

Automotive Software Engineering: Real-World Necessity and Significance

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ABSTRACT

The automobile industry is undergoing a fundamental shift as it transitions from a mechanical to a software-intensive business, in which most innovation and competition depend on software engineering expertise. This shift is occurring due to the industry's shift from a mechanical to an electronic focus. Over the past few decades, the significance of software engineering in the automobile industry has grown substantially. As a result, it has garnered a great deal of interest from academics and industry professionals. Even though a considerable amount of information concerning automotive software engineering has been published in various scholarly journals, there needs to be a comprehensive study of this information. This systematic mapping project aims to classify and analyze the literature linked to automotive software engineering to offer a structured body of knowledge, identify well-established themes, and uncover research gaps. This study considers 679 publications from various academic fields and subfields published between 1990 and 2015. The primary studies were dissected and categorized based on five distinct dimensions of interest. In addition, potential holes in the research, as well as suggestions for directions for further investigation, are offered. The literature mainly focused on three different areas: system and software architecture and design, qualification testing, and reuse. These were the issues that were discussed the most frequently. There were fewer comparative and validation studies, and the research body needs to contain practitioner-oriented suggestions. Overall, the research activity on automotive software engineering has a high industrial relevance, but its scientific quality is relatively lower.

Key words:

Automotive Software, Automotive Embedded Systems, Automobile, Software Development

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INTRODUCTION

Over the past few decades, software has had a considerable impact on the functioning and innovation of embedded systems in a wide variety of industries. These industries include telecommunications, medical devices, automotive, and aviation systems. Many devices with embedded software have been developed for usage in various industries, resulting in

positive contributions to society (Amin & Mandapuram, 2021). Functions that require a lot of intensive mechanical work are gradually being replaced by software functions, which make it possible to innovate, speed up delivery by reusing components, and differentiate new goods (Mandapuram, 2017b). Because of these shifts in the environment, software engineering has emerged as an essential field of study in embedded systems and a significant factor in both the development of innovative products and the level of competition seen in the market. By this pattern, the automotive industry is undergoing a fundamental shift as it transitions from a software-intensive to a mechanically-intensive business (Haghighatkhah et al., 2017). As a result of this shift, the bulk of innovation and competition depend on software engineers' technical expertise.

About forty years ago, small software programs were deployed to regulate engines and ignition systems in the automotive industry. In the automotive sector, the initial generation of software functions was purely local, and they were technically and functionally separated from other software operations (Ballamudi, 2020). These days, the jobs software performs in automotive systems are numerous and pervasive. They range from low-level control software to modern driver-assistance and infotainment systems and everything in between. In addition, they have a high degree of interactivity and are dispersed among various electronic control units (ECU), all connected via several networks within the vehicle (Ballamudi et al., 2021). Today, software-intensive systems are responsible for more than 80 percent of the advancements made in the automotive sector. This is demonstrated by premium vehicles, which have approximately 270 user tasks and as many as 2500 separate atomic software functions, all spread over 70 embedded platforms. In addition, the quantity of software found in automobiles has increased from 0 to hundreds of millions of lines of code over the past four decades, and this trend of expansion is anticipated to continue into the foreseeable future (Bodepudi et al., 2019). The availability of inexpensive and powerful hardware resources, as well as the need for innovation and new functions, are the primary factors that have contributed to this rapid development (Desamsetti & Lal, 2019). Through the electrification of automotive systems, the implementation of software in the automobile industry has not only made it possible to realize creative functionalities. Still, it has also resulted in a reduction in gas consumption and improvements in overall performance and levels of comfort and safety (Desamsetti, 2018). In addition, the software has a negligible cost of replication, allowing hardware to be reused in various vehicles, and enables mass differentiation and customization, all of which contribute to its economic significance (Desamsetti, 2020).

In general, despite the many obstacles that have been placed in its path, software engineering has emerged as an essential subject in the automobile industry, particularly in promoting innovation and intensifying competitiveness. Many underlying factors contribute to these difficulties, such as the one-of-a-kind qualities of the automotive industry, the distributed nature of software functions, and the ever-increasing demand for non-functional requirements like safety, reliability, and performance (Thaduri, 2017; Thaduri, 2018). The automobile industry has developed and embraced several standards, solutions, and platforms to manage this complexity better. These countermeasures include both product-based and process-based countermeasures. Therefore, the software-intensive systems used in modern automobiles are developed based on and in compliance with several different standards and models (Ballamudi, 2016). These include Automotive SPICE, ISO-26262, the Motor Industry Software Reliability Association (MISRA), AUTomotive Open System ARchitecture (AUTOSAR), OSEK (open systems and their interfaces for the

electronics in motor vehicles), and a great deal of other models and standards. Even while the automobile sector might generally adopt the results and solutions presented in the body of knowledge gathered by software engineering in other domains, the specific characteristics, restrictions, and requirements of the automotive industry require individual solutions to be developed (Harris, 2013). The research goal in software engineering has shifted from finding universal answers through various concepts, models, and technologies to developing domain-specific solutions that capitalize on the particularities of a given domain. It is possible to make the case that the automotive industry is a prominent example of this type of development through the adaption, design, and exploitation of domain-specific technologies (Lal, 2016). It is possible to identify the development of the field of research known as automotive software engineering (ASE) as a direct consequence of the efforts made to investigate the existing knowledge in software engineering to design software-intensive automotive systems. In the past several years, a considerable body of knowledge and evidence has been produced due to various published studies studying how software engineering has been used to create automotive software-intensive systems (Lal, 2015). Various researchers have conducted these studies and published them in academic journals. On the other hand, work that has yet to be done in the past has provided both a comprehensive overview and a panoramic picture of how software engineering methods have been applied to construct software-intensive automotive systems (Gutlapalli, 2016b).

AUTOMOTIVE SOFTWARE ENGINEERING

Connecting embedded software with massive IT systems, developing it globally in scattered teams, and having one of the lowest cycle times in all industries make automotive software development challenging. Modern cars use 50 to 120 embedded microcontrollers and external ports to link to cloud and infotainment systems. Onboard software is 100-MLOC and growing exponentially. Automotive software is among the most extensive and most complicated in all sectors. Many say the car is becoming a "computer on wheels." Automotive suppliers and manufacturers drive software engineering technology breakthroughs (Pike et al., 2017). Automotive development processes are above average due to liability issues. Process quality must be measured and enhanced across the supply chain. Automotive SPICE is the de facto development standard (Hosen & Gutlapalli, 2021). Original equipment manufacturers require vendors to be mature 2 or 3 across the value chain. System-level modeling and traceability from requirements to design began in aerospace but are now widely employed in automotive. Automotive businesses like Toyota pioneered lean, agile development (Gutlapalli et al., 2019).

In this market, quality, timeliness, and cost are crucial. Thus, processes and project management are improving rapidly. Demand for agility and flexibility is rising. Users demand mobile-device-like adaptive behaviors and continuous delivery methods (Thaduri, 2018). Rapid improvements in autonomous driving and open car communication are stretching standardization as developers battle with legal and ethical responsibilities, cybersecurity, and short-cycle recertification after OTA software changes. BMW, Bosch, Daimler, Ford, GM, Hyundai, Magna, Toyota, and ZF pioneer embedded software technology, global software engineering methodologies, and collaboration tools. Many are creating global IT development centers to accelerate IT-electronics convergence (Gutlapalli, 2017a). Many new firms like Apple, Google, and Huawei are entering the automotive software business because of their fast growth, double-digit market penetration, and good profitability.

OUTLOOK ON AUTOMOTIVE SOFTWARE

Automakers and government agencies like the NHTSA and the National Academy of Sciences have launched high-profile investigations into recent incidents involving braking problems and unintended acceleration that resulted in fatalities, injuries, or high levels of distress among drivers and passengers (Ballamudi & Desamsetti, 2017). Congress held hearings on the occurrences and the manufacturer's response. Once discussed only by electrical and mechanical engineers and a few software engineers who entered the car industry, automotive software and electronics today receive extensive national media coverage. Automotive electronics, especially software, dominate the automotive engineering process. Software generates 38% of car electronics value worldwide by 2010. Software drives most automobile improvements, including increased fuel economy, decreased emissions, and higher safety and comfort standards due to automated fuel injection and motor control, stability control, and park assistance (Shu et al., 2016).

Driver safety may be improved through automobile electronics and software. In some studies, stability control alone reduced fatal single-car accidents by 30%–50% and sports utility vehicles by even more (Gutlapalli, 2017b). Contrary to the perceived and genuine increase in accidental acceleration incidents. According to a recent article, Americans have a 19 one-thousandth of one percent chance of dying in an automobile crash in the next two years. Even though recorded incidences have increased in recent months, driving a car of one of the implicated brands very slightly increases these odds (Thaduri, 2019). After rounding off, they stay at 19 one-thousandths of one percent.

Thus, automobile software and electronics have lowered important accident classes on average. Intentional acceleration causes more accidents than unintended acceleration. Recent probes are noteworthy for what isn't mentioned and done (Thaduri & Lal, 2022). Despite the intricacy of vehicle electronics and software, we still need to prove that some situations, such as unexpected acceleration, are excluded (Mandapuram et al., 2018). We cannot trace an observed failure incidence to its root because much of the information needed to analyze an incident is the sequence of signal exchanges and other events that led to it. Today, most of this information is only available briefly on communication buses and is lost when the electrics/electronics are turned off (Ballamudi, 2019a). These two inabilities inspire a wide variety of suspicions and hypotheses that may never be resolved or maybe "resolved" in court.

The thousands of interrelated software functions running on up to 80 electronic control units (ECUs) scattered over numerous network systems across the vehicle make automobiles today complex, which must be handled (Gutlapalli, 2016a). One could argue that much of this intricacy is inadvertent. Organic growth of electrics/electronics infrastructure feeding hard real-time safety crucial engine management, comfort electronics, and infotainment systems is mainly responsible. Many isolated subsystems became heavily networked during approximately four decades (Thaduri, 2020). Car firms have become system integrators, receiving, calibrating, and merging subsystems from massive, often multitiered vendors to create an unparalleled number of vehicle platform variants. The sophistication and in-house expertise of software systems, their relationships, and, most crucially, how they execute the automobile's needs increasingly influence car makers' success in providing revolutionary features (Kruger, 2010).

Complexity is increased by varied needs, extensive product life cycles, demanding time-to-market, and the necessity for competitive unit costs (Ballamudi, 2019b). Automotive mass-

market economics distinguishes it from avionics. Even little unit cost savings add up to millions of dollars and hundreds to thousands of jobs for manufacturers and suppliers. Recalls, "bad press," and liability claims create the opposite impact.

New developments: Car manufacturers and suppliers have invested much and developed standardization groups like the automotive open system architecture (AUTOSAR) consortia to address this difficulty. They focus on eliminating incidental complications and providing a disciplined, architecture-centric approach to vehicle electronics and software (Dekkati & Thaduri, 2017). Market and policy implications exist. Customers will demand minimal safety requirements, affecting electronics and software development (Mandapuram et al., 2020). Demands for brake override systems—already available on many automobiles but absent from others making headlines—to prioritize the driver's desire for stopping over acceleration, wherever the latter may have originated, are already having an impact. Mandatory stability control is one example of new traffic safety regulations. The trend is toward greater alignment with safety-relevant and software-intensive fields like avionics and train transportation systems (Ballamudi, 2019c).

Due to increased networking within and beyond car boundaries, automotive security issues like who gains access to the vehicle and, more importantly, the vehicle's electric/electronic functions will be as important, if not more so, than adding new features. Disgruntled employees have used wireless vehicle access to manipulate core vehicle capabilities from afar using a device designed for remote immobilization in car payment delinquency situations (Oliynyk et al., 2017).

Future cars will have written vehicle, subsystem, and component requirements with traceability. It will trace these requirements to an overall system architecture so manufacturers and suppliers can determine compatibility between components, subsystems, the vehicle, safety features, and failure sources at the architecture level rather than by dissecting partial information distributed over space and time across development processes and "runtime" (Hosen et al., 2021). Instead of costly and error-prone rework from vehicle to vehicle and product line to product line, this will encourage the reuse of established concepts (Mandapuram & Hosen, 2018). It will provide car-wide diagnostic capabilities beyond ECU error codes to enable quality assurance, incident analysis, and product line development. It will give car-wide software lifecycle management from deployment to update and replacement and system-wide energy distribution, failure management, access control, and information assurance policies (Dekkati et al., 2019).

NECESSITY OF AUTOMOTIVE SOFTWARE DEVELOPMENT

The development of automotive software, which uses artificial intelligence and machine learning principles, presents various prospects and advantages for businesses and their customers (Thaduri, 2021). The following is a list of some of the most critical areas for software development in the automotive industry:

- Processing the ever-changing demands of the customer.
- Creating and implementing brand-new functionalities for the vehicle.
- Ensuring that transportation operations are both dependable and safe.
- Having completed rigorous testing to meet the requirements of the specification.
- Offering remote diagnostics of the state of a vehicle's health and administration of a fleet.

- Ensuring the confidentiality of remote access to critical vehicle data from any location.
- Installing updates to the car's firmware remotely.
- Developing highly effective software for tracking vehicles.
- Providing software for professional drivers' navigational needs in their vehicles.

BENEFITS OF AUTOMOTIVE SOFTWARE DEVELOPMENT

Accident Reduction: Foremost among all other considerations, the operation of any vehicle necessitates the most excellent standards of safety, both from the point of view of the manufacturer and of the end-user (Mossinger, 2010). Embedded sensors and specialized software designed for use in autos have the potential to make digital cars significantly safer in general, particularly in comparison to conventional motor vehicles. It is common knowledge that drivers are to blame for most motor vehicle accidents. Technology has the potential to drastically reduce the number of accidents that occur daily by addressing frequent driver errors (Lal et al., 2018). Automated early warning systems can prevent drivers from drifting into another lane, while advanced automobile control systems can begin braking or steering to avoid collisions (Lal & Ballamudi, 2017). Both of these safety features are designed to keep drivers and passengers safe.

Predictive Maintenance: Routine vehicle maintenance helps keep an owner's annual operating costs down and lessens the likelihood that an accident will occur on the road or that our vehicle will break down in the middle of nowhere (Desamsetti & Mandapuram, 2017). Both of these outcomes are avoidable. When our car's tires need more air or when our vehicle needs more water to prevent overheating, software designed for automobiles can let us know when these things are necessary. Real-time data for every aspect of the vehicle's operation is provided via sensors embedded throughout the vehicle (Desamsetti, 2021). When a vehicle's owner is given real-time warnings about impending breakdowns, they can make more informed choices in a shorter amount of time, lowering their expenses for repairs and creating a more secure driving environment (Chen et al., 2019).

Intelligent Diagnostics: It is now possible to drastically minimize the time our vehicle needs to spend at the mechanic's garage. This is possible because cars increasingly contain millions of lines of code and are controlled by intelligent software (Desamsetti, 2016a). Traditionally, auto mechanics can spend much of their customers' money and a significant amount of time just trying to figure out the problem with their vehicle. For instance, to locate the source of the problem, a faulty component on a relatively minor scale may have necessitated the complete disassembly of an automobile engine. A technician can almost instantaneously identify a problematic component in a vehicle by using innovative diagnostic software for vehicles. This results in a significant reduction in the amount of time spent on labor and total costs for the vehicle owner.

Customer Service: The consumer of today, who is already accustomed to the versatility of online shopping, anticipates having a more significant influence over purchasing and owning a vehicle. The habit of maintaining an "always-on" connection to automobile dealerships and communicating with salespeople via instant messaging is rapidly becoming the norm. A prospective purchaser has to be able to communicate with a

seller at any time and in any location using whatever device they choose (Desamsetti, 2016b). The ability of automotive software to facilitate quick and painless interaction between businesses and their customers ultimately leads to increased customer satisfaction (Dekkati et al., 2016). Now, software is used to arrange test drives, discuss automotive finance options, and pick vehicle maintenance and repair plans.

Fuel Efficiency: Companies responsible for managing fleets of transport vehicles for their products should prioritize energy savings and efficiency. The development of software for automobiles can result in savings on the cost of fuel by the following means (Ebert & Favaro, 2017).

- Increasing the fuel efficiency of automobiles and trucks.
- Identifying drivers who are considered "problematic."
- Keeping tabs on the amount of fuel used.
- Identifying the activities that result in unnecessary fuel waste.

This kind of software can assist businesses in monitoring the amount of gasoline used by huge fleets and optimize their products' routes to ensure the lowest possible carbon emissions and the highest possible fuel economy (Reddy et al., 2020). Software has a significant impact on the overall energy efficiency of a vehicle. This is true whether the software in question is an intelligent cruise control that improves fuel usage by managing the acceleration and deceleration of the vehicle or optimized engine settings with dedicated parameters that reduce fuel usage (Mandapuram, 2017a).

Autonomous driving: Are you concerned about our elderly parents or our teenage son getting behind the wheel of our expensive vehicle? These concerns may quickly become a thing of the past once the widespread use of autonomous automobiles becomes a reality. A digitized car must be equipped with several intelligent sensors integrated throughout the vehicle to be capable of autonomous driving (Gutlapalli, 2017c). Among the many advantages are:

- Increased protection for motorists.
- The link between modes of travel has been improved.
- A lessening of the traffic on the roads.
- Pollution and emissions have been cut down significantly.
- More comfort and dependability are at our fingertips.

AUTOMOTIVE ELECTRONICS AND IT

Electronics and information technology in automobiles are undergoing rapid development. Automobiles and public transportation are two examples of the types of transportation brought together by multimodal mobility. Mobility-focused services, such as car sharing, establish ecosystems and business models that are very different from the traditional strategy of purchasing one's vehicle (Amin & Mandapuram, 2021). The functionally segregated control units already in use cannot compare to the requirements for highly interactive services and multisensor fusion that come with autonomous driving. Connectivity and infotainment are changing automobiles into distributed information technology systems that include cloud access, over-the-air (OTA) functional upgrades, and high-bandwidth connection to mapping services, media content, other vehicles, and the infrastructure in the surrounding area (Deming et al., 2018)). The traditional powertrain is replaced with high-voltage hybrid and

electric engines to improve energy efficiency (Yin et al., 2012). IT will converge with embedded-system paradigms such as the Internet of Things (IoT) and Industry 4.0, with automotive applications as a significant driver. At the same time, embedded industries will advance toward IT with cloud solutions and dynamic OTA upgrades.

Automotive software, in contrast to software used in any other industry, must fulfill virtually all quality requirements, including those about safety, cybersecurity, usability, performance, and adaptability (Koehler et al., 2020). It encompasses everything, from embedded real-time firmware to complicated solutions for encrypted cloud storage. The company may be subject to costly recalls and legal action if these quality requirements are unmet. These problems will quickly spread to all sectors of the economy.

Drivers of today's vehicles are increasingly making their selections based not only on the outside styling or performance of a vehicle's engine but also on the ecological footprint of the vehicle and the software applications it comes equipped with. It is the primary driver of innovation in the automotive industry (Thaduri et al., 2016). Already, software-driven solutions have opened the market to new competitors with strong IT backgrounds who are teaming up with or competing against existing automobile manufacturers.

Connectivity is one example of this lightning-fast evolution. IT and software solutions based on new computer paradigms and infrastructure are required to facilitate enhanced driver interaction, fluid upgrade procedures, predictive maintenance, fleet management, and other similar functions. Examples include scalable automotive designs that permit seamless communication, robust infrastructures for V2X (vehicle-to-everything) systems with safety-critical demands, and data analytics to predict essential maintenance and improve the customer experience. These examples apply to the automobile industry (Aerts & Schaminée, 2017).

Connectivity raises new concerns about information security, as well as its robustness and usability. Both potential liability and economic models are significantly influenced by a system's level of security and robustness. The more we network and share information, the more vulnerable we are to many attacks (Thaduri & Lal, 2020). This influence is reflected in the rapidly growing demand for end-to-end corporate processes protected by security schemes and secure software. Imagine autonomous driving equipped with multisensor fusion coupled with GPS and vehicle-to-vehicle communication. This enables the system to identify crucial scenarios and foresee suitable measures where even the driver might not know what will happen (Bodepudi et al., 2021).

Usability must be prioritized if complexity and scale are to be overcome. We are already confronted with scenarios in which drivers are overwhelmed by the range of help functions and, at times, rely excessively on the integrated IT rather than maintaining control of the vehicle. Inadequate usability significantly contributes to crucial errors that humans generate in healthcare, transportation, and production plants (Thodupunori & Gutlapalli, 2018).

CONCLUSION

Each of these shifts, on their own, is significant. Regarding consumer electronics and traditional information technology, safety, performance, and usability are not necessarily required skills; they are essential for modern IT. When taken together, these developments indicate one thing very clearly, even though it is not impossible to handle them: the software endeavor that is automotive electronics is the most demanding software endeavor we can conceive. Young engineers looking for real challenges and rapid innovation cycles will find

it an ideal work environment. The famed automotive entrepreneur Robert Bosch said, "Without exception, our aim must be to improve the current status; and instead of being satisfied with what has been achieved, we must always strive to do our job even better." Let's evolve the essential technology, processes, and competencies in the right direction to maintain control and clear the many dangers inherent in traditional IT systems.

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