, marketplace size, and success of Google and Facebook, who have built walled gardens for their platforms, makes B2B data an interesting place to watch.

These new business models will have profound implications on how IT infrastructure is designed. The next sections delve deeper into these implications.

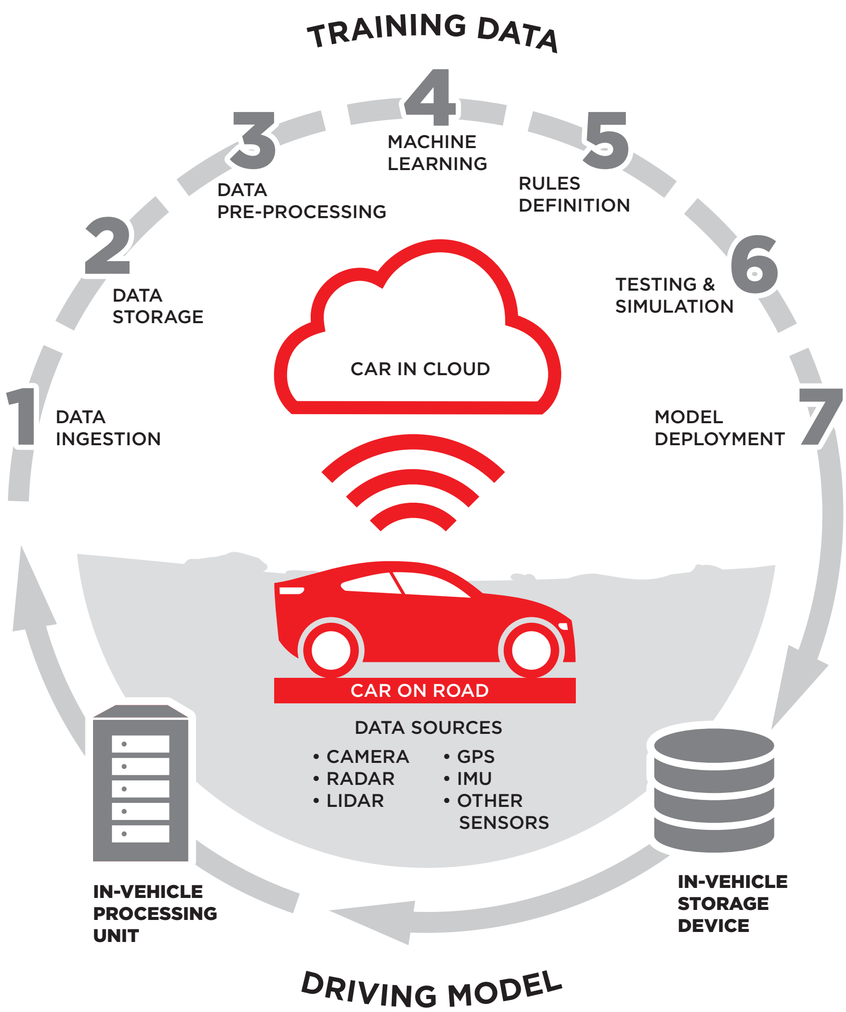

Figure 4. New business model data flows

THE CAR IS THE NEW DIGITAL EDGE

As mentioned, OEMs will likely want to maintain ownership of all data related to critical car systems. Any personally identifiable or safety-critical data (70%–90% of data) will be processed at the decentralized edge—meaning on the vehicles themselves—and in real time to minimize latency and comply with data privacy requirements.

Deep learning and non-critical data processing, such as route optimization, can occur in edge data centers (EDCs), that provide data processing power via cloud or colocation typically in city centers, instead of in a centralized or remote location. This setup enables OEMs to reduce risk and solve compliance challenges by deploying and connecting security services and expanding security ecosystem connectivity in the EDCs.

DATA MONETIZATION & INFRASTRUCTURE

An OEM's choice of business model, along with regulatory and geopolitical constraints, are drivers for its data strategy and infrastructure requirements. Key considerations are what data is collected and its criticality, how to handle large data volumes, how frequently data changes, and how it is protected, analyzed, and stored.

If an OEM chooses to monetize data, infrastructure must be able to efficiently and cost-effectively filter data, move it where needed and as needed, and send it to the cloud when necessary. When data resides in the cloud, pulling it out of one cloud and sending it to another adds expense as cloud providers bill for every bit or byte downloaded from the cloud.

While data aggregation and networking have their own infrastructure requirements, those for compute and storage must also be considered. As CASE evolves, it is typically not realistic or cost-effective for OEMs to build private data centers all over the world, given the uncertainties around business models and revenue opportunities. A distributed digital infrastructure, incorporating hybrid and multicloud, can be a critical enabler here.

The "Car in Cloud" and "Car on Road" concepts illustrated in Figure 4 show the flow of data that will be required.

The Car in Cloud delivers critical deep learning capability while the Car on Road processes critical in-vehicle data.

"The autonomous vehicle will have to perform many more functions beyond driving (e.g., correctly recognizing passenger identities, using child locks for younger passengers, assisting passengers with limited mobility) and handle tons of safety-critical data in real time. The majority of data processing will be on the edge, while deep learning will be in the cloud."

Tier 1 Automotive Supplier

IT ARCHITECTURE FOR CASE-FOCUSED BUSINESS MODELS

The next section discusses the technology architecture required to support evolving CASE-focused business models.

As OEMs shift to CASE-focused business models, the underlying technology architecture will need to change, for example, to enable data flows. OEMs are grappling with these challenges and trade-offs. To help navigate the uncertainty, we illustrate below how, based on the IT stack and three use cases, different components of technology architecture will need to evolve.

The likely future stack enables services through governance, management and provisioning of workloads. These in turn are dependent upon a much more sophisticated approach to machine learning and data.

For example, functional safety data will be tightly controlled by OEMs and will reside in their data centers, while infotainment will likely follow the API-based route, allowing content and app providers to deploy content within the car. Data related to in-vehicle operation will be processed in the car, while data needed to develop an autonomous driving model will be processed outside the vehicle. OEMs will therefore need to be thoughtful about what gets processed and where.

The other major change we see is the redesign of the data center infrastructure as a result of massively increased R&D, automated manufacturing and the harvesting of data from connected cars. Some OEMs have announced plans to build their own data centers (e.g., BMW, Ford),[12][13] but as a general trend, automotive CIOs are diverting spend away from infrastructure in favor of outsourced solutions. For example, BMW chose IBM Cloud for its CarData platform, and Toyota partnered with NTT to build a global network for connected car data centers.[14]

Today, auto industry participants rely on network attached storage (NAS) distributed around the globe to store data (i.e., “data at rest” in the data life cycle). Given the sheer volume, variety, velocity and veracity of data in the autonomous test environment, this approach will likely reach its limits. Data management will become more complex at the edge, and it will need to be optimized to create separate data sets for monetization. Cost, scale and performance constraints will soon surface as test fleet data consume conventional storage infrastructure. Therefore, companies testing autonomous vehicles will need to look for alternative solutions such as edge infrastructure to improve efficiencies and contain costs.

USER INTERFACE AND SERVICES

Security overlay
Workload governance
Workload management
Workload provisioning

WORKLOADS

Use cases
Machine learning
Data life cycle

COMPUTE

CPU
GPU
Memory

STORAGE

Traditional
Software defined
NAS

NETWORKING

Virtual Network Functions (VNF)
IP - VPN
Ethernet
Software defined
ITE, 5G

Figure 5. Likely Future Stack

Even as data at rest becomes an infrastructure issue, data in motion presents additional, more complex infrastructure issues. Autonomous test fleets ideally should be colocated with infrastructure where they can be locally trained and aligned with conditions and regulations in those geographies. Huge data volumes must also be moved to geographically dispersed workstations where engineers can develop, test, create and train new models. This data interchange consumes network, storage and compute resources at an unprecedented rate. It requires companies to rethink their infrastructure investments as on-premises data center and public cloud can add cost and inefficiencies to vehicle testing and validation. Colocation at the edge generally can provide a "sweet spot" here, as it optimizes for cost, performance, speed of development and agility.

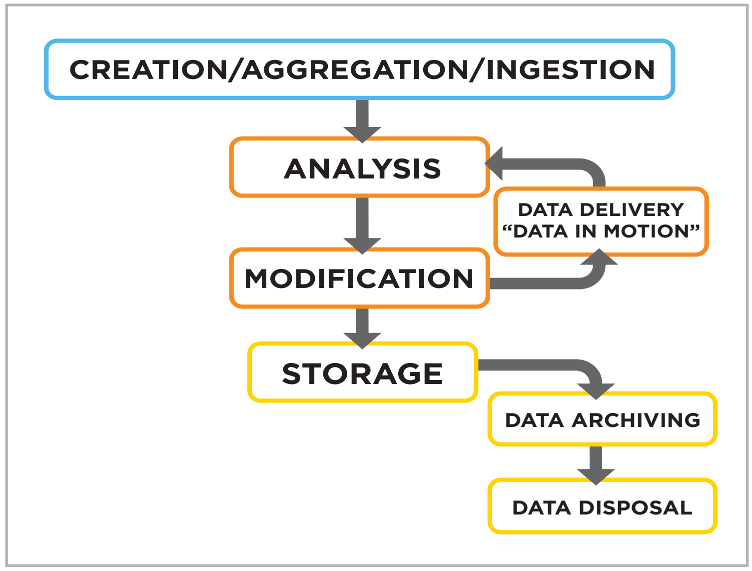

Figure 6. Data life cycle

However decentralized the data and infrastructure, governance, security, and privacy across the data life cycle need to be centralized to allow adequate data control plus accurate logging, monitoring and reporting. Governance policies and management of privileges, traceability and audit trails must also be centralized. This is much harder to do with fractured data footprints across multiple clouds, on-premises, etc.

There are also cases where features such as automatic braking or lane changing are developed by different teams located across multiple geographies. These applications need to access the same data; therefore, data quality, integrity, synchronization and availability are critical. Perhaps it is time to think of a one-stop shop with optimized infrastructure at the edge.

At the connectivity level, we expect to see a hybrid cloud approach with distributed nodes to provide latency, privacy, and safety and to comply with geography-specific data protection requirements. Dynamic and multiprotocol networking (wifi, cellular, LoraWAN, fiber and others) will also likely be an integrated part of the infrastructure.

The use cases in the next few sections illustrate the potential impact on the stack as CASE continues to evolve.

USE CASE 1: PREDICTIVE MAINTENANCE

As discussed earlier in this paper, connectivity is increasingly part of vehicle design for vehicle management, safety, navigation, autonomous driving, communication, and entertainment. Between 60% and 80% of cars sold in 2017 included OEM-installed telematics, which combine IoT with machine learning/AI for condition monitoring and predictive maintenance.[15] Multiple sensors in these vehicles monitor engine performance, transmission and exhaust system conditions, tire pressure and oil levels. These sensors will need to evolve considerably to support predictive maintenance.

Additional smart systems track weather conditions and vehicle location. Sensor and system data are aggregated and transmitted for analysis by a service provider, which can then trigger appropriate follow-up steps.

Condition monitoring and predictive maintenance can help consumers and fleet managers avoid unplanned vehicle downtime as well as offer insights into parts usage and wear. For instance, data about road conditions, tires and brake systems transmitted to the OEM can be analyzed in real time (as in GM's On-Star or BMW's Connected Drive solutions) and a simple message sent to the driver, via text or in-car alert, stating "Brake maintenance required in 30 days." Reminders can be sent if the driver does not take action within the prescribed time frame.

Condition monitoring has the potential to generate 600 MB per day per car,[16] according to our industry interviews. As more vehicles are delivered with condition monitoring and predictive maintenance capabilities, the large quantities of data produced in real time will require that **OEMs proactively manage the data life cycle (Figure 6) to unlock value and leverage opportunities.**

OEMs should start by understanding which data types must be collected, aggregated and ingested, and seek to ensure compliance with privacy laws throughout the life cycle.

Data value increases as it is analyzed and enriched with other data, creating predictive insights. With the brake failure example above, the combination of sensor and system data enables valuable insight into the time left before the car's brakes will fail. Further, when insights from hundreds or thousands of individual vehicles are aggregated and synthesized with high-performance computing capabilities in a hyperscaled cloud or colocation environment, the OEMs can monetize these insights, sharing them with parts manufacturers, insurance companies and others in the ecosystem.

Global engineering solutions company chooses Platform Equinix® to deploy near-real-time analytics tools for predictive maintenance services for internet of trains

German company Siemens AG (annual revenue of 75 billion euros) has launched the internet of trains to offer predictive maintenance services alongside the sales of trains. Siemens remotely monitors diagnostic sensor data in near real time to predict when a train component is likely to fail, so it can be repaired preemptively. Siemens partnered with Teradata for Aster Discovery Platform's range of analytic tools, deployed on Platform Equinix. Platform Equinix has been chosen for a direct and secure interconnection with leading network and cloud providers via Equinix Cross Connect and Equinix Cloud Exchange Fabric™, as well as for scalability, reliability and optimized automation. The benefits of predictive maintenance have enabled Siemens to revolutionize its pricing model by enabling uptime guarantees, risk-sharing models and performance-based contracts for mobility. The results from Spanish railway company Renfe, for example, for using Siemens' predictive maintenance services are that only one of 2,300 journeys has been delayed by more than 5 minutes.

USE CASE 2: FLEET MANAGEMENT

Although fleets can range in size from just a handful of vans for a small security-alarm firm, to thousands of big rigs operated by a long-haul transporter, all fleet operators face the same challenges: Where is my fleet located right now? Where are vehicles needed? How can I optimize fleet operations to improve productivity and reduce costs?

IoT sensors embedded in fleet vehicles are now enabling fleet managers to capture and analyze data via predictive analytics for driver behavior, maintenance, fuel efficiency, route planning and more. With better route management, fuel consumption optimization, increased safety, driver performance management and vehicle maintenance, managers are positioned to reduce the total cost of fleet ownership.

Incorporating IoT for any size fleet requires connectivity to a software platform and a data architecture that can handle large quantities of data generated from many endpoints. This data needs to be aggregated, processed and stored at the edge where it has been collected or created, to support seamless, real-time data transfer and quick decisions for instant improvements.

Actionable insights can be gained from deeper learning in the cloud. For instance, when one package-delivery company analyzed fleet data and added vehicle accident data, it realized more traffic accidents occurred when its vehicles made left turns. Optimizing route planning software to avoid left turns—even if it meant vehicles traveled several miles out of the way—resulted in fewer traffic accidents and lowered costs.

Interconnection that links IoT assets with multiple big data platforms and data users/points of action is becoming critical to smart fleet management. Agile and secure, interconnection brings commercially viable, high-power processing capabilities to the autotech ecosystem.

Ride-hailing company relies on fast connectivity to enhance customer experience, drive revenue growth and operational efficiencies

Grab Taxi, a born-in-the-cloud ride-hailing company, is based in 132 cities in Southeast Asia. When its fleet tripled in under a year, the company found it increasingly difficult to map drivers to customer locations in real time. Data management company iguazio teamed with Equinix and AWS to offer Grab a more modern data architecture for real-time reporting and analytics. By working out of Equinix International Business Exchange™ (IBX®) data centers, iguazio leveraged fast connectivity to cloud service providers and delivered its secure Unified Data Platform. This approach enabled Grab to deploy its continuous analytics at the edge, in near real time, to ingest and analyze large and varied data sources such as fuel consumption, vehicle location and road conditions. The result: with real-time heat maps of vehicle locations and peak pricing capabilities, Grab can now deliver a more seamless door-to-door transport service with improved operational efficiencies.

USE CASE 3: AUTONOMOUS DRIVING TEST ENVIRONMENTS

As OEMs and tech companies develop autonomous vehicles over the next few years, they will subject driverless prototypes to stringent and repeated testing across multiple geographies and physical environments. Deep learning and prototype validation will come from exploiting the data life cycle: collecting, analyzing, storing, processing and archiving data for attributes including vehicle location, road and weather conditions, anomalies and more. In the early stages, all data will need to be collected and analyzed; however, the challenge of data collection, transfer and analysis requires attention to connectivity, compute and storage infrastructure. As the algorithms associated with navigation, safety, comfort and so on improve, there may be a reduced requirement for collecting and analyzing as much data.

IMPLICATIONS FOR THE IT STACK

Use Case 1 has profound implications for in-car sensors and analytics of the measurements. For example, tire sensors will need to evolve from measuring tire pressure to measuring tire health, including, for example, tire tread. The data generated by these sensors will need to be analyzed on board as well as in the cloud, using high-performance computing (HPC) to create and amend complex, multidimensional algorithms. HPC used to be a domain of specialists and require expensive equipment, but technology advances have brought to market a cost-effective commoditized infrastructure that provides scalable storage and high bandwidth for any organization. Dell EMC, for example, has launched Ready Solutions—an end-to-end portfolio of HPC technologies to support engineering and analytics workflows; it is aimed at small and medium enterprises.

An increase in the number of ecosystem players, exchanging data and moving it across cloud environments, will also have a profound impact on the security overlay, and in particular on data encryption. Solutions based on separating key management from data management, enabling the players to build their own digital vaults and generate and manage keys in a way that only they can access, enhance key security while data is at rest, in transit and while it is being used. An example of that technology is Equinix SmartKey™, available in Equinix data centers with public cloud providers and select SaaS providers. SmartKey is a hardware security module that keeps the encryption keys close to where they are needed and allows customers to use a single platform for all keys, no matter what the cloud platform is, including on-premises.

Use Case 2, with its requirement for deeper learning in the cloud and real-time notifications, will place even greater requirements on technology across the stack.

Testing of autonomous driving (Use Case 3) will require an extensive upgrade across the stack. With each car generating an estimated 8 to 10 TB of data each day, all subject to machine learning, OEMs and suppliers will need an agile, flexible infrastructure for data processing, analysis and deployment of updates as they work to enhance vehicle safety and autonomous performance to constantly increase safety and autonomy performance.

USE CASE 1: PREDICTIVE MAINTENANCE	**USE CASE 2: FLEET MANAGEMENT**	**USE CASE 3: AUTONOMOUS DRIVING TEST**
USER INTERFACE & SERVICES	**USER INTERFACE & SERVICES**	**USER INTERFACE & SERVICES**
Security overlay Workload governance Workload management Workload provisioning	Security overlay Workload governance Workload management Workload provisioning	Security overlay Workload governance Workload management Workload provisioning
WORKLOADS	**WORKLOADS**	**WORKLOADS**
Use cases Machine learning Data life cycle	Use cases Machine learning Data life cycle	Use cases Machine learning Data life cycle
COMPUTE	**COMPUTE**	**COMPUTE**
In-car CPU, GPU & memory	CPU, GPU & memory	CPU, GPU & memory
STORAGE	**STORAGE**	**STORAGE**
Traditional, software defined, NAS	Traditional, software defined, NAS	Traditional, software defined, NAS
NETWORKING	**NETWORKING**	**NETWORKING**
IP-VPN, Ethernet, Software defined, LTE, 5G	IP-VPN, Ethernet, Software defined, LTE, 5G	IP-VPN, Ethernet, Software defined, LTE, 5G
PHYSICAL CAPABILITY	**PHYSICAL CAPABILITY**	**PHYSICAL CAPABILITY**
On-premises, colocation hybrid/TAAS, public cloud	On-premises, colocation hybrid/TAAS, public cloud	On-premises, colocation hybrid/TAAS, public cloud

FUNCTIONAL IMPACT **VOLUME IMPACT**

ADOPTING DIGITAL INFRASTRUCTURE IS KEY TO UNLOCKING VALUE

The use cases presented in this paper are not just IT problems—they touch on a company's business model, system architecture and IT, plus regulatory and geopolitical constraints, and are complex to solve. While it may be tempting to leave infrastructure decisions to the back of the queue, such an approach exposes OEMs to a potentially uncontrollable and demanding cost structure. Digital infrastructure is key to gaining valuable insights in the data life cycle and expanding business opportunities in the evolving auto industry.

OEMs should seek to unlock the following benefits as they evolve their technology infrastructure to support new services:

- **Leverage a true hybrid cloud.** Off-load critical data and analytics through API gateways and private connectivity to cloud providers to enable agility and flexibility.
- **Eliminate vendor lock-in**. Avoid proprietary APIs that can compromise quality and cost-efficiency, leading to vendor lock-in.
- **Identify your digital supply chain.** Determine the partners with which you expect to share the most data and provide open platforms for third-party access for future ecosystem partners.
- **Ensure data integrity with fine-grained security.** Multilayered access and life cycle policies help you control data access, implement backups, import/export content and guarantee compliance.
- **Build in connectivity.** Develop flexible network infrastructure to transfer data to and from vehicles and across software platforms or clouds.
- **Empower real-time insights.** Run data services requiring fast responses on dedicated platforms; non-critical data services can be run in the cloud.
- **Ensure compliance.** Use the edge thoughtfully to satisfy local data regulations.
- **Deploy in a timely fashion.** Use combinations of public cloud for development and testing, plus on-premises environments for production workloads. The architecture should support scalability around the globe as needed.

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