Capgemini engineering

AUTONOMOUS DRIVING

How to overcome the five main technology challenges

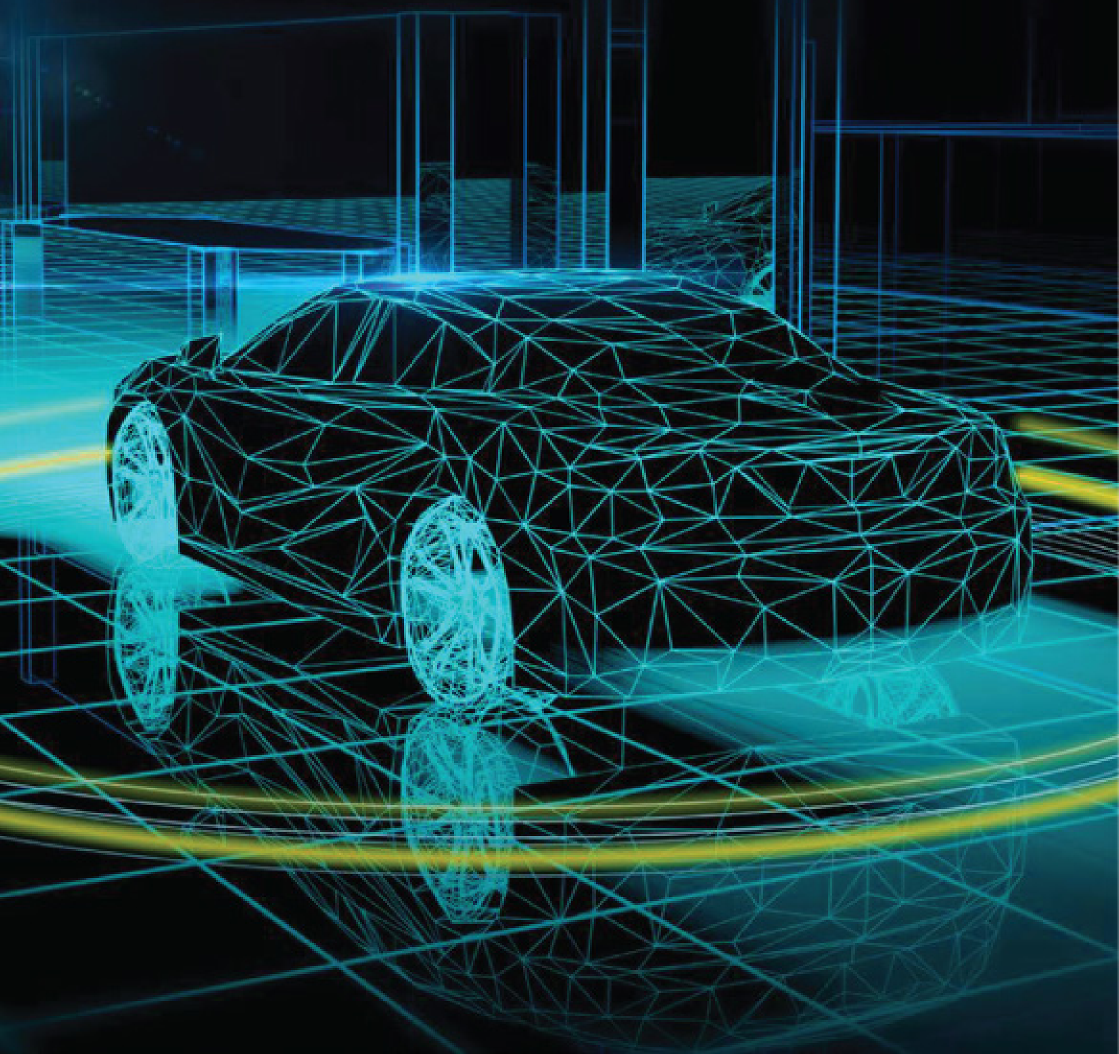


Table of contents

$60 billion

Is the autonomous car market size forecast in 2030 vs. $5.7 billion in 2018, with a CAGR of 21.7%

$17.5 billion

Is the full automation car market by 2030

18% CAGR

Is the expected growth of the global autonomous and driverless car market during 2020–2025

220 million

Is the total number of connected vehicles by 2020 (vs. 48 million in 2016)

Introduction

Autonomous vehicles – whether for personal transport or freight delivery – could offer a potentially enormous disruption to life, business, and society. The possible benefits, such as reductions in accidents arising from human error, reduced cost and environmental impact of transport, liberation of time currently committed to driving, and accessibility to a wider range of users, are all theoretically addressable.

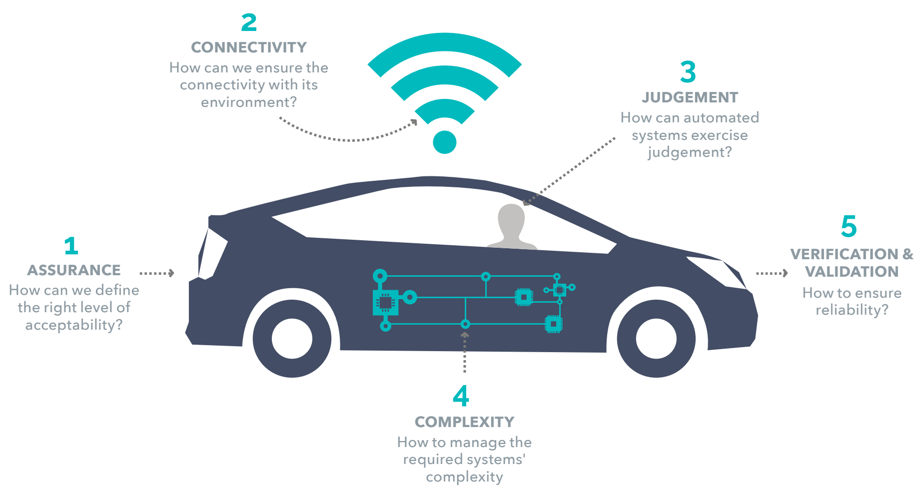
To achieve this, the following key challenges must be overcome:

- **Assurance of systems and software:** how can we define and demonstrate the right level of acceptability?
- **Sensing and connectivity:** how can we ensure the right relationship between a vehicle and its environment?
- **Judgment:** how can automated systems exercise judgment?
- **Architectures for managing complexity:** how can we manage the resulting system complexity?
- **Verification and validation:** how much testing do we need, and how can we achieve it?

Based on this market context and analysis, a number of implications and approaches to overcome these challenges can be considered:

- **The ultimate acceptability of autonomous vehicles** will be a societal and political decision. Consequently, those involved have a duty to be transparent about their choices and the rationales. Assurance in the sense used by other regulated industries will, in any case, be difficult to obtain
- **The complexity of the driving environment** will demand both new sensors and new communications channels, and also increasingly sophisticated approaches to capture and interpret information
- **The implementation of decision-making processes** must consider:
  - An appropriate division of responsibility between operators, manufacturers, and other parties, based on clear technical requirements instead of abstract goals
  - The ability to correct and update decision-making policies over time
  - The role of human-machine interactions will require user-centered design approaches to be adopted
- Autonomous systems will tend to high complexity, and architectural methods will be needed to keep costs manageable, and to make safety assurance plausible

- Whatever assurance targets are set, the complexity of vehicles and their environment will make testing challenging, so:
  - Test approaches capable of supporting massive and well characterized test programs are needed
  - Evidence gathered from a wide range of assurance methods (not only dynamic testing) will need to be used
- In addition, this technological domain is changing rapidly. Companies and governments will need to invest to track emerging technology trends



Motivation to move toward autonomous vehicles

Looking at the next generation of cars, we notice a wide range of motivations for the move to autonomous vehicles, and a potentially enormous disruption to life, business, and society. Possible benefits are all theoretically addressable, and initial demonstrations and experiments (from traditional OEMs and technology companies) are encouraging.

A reduction in road traffic casualties
According to the World Health Organization, a specialized agency of the United Nations, the number of road traffic deaths worldwide hit 1.35 million every year, not including injured or disabled people. Latest studies show that human error accounts for more than 90% of road fatalities, leaving high improvement opportunities for autonomous driving technologies. In particular, more than half of the road fatalities occur among pedestrians, cyclists, and motorcyclists.

Controlling for variables such as fatalities caused by car accidents could further show the potential of autonomous driving features. Although there is a lack of consistent global estimates, the WHO estimates that the cost of injuries is approximately 3% of a typical country's gross national product[1].

Reduction in social and environmental costs of driving
With as many as nine billion people predicted to live in urban areas within the next 25 years, automakers are under pressure to reduce the environmental and social impact of driving. The adoption of autonomous features in cars will lead to environmental benefits. Autonomous technologies have the potential to ease traffic flow by allowing optimized acceleration and deceleration, thus reducing fuel consumption and emissions, and to allow better arbitration of roads and parking to reduce their impact[2][3][4].

Changes in vehicle use may also bring benefits. Autonomy can facilitate vehicle sharing, and for each car-sharing vehicle on the streets, more than 20 vehicle sales are forecast to be deferred. For higher speed journeys, benefits could ultimately be derived from technologies that allow vehicles to follow each other closely (platooning), reducing aerodynamic drag by 20-60%.

1. World Health Organization, 2015, available from: www.who.int/violence_injury_prevention/road_safety_status/2015/en/
2. Traffic Safety Store, 'Driving Vehicle Automation Forward', 2016, available from: www.trafficsafetystore.com/blog/autonomous-cars-environmental-impact/
3. Rand Corporation, 'Autonomous Vehicle Technology', 2014, available from: www.rand.org/content/dam/rand/pubs/research_briefs/RB9700/RB9755/RAND_RB9755.pdf
4. Inrix, 'Cost of Congestion', 2015, available from: www.inrix.com/wp-content/uploads/2015/08/Whitepaper_Cebr-Cost-of-Congestion.pdf

Economic benefits of making travel time productive
In its blue paper about autonomous cars, Morgan Stanley states driverless cars could contribute $1.3 trillion in annual savings to the US economy alone and $5.6 trillion in global advantages. Focusing on productivity, the paper further suggests that gains would come to $507 billion annually in the US. Such benefits accrue to consumers who experience a transformation in the ease at which they can travel, which in turn generates wider economic benefits[5][6].

Potential improvements of access to mobility
While driverless technologies are being implemented first in luxury segments, once fully autonomous cars are available, significant improvements will be held in access to mobility. Such technologies will in fact act as key enablers for people with physical limitations, the young, and the (increasingly numerous) elderly. A UK study shows that about 1.45 million people are facing mobility issues and that is only taking into account those over 65 years old and in England alone[7].

But what challenges must be overcome to achieve this vision? Is our technology, and the industries that support it, able to achieve these benefits?

5. Morgan Stanley, 'Autonomous Cars: The Future Is Now', available from: www.morganstanley.com/articles/autonomous-cars-the-future-is-now
6. Forbes, 'The Massive Economic Benefits Of Self-Driving Cars', 2014, available from: www.forbes.com/sites/modeledbehavior/2014/11/08/the-massive-economic-benefits-of-self-drivingcars/#1d2e263968d9
7. The Telegraph, 'How driverless cars could revolutionise old age', 2015, available from: www.telegraph.co.uk/news/uknews/road-and-rail-transport/11684562/How-driverlesscars-could-revolutionise-old-age.html

Challenge 1: assurance of systems and software

How can we define and demonstrate the right level of acceptability?

Assurance (n): a positive declaration intended to give confidence
oxforddictionaries.com

In order to produce or operate an autonomous vehicle, we must provide a range of stakeholders with assurance that the vehicle will operate safely. This is no different from the principles that apply to manually-controlled vehicles or to any other system we deploy. But, can we construct and maintain systems (across a potentially large vehicle population) that give us necessary confidence in their operation?
What criteria will determine the acceptability of autonomous operation? How can confidence be maintained in the face of malicious activity?

Safety

The process of providing this confidence shares many factors with existing systems and vehicles:

The difficulty of bounding responsibility
Safety applies to a road system, not a car. Safety cannot be measured directly, only judged from the examination of dynamic interactions between components and effects outside the system boundary.

The difficulty of characterizing the environment
There are features of day-to-day driving that will be difficult to characterize for development or to replicate for testing: temporary infringement of traffic laws, snow on road markings, hand signals from police officers at an accident, and other everyday "black swan" situations.

But there are also factors specific to autonomous road vehicles.
Automotive transport is much less regulated (and quantitatively less safe) than other environments such as rail or aviation.
The road system is also already prone to single-point failures, that is, misbehavior of a single vehicle or pedestrian.

- Autonomous vehicles will make mistakes that are different from those humans make because they sense the environment differently. This has implications both for the vehicle itself, as the design must not simply seek to replicate human behavior, and for other road users whose safety may be jeopardized by the presence of entities that don't respond as expected

- Functions that replace the driver in certain situations, but which must be replaced by the driver in situations they cannot handle, raise the question of why the (uninvolved) driver will be effective once the automation becomes ineffective. Automation will reduce driver attention to hazards. Control cannot be returned to the driver instantaneously, unless there is look-ahead prediction that detects a difficult situation and can alert the supervising human in good time, without triggering a panic (over)reaction

The current regulatory framework for road vehicles, exemplified by the UNECE Transport Regulations and ISO 26262:2011, is not intended to address such issues and is likely to need substantial evolution in order to do so. There is a risk that shifts some responsibility from the driver of a manually driven vehicle to the manufacturer of an autonomous vehicle – which may well need legal and administrative changes – and trigger an over-reaction, resulting in setting impossibly high standards compared to human drivers.

Security

Security is an emergent property of a system in a changing environment and we believe this can only be addressed by a combination of approaches.

Security is a particular concern with computer-based systems and underlies any other aspect of assurance. If a system is open to malicious modification, no other behavior can be relied upon.

Attention will be paid to autonomous vehicles, both by potential attackers and those attempting to maintain security, because the potential impact of a risk – perhaps even multiple simultaneous failures across a whole vehicle fleet – could be so great. The likelihood that autonomous vehicles will be networked presents two further aspects: connection to offboard computer facilities (or the cloud) opens new vectors of attack, but also enables cloud-based behavioral monitoring of the vehicle fleet that can identify malicious activities early.

A set of principles we have found useful elsewhere[8] is:

- **Know your enemies:** understand the security risks posed by a system and form a comprehensive policy to deal with them

- **Take security to the edge:** address security from end devices to central services, and from initialization to disposal

- **Know who you're talking to:** understand the identities, roles, and authorizations of people and equipment. Address the provisioning of new identities, maintenance, change of ownership, and withdrawal of trust

- **Create a strong network:** ensure communications are resilient and resistant to attack

- **Don't trust it, watch it:** monitor behavior for signs of attack, don't rely on fixed defences. Use SIEM (security information and event management) techniques including advanced analytics

- **Build it right:** minimize the vulnerabilities exposed to an attacker. Use security-oriented architecture, separation of security domains, highly-assured software and hardware components, and generate assurance evidence during development

- **Base on firm foundations:** use trustworthy services for communications, computation, storage, and management

8. Capgemini Engineering, 'Seven principles for achieving security and privacy in a world of Machine-Driven Big Data', 2016, available from: https://capgemini-engineering.com/as-content/uploads/sites/5/2017/05/seven-principles-for-achieving-security-and-privacy-in-a-world-of-machine-driven-big-data_-white-paper.pdf

Challenge 2: sensing and connectivity

How can we ensure the right relationship between a vehicle and its environment?

How can autonomous vehicles gain sufficient information on their environment to operate efficiently and safely under all circumstances? What sensors, and what analytics applied to sensor data, will be required? What communications channels – vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) – will be used? How can external data be used? How do we manage transient connectivity?

Vehicle sensors

The process of providing this confidence shares many factors with existing systems and vehicles:

The difficulty of bounding responsibility
Safety applies to a road system, not a car. Safety cannot be measured directly, only judged from the examination of dynamic interactions between components and effects outside the system boundary.

The difficulty of characterizing the environment
There are features of day-to-day driving that will be difficult to characterize for development or to replicate for testing: temporary infringement of traffic laws, snow on road markings, hand signals from police officers at an accident, and other everyday "black swan" situations.

But there are also factors specific to autonomous road vehicles.
Automotive transport is much less regulated (and quantitatively less safe) than other environments such as rail or aviation. The road system is also already prone to single-point failures, that is, misbehavior of a single vehicle or pedestrian.

The role of communication

Direct sensing represents the simplest, but not the only, means for a vehicle to build a model of its environment. It may also directly receive environmental information via wireless communications channels. These channels may be established between vehicles – vehicle-to-vehicle (V2V) – or between a vehicle and fixed infrastructure – vehicle-to-infrastructure (V2I). Possible applications include:

- Signaling of presence and planned behavior between vehicles (radio brake lights)
- Sharing of environmental information among local users via V2V communication (e.g., stationary traffic or icing warnings)
- Warning and control information distributed by V2I channels (radio traffic lights and road signs)

The major challenge regarding such systems is the level of dependence which can be placed on communications systems in implementing safety-related functions. Although V2X technology has been developed and standard promulgated, there are limits to the assurance that can be established for radio communications, particularly with (or between) rapidly moving vehicles, limiting their applicability for safety-critical functionality. Nevertheless, if the travel efficiency benefits of autonomous vehicles (or even of advanced driver information systems) are to be realized, a level of information must be shared in real-time, although whether this is through automotive-specific V2V or V2I technologies or simply over standard mobile (3G/4G/5G) networks is open to question.

The role of analytics

Successful designs will make the greatest possible use of the data available from their sensor suites. Signal processing and analytics in support of sensor interpretation will be key technologies. Examples include:

- Sensor fusion to take advantage of multiple input sources
- Vision processing for the extraction of road features and signage
- Object recognition, and even intent recognition[9], to facilitate accident avoidance and to improve trajectory and maneuver planning and execution

The techniques, such as machine learning, used to achieve these results are computationally intensive and difficult to verify by traditional means. Bringing such systems into mass production will require advances in both implementation and verification.

9. KIT, 'Pedestrian intention recognition for active safety systems' available from: www.mrt.kit.edu/mitarbeiter_3269.php

Challenge 3: judgment

How can automated systems exercise judgment?

How can autonomous vehicles be constructed to manage the often conflicting expectations placed on them? Can algorithms make the subjective and ethical decisions required of human drivers? How can externally defined policies be communicated, validated, and updated? How will humans, inside and outside a vehicle, interact with it? How must user experiences change to adapt to autonomy?

Decision-making

A significant amount of discussion[10][11] has been published about the apparent need for autonomous vehicles to make ethical judgements about the consequences of particular actions, even extending to surveys[12] of public attitudes.

Autonomous function certainly changes some aspects of responsibility and liability compared to manual driving – actions such as choosing an appropriate speed for prevailing conditions, which are the sole responsibility of a human driver in a manually driven vehicle become behaviors of a product that has a manufacturer, a designer, a vendor, and an operator. The legal and commercial aspects of this change are beyond the scope of this paper, but the expectations raised about decision-making functionality cannot be ignored.

We can argue that this discussion is of little practical relevance because the decisions taken during the design of autonomous vehicles are not expressed at a level where human interpretations are possible. Many other products with potentially lethal consequences are regularly used without such concerns being raised, nor are questions of moral philosophy often included in driving tests.

The challenge of defining and quantifying autonomous vehicle behavior may stem from the variability and complexity of the situations in which decision-making will be required and the numerous and frequent exposure of people to the consequences of those decisions that will arise if autonomous vehicles are widely deployed. In May 2016, Tesla already reported 780 million miles driven in vehicles equipped with their autopilot hardware, and 100 million miles driven with autopilot active[13].

10. UVA Public People Search, available from: www.people.virginia.edu/~njg2q/ethics.pdf
11. Driverless Future, 'Top misconceptions of autonomous cars and self-driving vehicles', 2017, available from: https://www.driverless-future.com/?page_id=774#ethical-judgements
12. Jean-François Bonnefon, Azim Shariff, and Iyad Rahwan, 'The social dilemma of autonomous vehicles', 2016, Science: Vol. 352, Issue 6293, pp. 1573-1576
13. Electrek, 'Tesla reveals new details of its Autopilot program: 780M miles of data, 100M miles driven and more', 2016, available from: www.electrek.co/2016/05/24/tesla-autopilot-miles-data/

In complex and ill-characterized road environments, both the algorithms adopted and the measures used to assess them will be statistical rather than entirely absolute in nature. This contrasts with other domains where, for example, railway control systems may be protected by interlocking systems with binary (on/off) specifications and implementations, or aviation, where substantial effort is spent in verifying control systems against precise abstract specifications, and the operational environment is rigorously controlled by highly-trained and monitored staff (both pilots and air traffic controllers).

The implications of the consequential growth in both test demands and available test data are considered further below.

Implementation technologies for autonomous vehicles are focused more on empirical observation of driving environments and decisions using techniques such as machine learning, where machine states and actions are characterized and models are trained by assigning rewards or costs for the system being in certain states.

While individual parts of such systems can be expressed and validated in absolute terms, we can specify and test that a vehicle never drives through an obstacle that is adequately represented in its situational model. Absolute tests of overall system behavior that tie to real-world observations are unlikely to be feasible. Overall system behavior is more likely to be able to be validated statistically with tools such as confusion matrices or receiver operating characteristic (ROC) curves.

Data and change

Because they operate in a rich and changing environment, autonomous vehicles are likely to need configuration and reference data that is liable to change. The quality and maintenance of such data is crucial, as autonomous vehicles will be much more dependent on available data than manually-driven ones.

Some data (for example, traffic management policies in specific jurisdictions, or system configuration data) may be relatively limited in volume and be amenable to rigorous change control and regression test processes. Others, such as map and electronic horizon data (if used) will be of such volume and complexity that comprehensive testing will be difficult, and will be captured by processes that lack the stringent independent checks that are used for data preparation in other industries.

A defense-in-depth strategy, with mechanisms in place to detect potential errors in data by cross-checking with observation, would seem sensible.

Human interaction

Autonomous systems will radically change human interactions with vehicles, both for their users and potentially for third parties. Much of the interface functionality may be relatively standard (setting objectives, querying status, and progress) but a crucial new interaction will arise when the autonomous system needs to pass control back to a human operator. The question of whether this can be done at all, in an acceptably safe manner, is still controversial.

Particular concerns include:

- The time delay necessary to alert the driver from an eyes-off condition, and whether autonomous function can maintain vehicle safety for such a period
- How control can be transferred in a way that prevents sudden overreaction or panic on the part of the driver

A user-centred approach will be necessary to address such issues.

Challenge 4: architectures for managing complexity

How can we manage the resulting system complexity?

Numerous interacting functions controlled by distinct stakeholders must come together to achieve autonomous driving. Can the architectures of our systems manage the consequential level of complexity? How will the industry adapt to the era of the software defined vehicle?

The autonomous control of a vehicle implies a large number of cooperating functions. At a high level, these functions include:

1. An interface to an end user who needs to provide goals to the vehicle, including destination, preferred route characteristics, intermediate stops, and possibly a target arrival time
2. A navigation system capable of planning the appropriate route, determining position (against a map), and developing machine executable instructions to follow the route based on the current position in real time
3. An environmental perception system that determines the external situation, in particular threats and safety-related constraints (other vehicles, objects, pedestrians, etc.)
4. A vehicle context system that maintains a model of the vehicle state including speed, fuel levels, or health status
5. An active safety system capable of using available data from the environment and the vehicle context to plan maneuvers and ensure safe actions by the vehicle
6. A vehicle control system that can take instructions from the navigation system (run left/right, etc.), the vehicle and environment context, and with the permission of the active safety system, issue control commands to the vehicle actuators
7. Actuators that perform actions on the physical driving components (steering, powertrain, braking, etc.)
8. Sensors that provide data to the various systems

The entity that results from the integration of these functions will exhibit high levels of function intelligence, a large number of interaction paths, a very large potential state space, and will operate in a dynamic and evolving environment.

In taking the above in consideration, it should be evident that creating such a system presents a major challenge of dynamic complexity. Such complexity leads to several serious issues, notably the cost and time of integration, the challenges of testing, assurance, and data quality (discussed elsewhere), and the difficulties of ensuring adequate performance and confidence throughout the life of a product, which must be maintained and adapted over many years.

Traditional automotive architectures are based on considerations of functional domain, supply chain structure, and historical networking heritage. In reflecting this, a current vehicle is structured as a collection of electronic control units (ECUs) wired together by CAN. Each ECU generally covers a unique domain and comes from one supplier. Interactions between the ECUs are through the CAN telegram protocols. This approach is struggling with the rise in complexity represented by the move toward advanced ADAS and autonomy.

The fundamental driver in this evolution is the increase in software volume (>100M LOC) and the complexity involved in ensuring and proving that such a volume of software provides its functionality with appropriate performance and in the presence of constraints on power, BOM, supply chain, and timescales.

In the face of these issues the traditional architecture suffers from the following shortcomings:

- Ad hoc and diverse approaches to such things as life cycle, error management, thread priority management, and communications
- BOM inefficient approaches to peak CPU requirements
- Ad hoc and divergent data, and software interaction semantics
- Low-bandwidth networking
- Timing divergence
- Supplier lock-in and lack of modularity at a software level
- Inflexibility and extreme brittleness in system reconfiguration and reengineering

Addressing these problems requires a new architectural approach with the goal of satisfying the traditional needs of performance and BOM control with a direct attack on the problems raised by complexity.

Future architectures are likely to be based on a number of key strategies:

- **A rethink of the HW structure toward a more centralized compute resource** with more power available to be managed for peaks across functions: this approach also offers a significant reduction in weight and cabling complexity in the vehicle. The domain controller approach is an example of such a strategy
- **The introduction of mainstream IP based networking,** albeit with some specific extensions for determinacy, where required: this will serve to support mainstream development styles as well as adding bandwidth
- **The introduction of a flat data plane for all data access, including for video and audio:** this will enable data to be acquired by software in a near arbitrary manner and with fewer configuration issues
- **A stricter definition of citizenship for software elements:** this will imply that certain aspects of software behavior will be uniquely defined at syntax and semantics for all software. One example would be software life cycle where a specific and unique API would be enforced for all software elements
- **A support enforcement of location transparency in all software transactions:** this means that all software will interface to an underlying and transparent communication layer. This implies that software will not need to know the system topology for communication
- **Direct architecture support for security structures and technology:** this will allow security to be managed as a configuration activity during system integration and based on standard system elements
- **Direct architecture support for safety measures:** this will allow safety critical aspects of the system to be isolated and monitored in a standardized manner

The global change this represents for the architecture is that the vehicle hardware and the base software will present a unified feature platform for the whole vehicle and not just for an individual ECU. This change will support a more disciplined approach to system engineering while providing key approaches to tackling the complexities of the system.

Challenge 5: verification and validation

How much testing do we need, and how can we achieve it?

How can autonomous systems be tested to the levels of confidence required? What data sources, and what reference cases, will be required? How much testing will be needed? How can we validate systems incorporating learning?

Achieving acceptable levels of safety and assurance for an autonomous vehicle will clearly demand substantial verification and validation activities – and while there is clearly an advantage to be gained from static or mathematical methods such as modeling and simulation, a large element of dynamic testing will inevitably be required.

This will take place at several levels and at several points of the life cycle:

- **Concepts and algorithms** will be validated by testing models or simulations in representative environments
- **Software units** or model elements will be tested in isolation via software-in-the-loop or model-in-the-loop testing
- **Physical components** and their associated software will be tested as a unit via hardware-in-the-loop testing
- **Integrated systems** (up to and including whole vehicles) will be tested in laboratory environments, on test tracks, or in the field

The extent of testing necessary is subject to much debate. Software-based systems are inherently difficult to test due to the enormous number of different states they can adopt and their discontinuous nature, which means that behavior can vary widely even between closely-related states. This leads the system engineering community to be cautious about the value of enormous test campaigns, particularly if they focus on typical conditions. Scenarios that deliberately target adverse conditions may provide more evidence in support of assurance.

Quantitative attempts to estimate the distance that needs to be covered in order to establish safe operation have yielded targets in excess of 200 million km without fatal accidents for a fully-autonomous system[14].

14. Hermann Winner, Stephan Hakuli, Felix Lotz, and Christina Singer, 'Handbuch Fahrerassistenzsysteme', 2015

The complexity of the environment that ADAS and autonomous systems operate in also challenges verification and validation technology – the systems are using complex high-bandwidth sensors such as cameras, lidar, and radar, and are deriving information that needs to be checked against independent, high-quality, reference data. Data volumes can reach 15-30 terabytes per test day, and perhaps 10-20 petabytes for a complete vehicle test campaign. Using Cisco estimates for late 2016, this latter number represents 5-10 minutes of all the Internet Protocol traffic in the world[15].

Simply storing such data is a challenge, but interpreting and managing it takes us further:

- In order to manage testing, we need to identify scenarios of interest, and to ensure all such scenarios are covered – identifying such scenarios (e.g., left turn from a high-speed road in the USA in wet weather) from raw data is not trivial
- The desired behavior (the right outcome from a test, or ground truth) is also difficult to recognize. Existing practice depends on manual labeling of scenes and objects, but this is clearly a slow and expensive process, and impracticable for data volumes in the one million km range. Any technological solution, however, would risk having defects itself, which may mask faults in the system under test – at the very least an argument that the system under test and the test oracle used to check the results are independent

The presence of many interacting features and demands within a sophisticated ADAS or autonomous vehicle system also brings direct consequences for testing:

- Sensor fusion and centralized logic will increasingly be used to establish a view of the driving environment. The fusion algorithms themselves must be tested and verified against known scenarios
- Vehicle in the loop tests will gain importance as to test and verify complete functions in an augmented reality for the vehicle

Finally, but importantly, the verification and validation approach must match the processes increasingly being adopted to meet the time-to-market and agility required of the automotive industry. Model-based systems and software engineering, and increasingly virtual engineering, require the ability to switch effortlessly between physical and synthetic worlds, and to apply consistent test conditions and test results analysis in either case.

15. Cisco, available from: www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-indexvni/vni-hyperconnectivity-wp.html

Approaches to overcoming these challenges

Each of these challenges brings implications for the actions required to achieve autonomous vehicle adoption.

How can autonomous systems be tested to the levels of confidence required? What data sources, and what reference cases, will be required? How much testing will be needed? How can we validate systems incorporating learning?

Assurance of systems and software
The ultimate acceptability of autonomous vehicles will be a societal and political decision based on a balance of perceived risk and benefit, not a technical decision. Consequently, those involved have a duty to be transparent and open about the choices they make and the rationales for them.

Sensing and connectivity
The complexity of the driving environment and of the information required by autonomous driving will demand new sensors, new communications channels, and increasingly sophisticated mathematical approaches to capture and interpret the information required.

Judgment
Implementing decision-making processes mechanically is never easy, and autonomy in vehicles is no different from other cases in this respect. Development must consider:

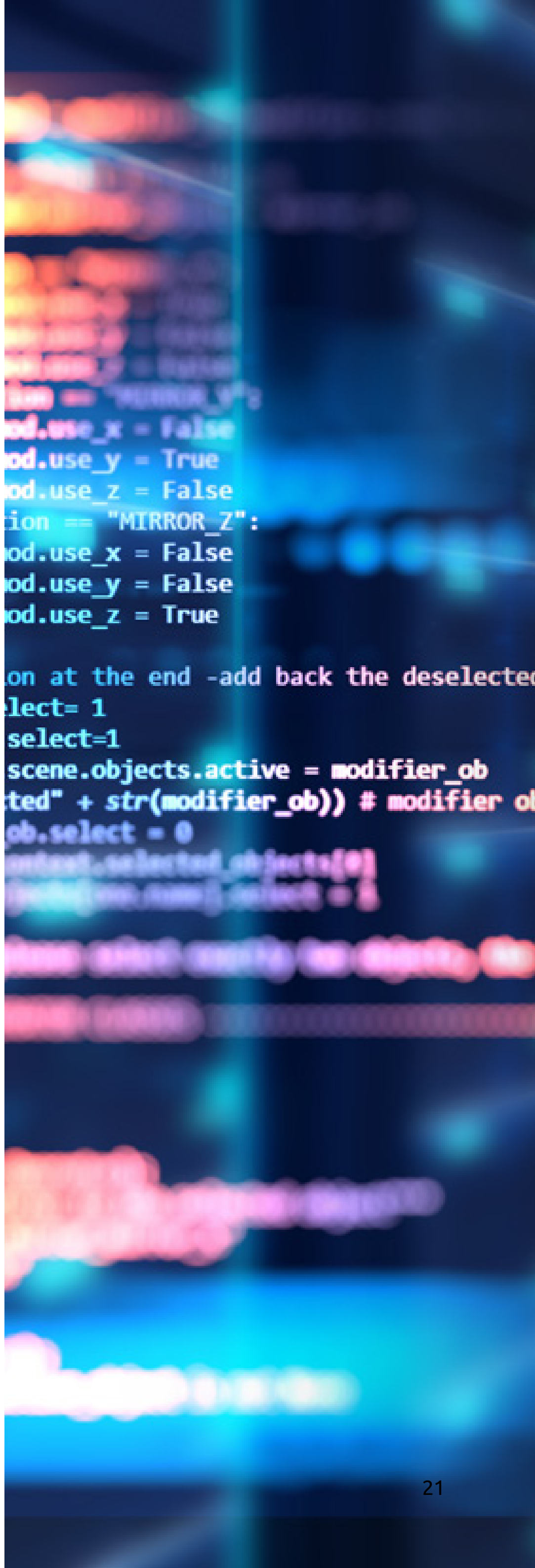
- An appropriate division of responsibility between operators, manufacturers, and other parties, which will ultimately require clear technical requirements to be placed on each, instead of abstract goals
- The ability to correct and update decision-making policies over time, requiring mechanisms to validate, deploy, and assure the integrity of new functionality and new datasets in service
- The role of human-machine interactions, which will be crucial to the efficiency and acceptability of autonomous vehicles, and will require user-centered design approaches

Complexity
Autonomous systems will tend to have high complexity and architectural methods will be needed to keep costs (especially integration costs) manageable, and to make safety assurance plausible.

Verification and validation
Whatever assurance targets are set, the complexity of vehicles and their environment will make testing challenging at a fundamental level:

- Test approaches capable of supporting massive and well characterized test programs are needed
- Evidence gathered from a wide range of assurance methods (not only dynamic testing) will need to be used

In addition, this technological domain is changing rapidly. Companies and governments will need to invest to track emerging technology trends, e.g., in sensing, machine learning, and test data management (a summary of some research initiatives is given in the Appendix).



The research agenda

Because of the potential public policy impacts of autonomous vehicles, significant effort is being committed to research by a variety of bodies.

Typical topics include:

- National test areas for driving (both a legal framework and necessary infrastructure)
- Areas for security testing of AVs
- Validation of complex systems
- H/M interaction

In particular, the EU Horizon 2020 program includes a number of topics under the heading of Automated Road Transport. The 2016-17 call includes:

- ART-01-2017: ICT infrastructure to enable the transition toward road transport automation
- ART-02-2016: automation pilots for passenger cars
- ART-03-2017: multi-brand platooning in real traffic conditions
- ART-04-2016: safety and end-user acceptance aspects of road automation in the transition period
- ART-05-2016: road infrastructure to support the transition to automation and the coexistence of conventional and automated vehicles on the same network
- ART-06-2016: coordination of activities in support of road automation
- ART-07-2017: full-scale demonstration of urban road transport automation

Representative of a typical national program is that in the UK, which includes[16]:

- Publishing a code of practice for testing driverless cars: www.gov.uk/government/publications/automated-vehicletechnologies-testing-code-of-practice
- Launching collaborative R&D activities and feasibility studies
- Establishing the Centre for Connected and Autonomous Vehicles (CCAV) to coordinate policy in this area

Similar policies and programs exist at the national level around the world, and in collaborative frameworks such as the EU ECSEL partnership.

16. Further details are available from enquiries@ccav.gov.uk

Capgemini Engineering and autonomous driving

The automotive world faces many changes: the emergence of new players, powertrain electrification, autonomous driving, and increasingly draconian environmental and safety regulations.

Capgemini Engineering joins its clients as an end-to-end technology integrator to accelerate these business transformations. We combine a unique set of capabilities to deliver customized, leading-edge solutions to the next generation of cars.

We provide:

- Fast development of feature concepts into operational prototypes ready for showcasing to the market and starting series development
- Test program savings using our VueForge® for ADAS verification solution, an end-to-end V&V service allowing the efficient generation of enriched validation data, the swift execution of tests and software module tests itself, and traceable analysis of test conditions and results
- Increased efficiency in the management of features delivery to start of production, including system and functional architecture, requirements specification, test specification, functional safety and security and HMI design, and supply chain management exploiting our established knowledge of tier 1 product lines

In particular, Capgemini Engineering has co-developed, with Jaguar Land Rover, an innovative open software solution, CoherenSE®, for enabling and accelerating advanced software-intensive features such as autonomous driving. CoherenSE® enables future vehicles to be updated and customized like smartphones today, but with automotive grade quality, safety, and cybersecurity built in.

Capgemini Engineering WCC Advanced Networks

It designs, integrates, and manages the introduction of new network technologies and addresses the entire network life cycle, i.e., from design to deployment and optimization, along with dedicated support for the transition to mature operations in three main offering streams: network consolidation and modernization, virtualization and software-defined networking, and transition to 5G.

In the transition to 5G stream, Capgemini Engineering WCC Advanced Networks is complementing the traditional value proposition to support telecom operators in entering the IoT cross-industry context with new methodologies, tools, and technologies aligned to envision 5G reality. In particular, for 5G network design, planning, and optimization (NPO), iNP&O is a dedicated offering to effectively introduce 5G radio coverage complementing the legacy radio engineering practice with parametrization and configuration to finally target the specific use case.

On the road to 5G, Capgemini Engineering will actively enable the communication and translation between telecom operators and industry, leveraging its expertise in multiple (connectable and connectivity-demanding) industries and sectors such as transportation, utilities, or health. Combined with its R&D efforts in crucial 5G technologies such as SDN/NFV, MEC, LPWAN RATs, or SON, Capgemini Engineering is well positioned to aid its clients journeying into unknown fields and contexts, from definition to validation of new use cases and services.

Author

Dr David Jackson
Technology and innovation director

Capgemini engineering

About Capgemini Engineering

Capgemini Engineering combines, under one brand, a unique set of strengths from across the Capgemini Group: the world leading engineering and R&D services of Altran – acquired by Capgemini in 2020 – and Capgemini's digital manufacturing expertise. With broad industry knowledge and cutting-edge technologies in digital and software, Capgemini Engineering supports the convergence of the physical and digital worlds. Combined with the capabilities of the rest of the Group, it helps clients to accelerate their journey towards Intelligent Industry. Capgemini Engineering has more than 52,000 engineer and scientist team members in over 30 countries across sectors including aeronautics, automotive, railways, communications, energy, life sciences, semiconductors, software & internet, space & defence, and consumer products.

For more information please visit:
www.capgemini-engineering.com

Contact us at:
engineering@capgemini.com