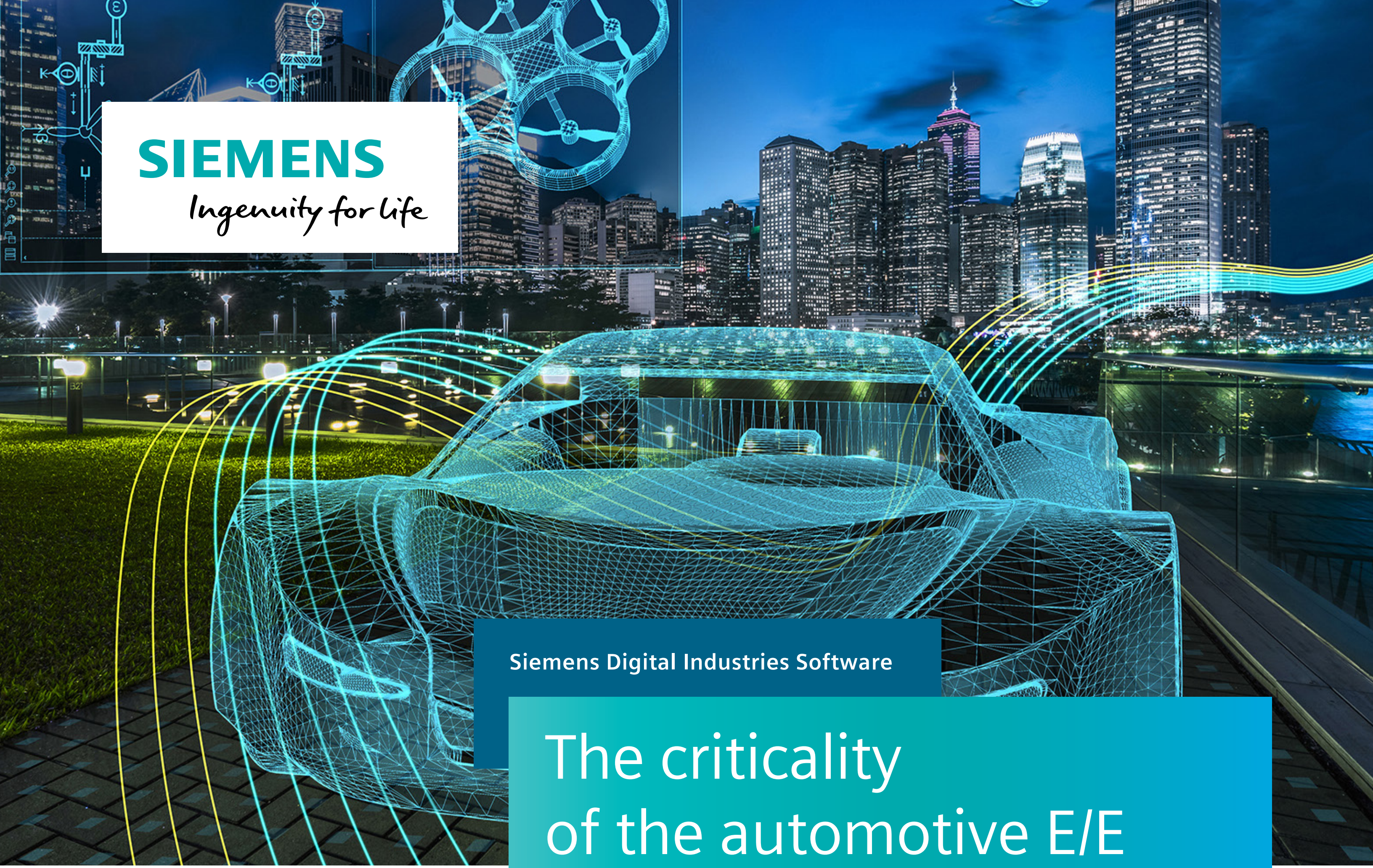

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The criticality of the automotive E/E architecture

Executive summary

Modern vehicles are highly sophisticated systems incorporating electrical, electronic, software and mechanical components. Mechanical systems are giving way to advanced software and electronic devices, driving automakers to innovate and differentiate their vehicles via the electric and electronic (E/E) architecture. Future architectures need to be scalable across vehicle platforms, flexible to future technologies, and reliable over extended lives in the field. Such architectures will enable new business models and the ability to bring new products to market quickly and efficiently.
As the pace of change accelerates, automotive companies need to evolve their development processes to deliver and maximize the value of these architectures.

Contents

Where did we come from, where are we going?

Modern vehicles are commonly described as “computers-on-wheels” due to the recent explosion of computing power and electronic features that they contain. The world’s first automobiles, however, were relatively simple, and entirely mechanically operated. The first automotive electronic components were not even available until the 1930s, when manufacturers began offering vacuum tube radios.

Over time, vehicles have become dramatically more complex due to technological advances and consumer trends. Mechanical systems accounted for most of this complexity for much of the car’s history, but electrical and electronic systems have steadily increased in sophistication. Today, a majority of vehicle features are aided or enabled by electronic components, the embedded software on these components, and the underlying electrical and electronic (E/E) architecture. Engine management, braking, steering, infotainment, and other comfort and convenience features rely on the electrical and electronic systems. Embedded software has also come to play a dominant role in vehicle functionality. Modern cars contain millions of lines of code that make up applications for everything from the most advanced infotainment and passive safety features to the automatic door locks.

As vehicle features continue to evolve and grow in sophistication, previously unrelated subsystems will come into contact. Systems that previously evolved independently will begin to integrate, and depend on each other to realize new functionalities. The introduction of cruise control in the late 1950s was the first integration of electrical and mechanical systems in a vehicle (figure 1a). Since then, cruise control has continued to evolve.

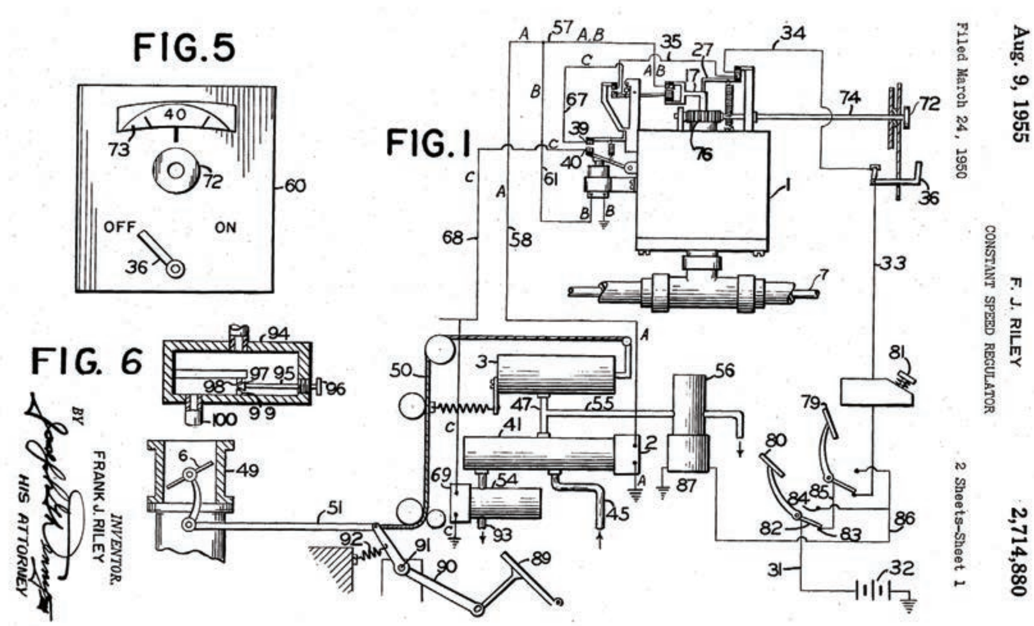


Figure 1a: Cruise control was the first integration of electrical and mechanical systems in a vehicle. Early systems used fluid pressure to activate the throttle and were governed by solenoids (U. S. Patent No. 2,714,880, 1955).

Adaptive cruise control systems allow modern cars to slow down and speed up as needed to maintain a driver-determined following distance (figure 1b). And, automated emergency braking systems can bring vehicles to a complete stop even if the driver is not paying attention.

The result of this innovation and integration is a tremendously complex system of electronic control units (ECUs), sensors, actuators, and wiring to connect it all together. The size and complexity of these architectures create new challenges for automotive OEMs and their suppliers. These challenges will only become more intense as companies continue to advance vehicle technologies, particularly in the automated driving space. In this environment, the importance of the underlying E/E architecture is paramount.

Despite the challenges, automotive companies are investing in exploring novel E/E architectures because they are becoming an enabler of new business models and new revenue streams. Wiring harness suppliers are expanding their offerings to cover design through manufacturing of vehicle wiring harnesses. Likewise, systems integration suppliers are providing a complete service for the implementation of vehicle subsystems developed from a combination of constraints and requirements defined by the OEM or the market.

Meanwhile, OEMs are also making large investments to bring key areas of development, such as software, in-house. Large OEMs around the world are recruiting large numbers of software engineers to develop basic software functions across their brands. With their own software teams, OEMs can improve the ownership experience with routine software updates to improve system performance and fix latent issues. The OEM may also offer entirely new functionalities that customers can purchase, thus extending the life or increasing the performance and value of their vehicle, while deriving incremental revenue after the vehicle sale.

Amidst large-scale technological change, established OEMs must innovate and differentiate via the E/E architecture. This means creating architectures that are scalable across vehicle platforms, flexible to future technologies, and reliable over extended lives in the field. Well-designed

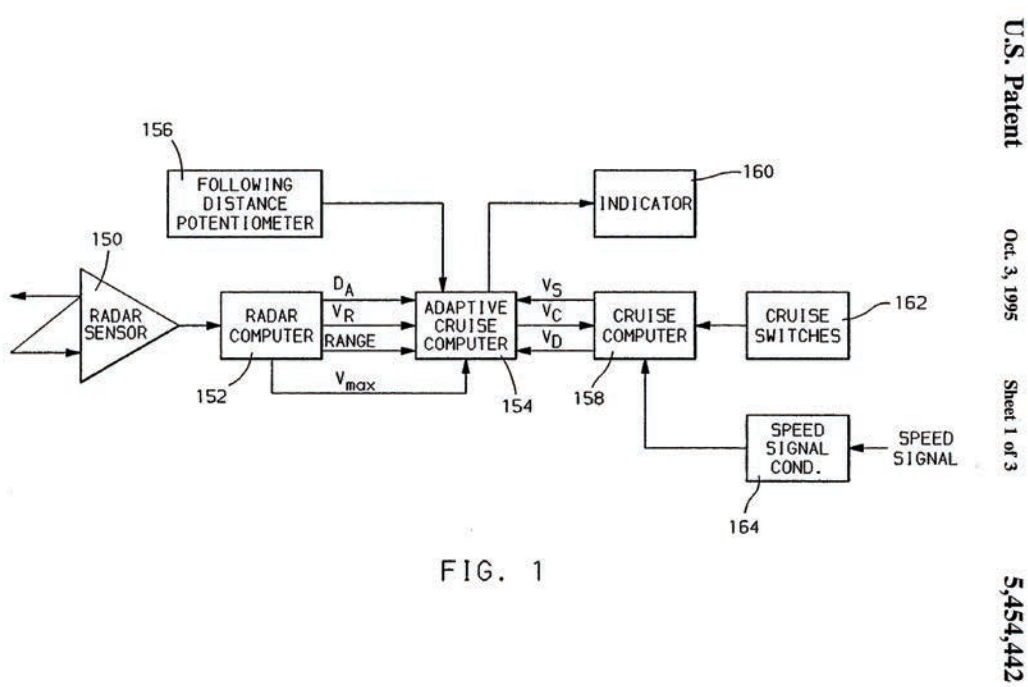


Figure 1b: Adaptive cruise control systems rely much more on the vehicle's E/E system to govern vehicle speed based on sensor inputs (U. S. Patent No. 5,454,442,1995).

architectures allow manufacturers to bring new products and features to market quickly and cost-effectively, enabling agile responses to industry pressures (figure 2). To innovate at the pace required by today's market, however, OEMs also need to evolve their development processes to integrate across domains, automate design tasks, and provide robust data coherency.

Roadblocks

Automotive manufacturers and suppliers will face several challenges as they adapt to new consumer demands and advancing technologies.

Consumers want increased freedom to customize their vehicles through optional features without paying a premium price. OEMs are attempting to provide this customization on a mass scale, as their business still relies on making and selling large volumes of vehicles. At the same time, OEMs try to re-use bills-of-materials (BOM) as much as possible across vehicle platforms to reduce costs in design and manufacturing, which is contradictory to customization. Thus, it becomes more challenging to track and coordinate components, such as the correct version of an ECU or software build, as well as corresponding connectors and terminals across the vehicle platform, all of which are needed to enable functional connectivity between devices.

Many, if not most, of the features consumers want are driven by E/E systems: infotainment, ADAS, and even air conditioning interface with an ECU running embedded software (figure 3). With a greater number of more sophisticated electronics, the typical automotive supplier pipeline is much broader and deeper than before. Longer and larger supplier pipelines can greatly increase the time required to cascade and implement design changes. Ensuring that all teams understand the change being

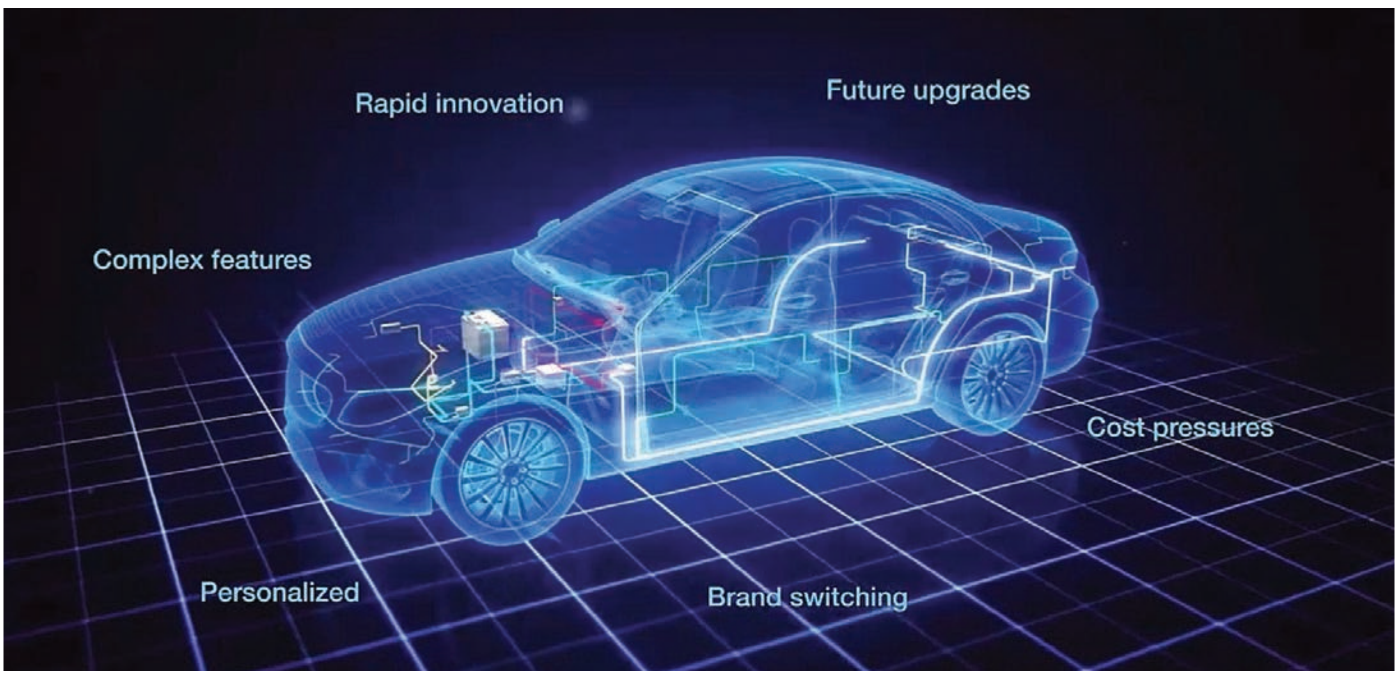


Figure 2: OEMs must create flexible, scalable, and reliable E/E architectures to overcome the new pressures in the automotive industry.

implemented and its effects on their domain is already a key challenge. Contracting with additional suppliers and expanding the supplier ecosystem to provide desirable features only compounds this problem.

Reducing the change implementation cycle enables OEMs to bring new vehicles to market more quickly, a key competitive advantage for companies operating in a very contentious market. Some manufacturers are attempting to shorten development cycles by bringing domains in-house that have been largely supplier-based. Information technology services and software are two common targets for OEMs as they seek to consolidate control in the supply chain.

Next, the average new car today contains between 70-100 ECUs. In future vehicles, OEMs will consolidate these into fewer more powerful control units. How far this consolidation should go; however, is a point of major debate. Some advocate for a centralized architecture with a few, or a singular, very powerful ECU(s) managing vehicle functions. Others consider a distributed architecture with a greater number of ECUs a better option, primarily to create redundancy in vehicle systems.

OEMs may also investigate component consolidation as a cost-saving strategy. By fusing sensors, actuators, and other components together, OEMs can achieve the same functionality for reduced cost. On the other hand, OEMs may want to maintain independent components to preserve system redundancy.

Moreover, OEMs will look to limit investments to save on cost, but increasing architectural complexity and more stringent safety requirements increase the challenge of vehicle design. This increased challenge equates to greater cost, as investment is necessary to deliver the sophisticated vehicles demanded by the market.

Figure 3: Electronically enabled vehicle features are a top priority for many consumers.

Clearing the road ahead

The road forward for automotive OEMs and their suppliers remains lengthy and confusing. While full vehicle autonomy is a popular topic, highly impactful technologies will reach maturity long before true self-driving is achieved. These new technologies will further increase the demands for capability and reliability from the E/E architecture.

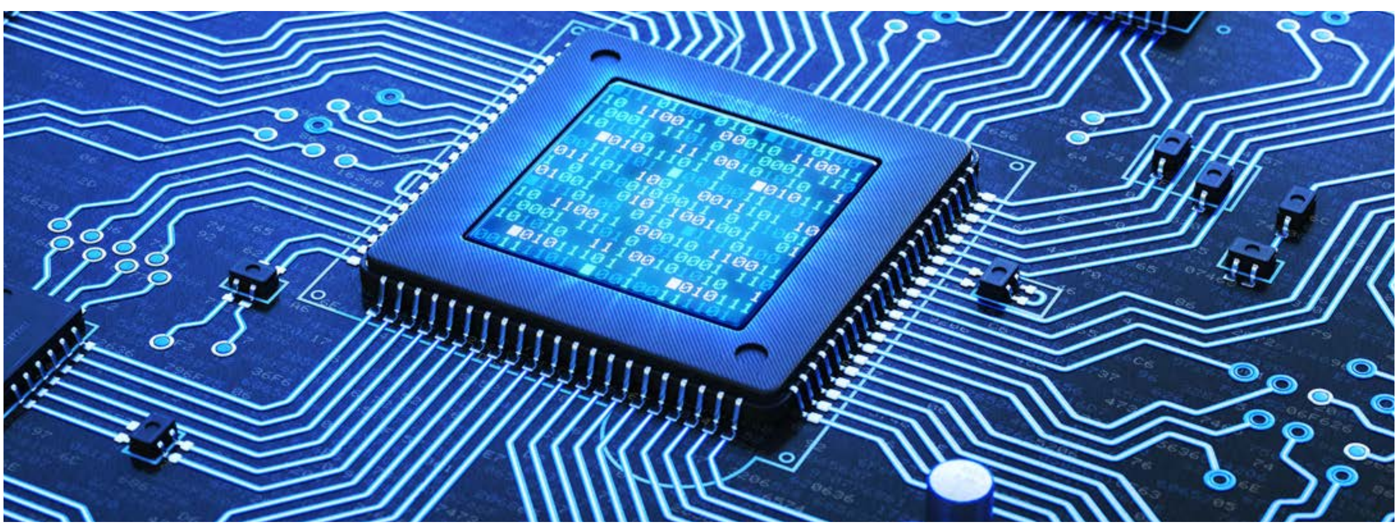
The E/E architecture is a convergence of domains: electronics hardware, network communications, software applications, and electrical wiring systems all combine to make up the vehicle architecture. Currently, these domains operate with only limited knowledge of the activities, constraints, and goals of the other domains. Likewise, functional domains, such as powertrain, chassis, infotainment, and others, are often only loosely connected. This can cause significant problems where these domains interact.

For example, several teams within an OEM may be developing software applications for the core ADAS ECU in the vehicle. These teams are organized by feature and work independently. There will be separate teams for the lane departure, active cruise control, and other applications. In order to ensure flexibility for future updates, a constraint caps the processor utilization for this ECU at around 75%. When each of the teams loads their software onto the ECU, they exceed the utilization cap and even the capabilities of the processor. This happened because each of the teams developed their implementations independently and had no ability to understand the totality of the load on the ECU until it was beyond a critical point in the development process.

Automotive manufacturers and suppliers will need to adopt a new, integrated design methodology to handle the interactions between these domains in an environment that is rapidly becoming more complicated. Major automakers are undertaking extensive reorganizations to better align with these needs.

A new methodology

Establishing an integrated and connected product design, engineering, and manufacturing flow is difficult. These domains have traditionally operated within silos, completing their tasks with minimal external interaction. In addition, the engineering tools in use at many OEMs and suppliers are not built to integrate among domains or share data in a controlled, streamlined fashion. Due to these organizational challenges, engineering decisions in each domain are not being made from a unified set of design data. As a result, errors and incompatibilities are common as cross-domain work is brought together to create the final E/E system design. Some of these may be relatively simple to resolve, but others, such as the ECU example above, result in major re-work efforts, costing time and money.



Many companies have attempted to facilitate collaboration among engineering domains to prevent these errors. Meanwhile, they continue to rely on legacy engineering tools that do not support such collaborative efforts. In particular, these solutions lack a unified data management system, causing engineers to spend time sorting through file systems and manually exchanging information. Design changes, especially those at the system level, are particularly arduous as engineers must propagate these changes to all affected domains and design variants manually.

The adoption of digitalized E/E systems engineering solutions that support the full development flow, from definition through manufacturing and maintenance, will prove critical as automotive manufacturers and suppliers meet the new demands of the automotive industry (figure 4). These solutions enable automotive companies to construct digital twins of vehicles and subsystems for virtual design and verification. Advanced solutions support data coherency and cross-domain integration throughout the flow while leveraging advanced automation capabilities to improve engineering efficiency. The engineering environment provided by these solutions enables each domain to operate within a system-level context during domain-specific engineering. With a system-level context, engineers can evaluate design alternatives, root out issues, and achieve higher quality designs in less time.

For example, as engineers define the E/E architecture for a new vehicle, they can leverage software models and early ECU abstractions to enrich the vehicle architecture, enabling optimization from the beginning. The robust data model of E/E systems development solutions, such as Capital, ensures that each domain has access to the most up-to-date information from the other domains. This helps engineers identify and resolve issues virtually, before they become too costly.

In another example, tight integrations between the E/E systems and mechanical engineering solutions allow the electrical system and wiring harness to be designed with explicit knowledge of the wet, hot, and noisy areas of the mechanical design. Doing so allows the ECAD designer to account for the impact on the electrical performance of these areas when designing the electrical system. On the mechanical side, space reservations can be made and the severity of bends in the harness can be adjusted to account for the wiring bundles that must route through the mechanical structures. With access to this contextual information from the other domain, both electrical and mechanical engineers are able to reconcile incompatibilities between the ECAD and MCAD designs quickly. This integration not only facilitates the development of a product that meets electrical and mechanical requirements, but also accounts for design for manufacturing (DFM) considerations from the onset of the process.

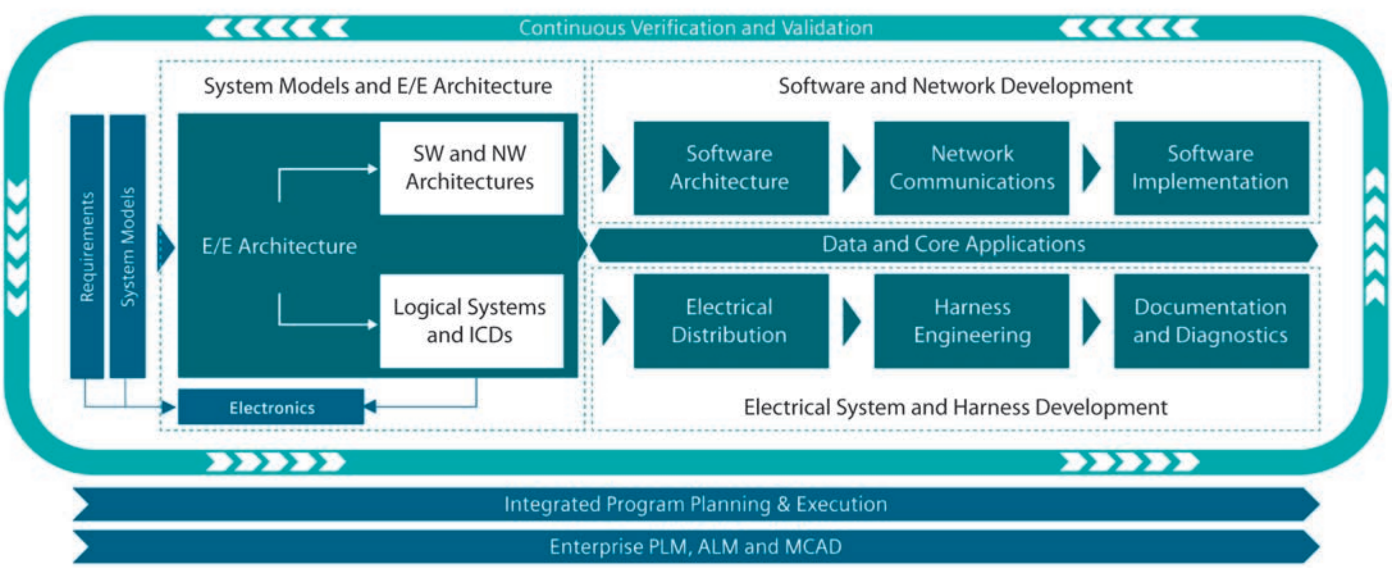


Figure 4: Automotive manufacturers will need a digitalized E/E systems engineering solution that supports the entire flow, from definition through production and maintenance.

The benefits of digitalization even extend into the service and maintenance of vehicles. E/E systems development software can automatically create service manuals and signage. These solutions reuse data directly from upstream engineering processes. Engineers no longer need to take data from a spreadsheet and manually redraw wiring diagrams. All the necessary data can be imported and automatically laid out into accurate wiring diagrams. In addition, the generated service manuals are smart, interactive documents that guide technicians through diagnosis and repair processes, and allow technicians to customize schematic views as necessary by VIN.

Change management

Change management is an ever-present challenge in automotive E/E systems development. Changes can be introduced in any functional domain and during any stage of development (figure 5). As changes are identified, they must be communicated to each affected domain, evaluated, integrated, and verified to ensure that vehicle functionality has not been disrupted. The effects of these changes, especially those made at the system level, can be broad. Each change can affect multiple systems, both software and physical, and the unforeseen effects can be very difficult to predict.

Migrating an ECU to a new location or network in the architecture may affect performance elsewhere in the vehicle. This change in behavior may cascade, causing any number of sub-systems or functions to fail. Such a change can even completely invalidate the technical implementation of the architecture, driving widespread re-design. For example, the type and location of the ECU that governs human-machine interfaces, such as a touchscreen infotainment system, can have dramatic effects on the responsiveness of the user interface. Failing to resolve issues with unresponsive or slow user interfaces can lead to customer complaints and negative brand evaluations from a perceived inconsistency or unreliability of vehicle functions.

Today's solutions facilitate all aspects of change management from definition, to implementation and review, to effective communication. Detailed change orders can be created within the E/E systems engineering solution, and quickly propagated to all affected designs. Integrated change policies automate control over the flow of changes by determining data ownership and permissions to make changes. The impact of the changes can also be assessed for all buildable configurations of a vehicle, then stored, rejected, or approved and re-applied to any revision in any order. Such capabilities can help companies turn the burden of change management into a competitive advantage by accomplishing it faster and more accurately than the competition.

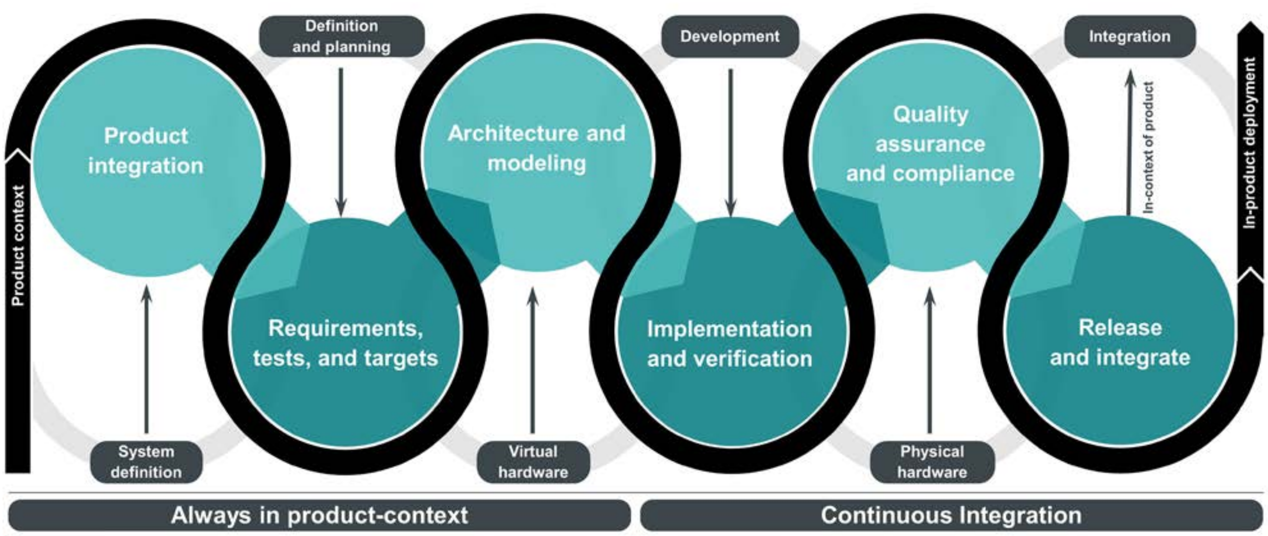


Figure 5: Change is a constant in vehicle program development. New requirements or changes can come from each process, functional domain, or abstraction level during vehicle development.

Evolution of the automotive enterprise

Industry challenges are not confined to technology innovation. As a result, the strategy for dealing with the immense and varied challenges of the mobility industry must extend beyond new design solutions. Major OEMs and suppliers alike are realizing that changes to their organizations and business models will lay the foundation for future success. OEMs are investing in increasing their software competency to bring the development of vehicle software in-house. This is changing OEM-supplier relationships, as automakers begin to source only hardware from their supplier networks.

In response, long-time automotive suppliers are expanding the services they offer to cover the full range of component development, from design through manufacturing. These suppliers, known as Tier 1 suppliers, are caught between legacy challenges like production efficiency and product quality, and emerging challenges such as ballooning harness complexity, accelerated development cycles, and the need to develop new technologies to stay ahead of competition. Moving forward, Tier 1 suppliers will need to move upstream in the value chain to offer full wiring harness and electrical distribution system design and integration services.

Other key investments in the industry have focused on the virtualization of product and production verification and validation through advanced simulations (figure 6). The increasing systems complexity of modern vehicles necessitates such virtual verification practices to deliver competitive products in an acceptable timeframe. Today, automakers must expand their simulation capabilities beyond mechanical analyses to include the multiple electrical systems, networks, electronic devices, wiring harnesses, and software stacks present in a modern vehicle. What's more, they will need to combine these simulations to create high-fidelity constructed scenarios that represent actual driving environments, especially to verify automated driving systems.

Figure 6: The use of simulation to perform virtual verification and validation of complex systems, such as wiring harness manufacturing, has been a growing trend in the industry.

In general, the real challenge comes from scaling and creating profit from a new technology once it has been validated. Capitalizing on the vast opportunity of advanced vehicle technologies requires comprehensive digitalization throughout an automotive company, connecting IT, engineering, and manufacturing with a single digital thread. Furthermore, this strategy must support agility and collaboration across the OEM-supplier ecosystem.

In addition to digitalized and integrated engineering solutions, companies will need to invest in product and application lifecycle management (PLM/ALM), as well as a cloud-based IoT data analytics environment to track, manage, and optimize the entirety of vehicle development. Cloud-based data analytics enable automotive companies to gain intelligence from connected manufacturing machines and vehicle prototypes under testing. Companies can then use this intelligence to close the loop between vehicle design and manufacturing, leading to higher production efficiency, optimized product design, and more.

Conclusion

The continued expansion of the automotive E/E architecture has made its design more challenging and more critical in the scope of vehicle engineering. All aspects of the E/E architecture occupy a larger role in enabling core vehicle functionalities. As a result, each of these components, from devices like sensors and ECUs to the networks and wiring, have grown in sophistication to meet these increased demands. ECUs have become more powerful to process the data coming in from larger sensor arrays using increasingly capable software. Meanwhile, vehicle networks have to manage the communications in this intricate system of sensors and controllers.

The companies that adapt both their development methodologies and organizational structures to provide the highest quality electrical, electronic, and digital automotive experiences will enjoy the most success in a changing industry. Transitioning to integrated, digitalized engineering solutions will enable closer cross-domain collaboration and a continuous digital thread throughout development. Closing the loop between engineering, manufacturing, and actual product with robust analytics will provide even more opportunities to evaluate and optimize vehicle design, manufacturing design, and more. Such comprehensive digitalization will engender strong collaboration throughout the OEM-supplier ecosystem.

Once a best-practice, these capabilities will become a competitive necessity as automotive giants, newcomers, and suppliers evolve to develop and launch new vehicles and features faster than ever. The automotive landscape is wide open; companies of all sizes will need to engage in a combined effort to innovate technologies and processes to thrive.

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