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Cars Are Moving Beyond Simple Automation

Car makers have gone beyond automation to create a new type of digital plant, which produces more than 100 million lines of code for each connected vehicle. This will change the way the industry works, moving from old practices and traditions to new requirements for specialized workers combined with new business models.

The digital transformation of the automotive industry exposes information technology security, commonly called *cybersecurity,* to new threats. Auto manufacturers face new challenges to protect connected cars and customers from hackers. In the past, what happened in your car usually stayed in your car. This is no longer the case. The influx of digital innovations, from infotainment connectivity to over-the-air (OTA) software updates, has turned cars into powerful high-tech gadgets. Although they bring significant value to customers, these changes also expose vehicles to the rougher side of digital innovation. Hackers and other shadow invaders are struggling to gain access to crucial electronic units and vehicle data, which can compromise critical security functions and customer privacy.

All of this leads to new transformative developments in the automotive industry. These developments can be summarized as follows:

THE DIGITAL TRANSFORMATION OF THE AUTOMOTIVE INDUSTRY EXPOSES INFORMATION TECHNOLOGY SECURITY, COMMONLY CALLED CYBERSECURITY.

- *Connectivity*: As a necessity demanded by users, connectivity is no longer a nice add-on. The new generation of drivers wants access to social media, music, and apps while in their vehicles. To meet these demands, car makers are producing vehicles that allow us to continue our social and professional life—and everything else—while driving. The constant need for connectivity pushes Wi-Fi into our personal and public cars. Auto manufacturers realize that they can no longer sell their current models without these connectivity features, prompting them to invest more. Now, all aspects of the factory are digitized to match consumer environments, which brings us to one of the next transformative trends.
- *Vehicular ad hoc networks (VANETs)*: A VANET is made up of groups of moving or stationary vehicles connected by a wireless network. Presently, its main use is to ensure the safety and comfort of drivers in automotive environments. This view is changing: VANETs are now considered infrastructure for intelligent transport systems with an increasing number of autonomous vehicles and for any activity that requires Internet connectivity in a smart city concept. In addition, VANETs allow onboard computers in predominantly stationary vehicles. For instance, vehicles parked at the same place can serve as resources for a mobile computing cloud with minimal assistance from the Internet infrastructure. The content vehicles generate and consume has local relevance in terms of time, space, and the agents involved—that is, producers and consumers. This information has local validity, finite spatial scope, an explicit lifetime, a set temporal interval, and local interest for relevant agents in a limited area around the vehicle. For example, information about a congested area on a highway will be relevant only for a specific portion of the road, at a specific time and just for nearby vehicles. Nonetheless, this powerful access and data exchange is very vulnerable to cyberattacks, and the data access should be secured and easy to use.
- *Protection and security*: New smart vehicles collect data about drivers, their destinations, routes,

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MANUFACTURERS UNDERSTAND THE IMPORTANCE OF SAFETY AND SECURITY AND ARE ALWAYS LOOKING FOR NEW DEVELOPMENTS.

traffic patterns, and so on. Car makers and software-development companies continue their work to establish levels of customer loyalty so that users are at the center of all efforts. The data are used to communicate and discover types of mobility services. However, connected software systems must be secured to protect consumer data. Manufacturers understand the importance of safety and security and are always looking for new developments. These widespread changes introduce new challenges, especially those related to security. However, the digital automotive revolution can overcome any challenge. The automotive industry is the second most data-driven industry in the world [2].

- *Predictive maintenance*: Internet of Things (IoT) connectivity is used to collect performance data, transferring such data to the cloud to monitor possible hardware or software misfunctions. After the information is processed, the driver will be notified and advised about any service needed to avoid incidents. Vehicle service has also been digitized; it now requires not only mechanical attention but also a qualified technician to maintain and update its software. Through remote service, live software updates will be possible. This predictive ability is particularly beneficial for the trucking industry. Sensor technologies and the IoT provide transport companies with the ability to monitor data, ensure truck safety, optimize fuel, and even monitor freight. Based on statistics, some of these system solutions have provided good results, improving the availability of trucks and predicting their failures with very high accuracy.

All of these developments are based on IoT connectivity and the emerging concept of an automotive IoT. The next major automotive developments will be based on the IoT, from simple software updates to vehicle feature enhancement that uses, for instance, IoT sensors for fleet management, automatic parking, and safer traffic circulation. This big step forward in the automotive industry must guarantee that all data exchanges are secure.

Protecting onboard computer-based systems and networks from theft or damage to their hardware, software, or electronic data, as well as from disruption or malfunction of provided services, is becoming a hot topic in the automotive industry. Accordingly, cybersecurity is growing in importance. This adaptation is driven by new concepts of personal mobility, autonomous driving, electrification, and motor vehicle connectivity. In fact, it has become a central concern, given the digitization of embedded systems, the dissemination of software, and the creation of new and fully digital mobility services. These services include several automotive apps, online offers, vehicle features that customers can purchase and unlock online, and electronic vehicle charging stations that "talk" to onboard electronic devices, infrastructures, and power grids.

Consumer requirements for security and software features are growing at an unparalleled rate. This increase in software capacity affects infotainment, user experience, active safety, and connected-vehicle services. These demands open the door for more automotive apps, autonomous driving, and so on. With these added requirements for software functionality comes a corresponding increase in the demand for computing power.

Similar to smartphone development over the last decade, where we needed to add more computing capacity to run all of the apps, we also require increasing computing capabilities in modern vehicles to run all of the latest features. This means that the traditional architecture approach will no longer be viable to support the growth of content and complexity. There is not enough computing capacity to run recent complex vehicle algorithms, and the network infrastructure does not support future data transfer speeds. An overview of the evolution of electrical architecture systems over the past seven decades, proposed by Aptiv [1], is summarized in Figure 1, which clearly presents this incredible growth and explains why the automotive world is shifting from a fragmented approach to a software-defined digital platform.

Modern cars have more than 100 electronic control units (ECUs); by 2030, we expect them to have more than 300 million lines of software code versus the 100 million lines of code of in current vehicles. For comparison, a passenger plane has approximately 15 million lines of code, a modern fighter plane has an estimated 20 million, and a traditional PC operating system (OS) has close to 40 million. This accumulation of complex software code results from the specific inheritance of electronic systems design over the past years and the growing demands of systems in connected and autonomous cars [Figure 1(c)]. This creates many opportunities for cyberattacks, not only in the vehicle but also along the value chain.

Cybersecurity Game

The automotive cybersecurity economy is inherently unfair. On the one hand, with the right advanced tools, attacks are relatively accessible and reasonably priced. On the other hand, establishing a coherent defense for the complex value chain and its products requires increasing efforts and investments. So far, this reality has tipped the balance in favor of the attackers. For instance, hackers took control of the infotainment system in recent electric vehicle (EV) models. They exploited a vulnerability in the embedded web browser during a hacking contest, forcing the automotive supplier to quickly release a software update to mitigate the problem. A Chinese security company found 14 vulnerabilities in the vehicles of a European premium car maker in 2018. Another global vehicle manufacturer recalled approximately 1.4 million cars in 2015 in one of the first cases involving automotive cybersecurity risks. This recall impact was significant, with a potential cost to the company of almost US$600 million [2].

Cybersecurity Standard Approach

For an industry used to solving complex problems and standardizing responses, cybersecurity remains a nonstandard anomaly. To date, automotive suppliers have struggled to cope with the diverse demands of original equipment manufacturer (OEM) customers. They must balance the common security requirements that go into their basic products with software adjustments made for specific OEMs. Nevertheless, current supplier relationships and contractual arrangements mostly do not allow OEMs to test the end-to-end cybersecurity protocols of a vehicle platform or technology stack made up of parts from multiple suppliers. This type of approach introduces difficulties in sharing work between OEMs and suppliers to achieve effective cybersecurity when developing and testing automotive software.

Minimum standards for vehicle software cybersecurity are under development, and they will impact

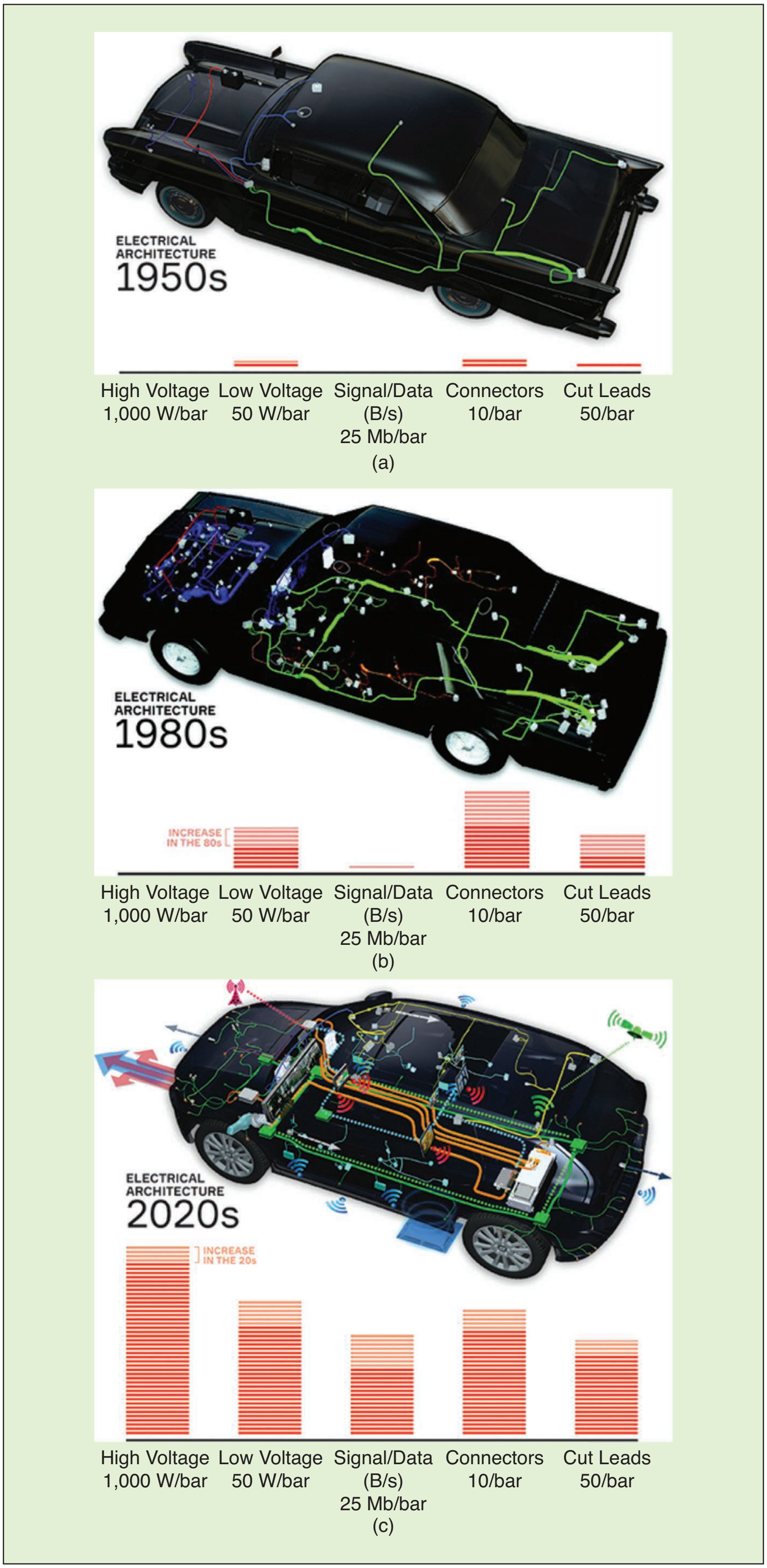

FIGURE 1 The evolution of electrical architecture systems over the decades [1]. (a) The 1950s: simplicity—minimal electrical content, no electronics. (b) The 1980s: takeoff—electronics integration means electric growth. (c) The 2020s: connectivity and safety—high power management takes charge. (Source: Aptiv.com; used with permission.)

THE AUTOMOTIVE CYBERSECURITY ECONOMY IS INHERENTLY UNFAIR.

the entire value chain. Currently, cybersecurity worries exist for all modern cars in the form of requirements made by regulators and type-approval authorities. For instance, California's final regulations on testing and deploying autonomous vehicles recently came into effect [3], requiring autonomous vehicles to meet appropriate industry standards for cybersecurity. Although these regulations will have an immediate impact on a limited fleet, the World Forum for Harmonization of Vehicle Regulations, under the responsibility of the United Nations Economic Commission for Europe (UNECE), is expected to finalize its cybersecurity regulations and software updates in 2020 [2]. More clear requirements will be created for future vehicle sales and new types of vehicles in more than 60 countries. Car makers and industry experts see the future UNECE regulations as just the beginning of a new era of technical-compliance regulations in the automotive sector, with a focus on the increasing importance of software and connectivity in this specific industry.

Although still relatively new, the threat of integrated cybersecurity will remain a constant concern. As such, auto manufacturers must now see cybersecurity as an integral part of their business functions and development efforts. In addition, the industry can no longer view cybersecurity as a merely an IT issue. Car makers should assign ownership and responsibility for all key activities in the value chain (including their many suppliers) and adopt a safety culture among core teams. Similarly, automotive suppliers must take OEM concerns into account in terms of cybersecurity, develop capabilities to integrate best security practices into their components, and collaborate effectively with OEMs to integrate and verify complete cybersecurity solutions.

This requires creating a true software-centric cybersecurity culture, given the spread of cybersecurity threats across the value chain. Car makers themselves have a solid track record of building a culture of security, but this is not yet true for cybersecurity in all of its dimensions. Examples should be considered from outside the automotive industry; for example, many digital companies have shown how to create strong safety cultures in their engineering departments. In these companies, everyone understands the importance of cybersecurity coding practices, and organizations maintain engineering awareness and education programs that train their technical staff in cybersecurity, encouraging them to delve deeply into this issue and constantly increase their hardware/software security levels.

Cybersecurity as a Good Practice in the Design Phase

Car makers must design vehicle platforms and related digital mobility services securely from the start. In fact, the inherent complexity of modern vehicle platforms, with their long development cycles and complex supply chains, does not allow late architectural changes to hardware and software. In addition, regulators are establishing strict constraints for OEMs to obtain approvals for new vehicles. At this point, the automotive industry should consider cybersecurity throughout the product lifecycle, not just until the car is sold to customers, as new technical vulnerabilities can arise at any time. These technical problems can have a direct impact on customers and cars on the road, forcing OEMs to provide security-related software to fix them throughout the vehicle's lifecycle.

High-tech companies, such as smartphone, tablet, and PC manufacturers, are currently addressing this issue by releasing software updates and security patches for their products after initial sales. Nevertheless, this is generally limited to a period of two or three years, while vehicles have an average lifecycle of a decade or more, depending on the region in which they operate. With the OTA software updating, car makers can keep fleets on the road and update their OSs and apps directly, in contrast to the current costly practice of "reflashing" ECUs through dealerships.

The automotive industry must, therefore, develop common practices in cybersecurity to control development and maintenance costs. At this point, OEMs and suppliers must create a common platform to ensure and correctly manage end-to-end secure solutions.

New cybersecurity and software-update challenges should be planned and designed along the value chain and across the digital lifecycle of new cars, focusing on the four actions proposed by Deichmann et al. [2]:

- establish a clear baseline for implementation
- create a true digital-security-by-design philosophy in engineering, quality assurance, and other core functions of the value chain and promote software architectures for cars with integrated security
- increase experience and the ability to monitor the cybersecurity of cars on the road
- adapt software-engineering practices that include function-based development, solid version control, and integration testing.

Hackers have begun to dedicate more energy to compromising connected cars, which represents a new challenge for car makers and suppliers. Although consumers consider cybersecurity to be largely guaranteed until the first breach, regulators are increasing pressure on vehicle manufacturer to provide better protection against attacks. The overall security of modern mobility services will depend on the ability of key players to manage all of the cyber risks in and around connected cars. However, just as for other devices, only strategic actions taken today can prepare cars for future attacks.

NVIDIA DRIVE AGX Orin

NVIDIA recently unveiled its AGX Orin (Figure 2), claiming it the world's most advanced processor for use in autonomous vehicles and robots. The new NVIDIA DRIVE AGX Orin chip can perform 200 trillion operations/s, as presented in [5]. This performance is seven times higher than previous NVIDIA chips (30 trillion operations) and is superior to the full self-driving (FSD) computer (144 trillion operations) currently used by Tesla. The AGX platform is powered by a new Orin system-on-chip (SoC), which consists of 17 billion transistors and is the result of four years of intensive R&D. The Orin SoC integrates NVIDIA next-generation GPU architecture and Arm Hercules CPU cores as well as new deep-learning and computer-vision accelerators.

Recently, NVIDIA focused on self-driving hardware, which is an area for potential growth. Autonomous cars need large amounts of data processing power to translate the world around them into pictures and properly process what they are seeing as quickly as possible for safety improvement and/or to replace human drivers.

Until now, the auto-grade NVIDIA Xavier SoC was used in a multiprocessor configuration and paired with GPUs on the NVIDIA DRIVE PX Pegasus self-driving computer, which offers level 5 autonomous driving. The new Orin chip could go from level 2 to level 5 and will be available at a large scale to car makers in 2022. There will be a variety of configurations available to manufacturers as functions of their product targets.

NVIDIA also offers open source access to its artificial intelligence models. This includes systems that involve the recognition of traffic lights and pedestrians, path perception, and eye detection. Tesla previously used the NVIDIA DRIVE PX 2, the predecessor of the PX Pegasus, for its AP2 and AP2.5 autopilot systems. Last year, Tesla started using its own HW3 FSD computer. Tesla is still using NVIDIA hardware in some data centers for image processing but does not plan to use the new Orin platform.

One weakness of the NVIDIA chip is power consumption, which is crucial for EVs. With all of the performance functions of this chip, it is natural that the final configuration of the next NVIDIA-independent computer will have higher consumption; however, this can be reduced in the near future through the development of a global system platform. An estimation of the power demand of the new Orin chip is approximately 60–70 W [5]. This is very insignificant, comparatively, to the capacity of an EV battery, but car makers are worried about every watt in EV energy balance.

There are additional issues to consider, including memory bandwidth and final chip configuration, so this newly released system cannot be compared directly to those onboard some actual car models, especially when we do not yet know all specifications of the NVIDIA Orin. In addition, all of this processing power depends on the data and algorithms that pass through the computers. Several companies are not content to stand still and want to offer more powerful computers with less power consumption for eventual self-driving applications.

System Design for the Next EVs

Several countries have announced plans to ban internal combustion engines (ICEs) and diesel vehicles by 2040. Consequently, EVs are slowly coming into the mainstream. The era of personal mobility and autonomous vehicles essentially built on electric powertrains is also fast approaching. However, practically all auto manufacturers offering EVs suffer some losses, mainly due to increased investments in engineering, R&D, and higher powertrain costs, all of which are essentially attributable to the battery system. To overcome this design challenge and to integrate technologies and address a wide range of vehicle electrification needs, a common practice is coming to the fore: systemic design.

By 2040, one in three cars sold is expected to be electric. Vehicle range remains one of the biggest concerns and must be addressed by innovations in the development of materials and battery cells, in addition to the design of electrical systems and new motors, and/or a combination thereof. Other important factors include reducing vehicle weight, improving product lifecycle management, and building powertrain components with fewer mechanical stresses (noise and vibration). EVs have more and different safety considerations than traditional vehicles. Subsequently, for autonomous vehicles, secure designs are needed to deal with the increased data on the vehicle network and meet the enhanced requirements for virtual validation.

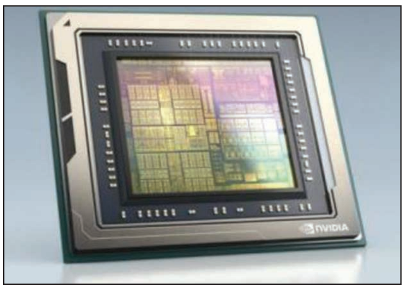

FIGURE 2 The NVIDIA Orin system-on-chip [5]. (Source: NVIDIA; used with permission.)

To ensure safety when innovations are added to the next models of EVs, manufacturers must verify and validate the functionality and reliability of the overall systems. The validation of these systems requires years, if not decades, of testing in all conceivable environmental conditions. To face these challenges, sophisticated, intelligent, and collaborative virtual solutions based on concepts such as the digital twin are required.

Design for Range and Time for Charging

Adequate autonomy for the main use case (which will be different, for example, for a passenger car versus an electric scooter or light urban truck) and fast charging technology (Figure 3) are essential for new EV models. For the demands of high-energy batteries, an actual level 1 or 2 charge cycle can take more than eight hours. As a result, car makers and charging infrastructure companies are investing heavily in fast charging (80% charged in 30 min) and ultrafast charging (80% charged in 15 min). In recent years, advanced lithium (Li)-ion cells have reached an energy density of 500–600 Wh/L at a price of US$150–200/kWh. Company joint ventures plan to develop Li-ion cells with an increased energy density around 50% while reducing costs by approximately 30%. To do this, OEMs and battery suppliers will need to focus on innovations for the new high-energy density chemistry, material optimization to reduce costs, cell and battery design and mechanical optimization, and an improved powertrain to maximize range. Robust design of the cells and thermal management of the packaging are also fundamental factors for the safety and durability of battery packs.

On the one hand, it is extremely difficult to develop batteries that meet all of these requirements. Simulation-based development, encompassing battery-chemistry optimization, cell and package design, and vehicle integration, can help reduce development time and costs. Accurate software forecasts can support the design and validation of an ideal battery for any driving scenario and/or climatic conditions and help expose the actual limiting mechanisms.

On the other hand, companies must develop and validate optimal charging algorithms and consider the impact of fast charging on battery life. During charging, if the temperature of the battery or charger exceeds a critical limit, the vehicle controller will reduce the charging speed, extending the charging time. Thus, the design of reliable power electronics for battery chargers, the development of algorithms, and thermal management go together. A large research area in this field is the development of a solid-state battery for EVs.

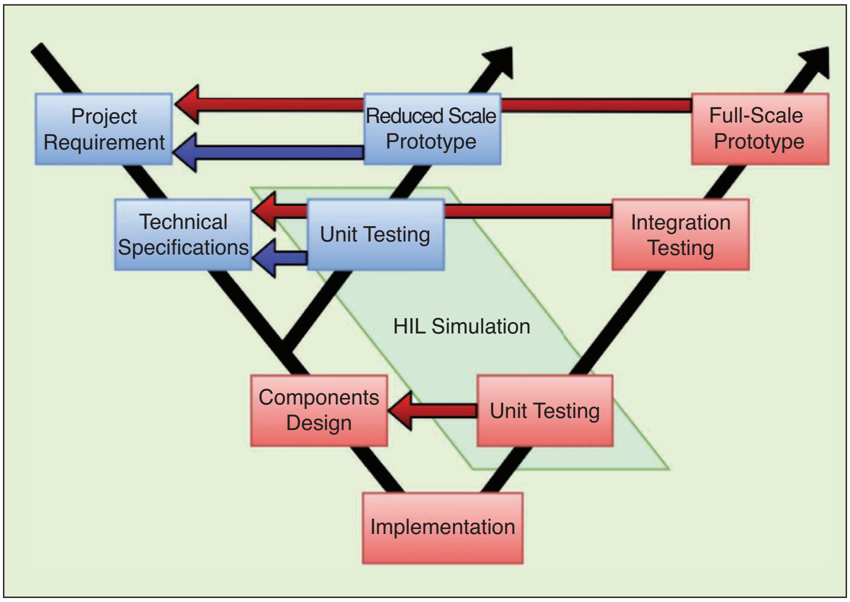

FIGURE 3 The V-shape development process [4]. (Source: e-TESC Lab; used with permission.) HIL: hardware-in-the-loop.

Design for Performance and Lifetime

The development of EVs presents unique challenges and requires balanced engineering to reach the desired performance and comfort without affecting the range and life of the vehicle. New aspects such as vibration and noise, typically masked by the ICE, become more dominant, affecting drivers' judgment and behavior. To achieve range and acceleration goals, car makers must explore the advantages of electric motor and battery design as a more efficient mechanism that can reduce the total number of cells in the battery pack, which should translate into a better electronic powertrain solution.

Reliability in the fields of battery, motor, and power electronics is also a major concern. The maximal temperature and its distribution during field operation represent a constraining factor that limits the life of powertrain components. Equipment suppliers and OEMs must consider not only the properties of the materials but also the uneven distribution of current, voltage, magnetic flux, and temperature, which is difficult to measure in these components for the dynamic cycles of an EV. The performance of one component can have an impact on the flow distribution in another. For example, battery voltage and current affect motor performance as the motor generates more heat due to an increase of losses.

Therefore, the interconnection of various domains, such as computer-aided mechanical design, computer-aided electronic design, and computational fluid dynamics software in the early stage of the system design concept, is crucial. System-level integration and exploits, if left to later steps, can lead to design iterations. In turn, these increase costs and time to market. For example, the energy converter and electric motor can be optimized separately. Global optimization of the converter/motor will surely reduce the volume and/or mass of the drivetrain to meet electrical restrictions. However, the system-integration phase can be challenging because some components may not meet other global requirements when optimized only locally, such as those related to noise, manufacturing capacity, and integration. Even a standard off-the-shelf solution will be valid only for a certain use and may not apply to other applications. This means that high-performance motor drives should be seen as complete solutions, not just as a single view on the component level.

To reduce time to market and costs, quick and reasonably accurate analysis at the system level and detailed models at the component level are required. They allow development teams to perform component-design engineering that considers the upstream implications of the system. This transparent component in system-level simulation allows companies to explore possible tradeoffs in the design of highly interdependent EVs, shorten design cycles, and ensure that the final product is fully optimized by using the V-shape development cycle model presented in Figure 3 [4].

Electrical Architecture

The electrical distribution system is the third heaviest system in a vehicle, after the chassis and powertrain. Mass reduction contributes significantly to the vehicle's overall weight goals. Managing physical size and mass to conduct high currents is one of the most significant challenges in the design of EV connectors and cables. For instance, OEMs are considering removing or reducing high-voltage (HV) cable shielding to optimize weight and packaging. One way to do this is to manage electromagnetic interference through integrations with tools that analyze high- and low-frequency emissions from sources such as HV cables, the battery-management system, and power electronics. Assessing and optimizing cable and harness routing requires tools that are tightly integrated with 3D CAD.

Finally, analysis of the optimal startup/shutdown sequencing of an HV system is also an important consideration. This is necessary, for example, to support analysis of the HV electrical system capacitance by calculating the right time for the system to automatically check the welded HV contacts (a basic test at the startup and/or shutdown of the HV system performed in all EVs). This is usually a safety-oriented functional mitigation action. It is also essential to obtain confirmation that only the necessary components in the HV system are activated for the appropriate vehicle modes (e.g., charging versus driving modes).

Several design software packages are available to support the different design levels of next-generation EVs [6]. Some use a model-based design paradigm to define system architectures, design rule checks, and compare multiple architectural options to ensure that designs meet the original intentions.

These automatic tools [6] integrate the electrical systems into a topological diagram representative of the vehicle. System devices are automatically placed and interconnected, and the entire cabling system is generated automatically using rules and restrictions built into the software environment. Design tasks that took months can now be completed in hours or days, with designs being verified when they are created. The data can be reused in all vehicle programs and in downstream manufacturing and service processes.

Software EV engineering solutions allow OEMs and key players in the supply chain to more quickly and economically develop vehicles marketed to various segments. The development of EVs with a range of more than 300 km (~200 mi), for instance, and fast charging capacity in various design variants and for different markets, but with the same cost of ownership as ICE/diesel vehicles, requires innovations and technical efficiency previously unknown in the automotive industry. At the same time, there can be no compromise on safety, reliability, and quality. For the development and engineering of EVs in the fields of electrical, mechanical, thermal, software, and controls, an integrated view coupling components at the system level is under development. A new V-shape development-process architecture is in progress to consider all of these dimensions of the EV-design problem.

Bombardier Recreational Products EV Concepts for 2020

In late 2019, Bombardier Recreational Products (BRP) presented its EV development at Club BRP 2020, showcasing six new electric concepts in its current product lines and beyond, as presented in Figure 4 [7].

These concepts offer a view of what the future could hold for both its current product lines and other potential new segments. As a leader in recreational products, BRP continues to push the limits and move people into unexplored territories, while still providing the fun experience that recreational-product drivers expect.

Since 2010, BRP has been working on how to create EVs that bring new experiences to potential and existing customers. For some time, the company has proposed an electric version of its side-by-side vehicle, Commander [Figure 5(a)]; but, like other EV models, it suffers from premature entrance to the market. Traditional users of BRP products were not prepared for the paradigm shift required to have an off-road EV with range and time-to-charge restrictions

Since then, BRP has worked hard to develop new electric concepts that follow a series of past ventures of parent company Bombardier into electric propulsion, which includes the introduction of a Neighborhood EV [Figure 5(b)] in the late 1990s. Thereafter, through BRP, an electric version of the Commander [Figure 5(a)] was offered. The development of the Can-Am Spyder electric prototype and the commercialization of its electric kart, Sonic (presented in Figure 4), are BRP's more recent propositions.

Recently, as an incentive for some of these vehicles, Canada has made off-road EVs eligible for immediate tax write-offs to encourage Canadian companies to buy them [8]. Last year, the federal budget office created a zero-emission business tax write-off for EVs, hybrid EVs, and hydrogen-fuel-cell EVs. Companies can amortize 100% of the purchase price, up to CAD$55,000, in the year the car goes into service.

This business program now extends to off-road vehicles, such as mining and agricultural equipment. Because the types of vehicles available increase each year, the program specifies that the 100% write-off will be available for vehicles to be used before 2024. A normal response to this governmental action will be the natural grow of these types of EVs in the next few years.

FIGURE 4 BRP electric concepts: two- and three-wheeled electric motorcycles, a go-kart, and a jet ski [7]. (Source: BRP; used with permission.)

(a) (b)

FIGURE 5 (a) The e-TESC electric Commander. (b) The BRP 72-V NEV golf cart smart car. (Source: e-TESC Lab; used with permission.)

Hybrid Battery-Powered Electric Motorbike Concept

A new hybrid energy-storage system was unveiled by Nawa Technologies at the International Consumer Electronics Show in Las Vegas, Nevada, in January [9]. It is a sleek-looking electric motorcycle that has a relatively small, lightweight 9-kWh battery, and yet it boasts a 300-km (180-mi) urban range and superbike-level acceleration, thanks to the addition of ultracapacitors to the Li-ion battery that form a hybrid energy-storage system.

After several years and hundreds of research papers on the hybridization of batteries and ultracapacitors [10], this is the first time that a motorbike prototype is using an ultracapacitor as a power boost. Ultracapacitors can charge and discharge almost immediately and reach at least millions of cycles, making them the perfect energy-storage system for extreme power outputs and rapid charging, as expected of a powerful motorbike. On the other hand, their small energy density and self-discharging process means they are far from the compactness of Li-ion batteries, which is the main reason they are not used as the energy-storage unit in EVs.

According to Nawa Technologies, a French manufacturer, supercapacitors are quite useful in a hybrid configuration associated with a Li-ion battery, which creates a power-supply system that increases the density and storage capacity of a simple Li-ion unit, with charge and discharge rates equivalent to those of a capacitor. For instance, regenerative braking is essentially based on high power in a short time: in a sole-battery configuration, the battery itself is the bottleneck to the full capacity of EV regenerative braking. The charge rates of the Li-ion battery are so slow that the battery simply cannot recover much of the deceleration energy. However, an ultracapacitor does not have these limitations and can recoup up to 80% of braking energy as a function of powertrain efficiency. Therefore, adding an ultracapacitor makes for a hugely efficient electric powertrain that can squeeze more range out of a given battery, especially in a stop–start urban environment.

The Nawa Racer (Figure 6) is inspired by 1960s cafe racers but is powered by a world-first hybrid battery system that combines the company's next-generation ultracapacitors with a Li-ion battery pack. The full power of the Nawa motorbike is 74 kW (99 hp), and it can reach 100 km/h (62 mi/h) in fewer than 3 s.

Compared to other products in the same segment, a 9-kWh battery pack would normally be good for an urban range of approximately 180 km (110 mi), but the addition of a 0.1-kWh ultracapacitor on top of the Li-ion battery pack massively increases that range to a claimed 300 km (180 mi), purely by harvesting and reusing so much braking energy. Nawa claims that its revolutionary system can reuse 80% of braking energy, with a global weight savings of 25%.

The motorbike prototype is simply a demonstration of what the technology can do when paired with a conventional battery powertrain. EVs are already great in the city, but ultracapacitor hybrid systems are ready to make them lighter, cheaper, and capable of significant acceleration for short bursts.

Nawa hopes to encourage car and motorcycle manufacturers to integrate its technology into some production vehicles, thereby becoming an OEM component supplier. In fact, as the Lamborghini Sián [11] demonstrates, there is no reason why hybrid supercapacitor systems cannot radically increase the acceleration and efficiency of any car.

Ten Years of EV Market Growth

The EV market saw big gains in 2019 in terms of the number of cars sold and leased. Investments of more than US$200 billion by car makers in electrification during the coming years have already been announced. In 2019, EVs captured more than 2% of the global vehicle market, and several new models will hit the road in 2020. Ford introduced its next electric Mustang Mach-E [12], and an electric F150 pickup [13] is being planned. Tesla, of course, shocked everyone by presenting and predicting an interesting future for its Cybertruck [14].

However, EV mass market penetration is not an easy task. Although in some countries, such as China and Norway, car buyers benefit from generous incentives, the EV market is still driven by early adopters rather than mainstream drivers. In general, EV sales for 2019 had a slow rate of progression. Some countries and states like California have seen EV capture 8% of new sales (including plug-in hybrids), but other countries and U.S. states have yet to embrace this mobility paradigm shift. The slow penetration rate has not reduced car makers' ambitions; they are betting that it is better to anticipate the inevitable transition to EVs. If the demand does not grow as they hope, however, it could mean bankruptcy for some small and/or start-up companies. Nonetheless, the automotive industry has even bigger plans for the next 10 years.

For example, Rivian [15] ended 2019 with an additional investment of US$1.3 billion. Tesla, meanwhile, posted a profit last year, made its debut with the Cybertruck paradigm, delivered the first Model 3 built at its Shanghai, China, plant, and announced an improved range on its Model S and Model X. On the European side, the Audi E-Tron [16] went up for sale, Porsche started production of its Taycan high-performance car [17], and Lamborghini announced its first hybrid supercar [11].

In parallel, increasingly restrictive emissions and fuel-efficiency regulations around the world are compelling car makers to deploy more vehicles able to meet the wishes of users. As a result, in recent years, auto manufacturers have announced a whirlwind of plans to bring more EV models to the market.

As recent examples of this market transition, Polestar (an automotive brand owned by Volvo Car Group and its parent company, Geely) opened its first EV store in Montréal at the end of 2019 [18], and Lunaz quietly decided to modernize classic luxury cars with modern capabilities, such as cruise control and regenerative braking [19]. We will also see a set of luxury sport utility vehicles (SUVs) on the streets with hybrid transmissions, such as the Bentley Bentayga

FIGURE 6 The Nawa Racer, a hybrid battery-powered electric motorbike concept [9]. (Source: Nawa Technology; used with permission.)

FIGURE 7 A fast-charging electric Volvo-Nova bus on STM Line 36-Monk [31]. (Source: STM; used with permission.)

[20], Jaguar I-Pace [21], and Mercedes EQC 400 [22].

In fact, one would be hard-pressed to find a car maker that is not currently developing an EV model or platform. Lexus recently unveiled its UX 300e [23]; Volkswagen revealed its EV wagon concept, ID BUZZ [24], following its ID 3 and ID Crozz; and Toyota presented its ultracompact battery EV at the recent Tokyo Motor Show [25]. Nissan is developing a dual-motor EV based on its Leaf platform [26]. BMW recently introduced its all-electric Mini Cooper [27] and a concept version of its i4 electric sedan with nearly 645 km (400 mi) of range [28]. Lincoln is building an electric SUV of its own based on the Rivian platform [29].

Lotus debuted its Evija supercar, capable of charging fully in just 9 min [30]. Even niche luxury car maker Karma is working on a pair of hybrid concepts [31]. Harley-Davidson, a major U.S. motorcycle manufacturer, is similarly making the jump to electric and recently resumed production of its LiveWire motorcycle [32]. Mercedes has already committed to having at least one EV option with all of its vehicle models in the next two years, and GM announced that most of its Cadillac models will be electric by the end of 2030.

Auto manufacturers are not the only ones playing a role in this decisive shift to electric mobility. German Chancellor Angela Merkel is planning the installation of one million EV charging stations by 2030, 50 times the number available today. The French government, led by Emmanuel Macron, has set an even more ambitious goal of completely banning the sale of ICEs by 2040. In the United States, Senate Minority Leader Chuck Schumer recently argued in favor of spending at least US$454 billion over the next 10 years to integrally swap every gas-powered vehicle on U.S. roads.

Electric Buses for Public Transport

Public transport is essential for daily life in large cities like Montréal. The next decade is anticipated to be a period of solid growth for the city's transport company, Société de transport de Montréal (STM), with several major new projects aimed at boosting its quality of service [33]. Over the next 10 years, more than US$16 billion is slated for infrastructure development projects as well as modernization and maintenance. STM is about to start the largest development phase since the construction of its subway in the 1960s.

A part of the investments will be directed at revitalizing its bus network, which covers a territory of 500 km^2 and connects communities all over the Montréal island and surrounding areas. With its high number of daily passengers, STM naturally wants to modernize and has decided to invest heavily in its bus network, considering the environmental concerns of an urban area.

The most recent change in the STM fleet is the addition of 300 hybrid buses made by Volvo-Nova Bus [34]. The acquisition will improve bus service across the network, with a 15% increase in the number of vehicles on the road. This is part of a larger order that provides for the delivery of 830 new hybrid buses over the next four years as a progressive replacement of the old STM buses. Currently, STM is in a transition phase, using hybrid buses as the path to more efficient and environmentally friendly vehicles. After 2025, STM plans to buy only electric buses.

The new hybrid buses, with air-conditioning, onboard USB chargers, and two wheelchair spaces, are helping improve the quality of offered services. In addition, the arrival of these hybrid vehicles contributes to reducing emissions in a saturated area as part of a more global action against climate change, since these buses can consume up to 30% less fuel.

STM requirements in terms of range, with buses traveling between 200 and 300 km without returns to the garage, challenge current state-of-the-art electric mobility. This requires solutions to ensure the reliability and flexibility of operation services. To overcome this restriction, three fast-charging electric buses are already in service on Line 36-Monk (Figure 7), and 38 electric buses of various types and using various charging technologies will be in service this year in a step toward developing a global strategy for a full electric fleet [33].

In many ways, the electric bus is a technology whose time has come. Several bus manufacturers are offering increasingly better complete solutions for city electric mobility requests. Certainly, depending on the electricity production share, electric buses are much better for the global environment than diesel buses, particularly in terms of reducing local emissions. Fundamentally, they are also more pleasant to be around: less vibration, little noise, and zero exhaust. In addition, in the long run, electric buses have lower operating costs, and, with their efficient electric motors, they are easier to maintain. All of these factors combine to encourage a long future for electric buses. With its strategy already underway, the STM is being recognized as a pioneer in the electrification of public transport in North America.

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