Electrics/Electronics Platforms in the Automotive Industry: Challenges and Directions for Variant-Rich Systems Engineering

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ABSTRACT

Within the automotive industry, platform strategies are successfully used to efficiently develop large variant-rich systems. In parallel, new features in automotive systems continue to originate more and more from software-driven rather than hardware-driven innovations. To manage the growing relevance of software, automotive companies increasingly adopt concepts and methods from software-platform engineering, such as software product lines. However, there is a lack of concepts for integrated systems-platform engineering to support the management of hardware, software, and particularly their interactions within a (cyber-physical) variant-rich system. One particular concept that has been proposed to manage automotive-systems engineering are electrics/electronics platforms, but these are not well researched in the context of managing variant-rich systems. In this paper, we investigate the feasibility of electrics/electronics platforms for managing variant-rich automotive systems throughout their whole life-cycle with their increasing share of software as well as of hardware-software interactions. For this purpose, we build on literature to elicit and compare concepts of electrics/electronics platforms with those of software and hardware platforms, and map these concepts to state-of-art practices employed at one automotive company. Based on these comparisons, we identify key challenges and research directions to move towards the practical adoption of electrics/electronics platforms in the automotive industry.

CCS CONCEPTS

• **Computer systems organization → Embedded systems**; • **Software and its engineering → Software product lines**; **Maintaining software**.

KEYWORDS

automotive, variant management, electric/electronic platform, life-cycle management, cyber-physical system

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1 INTRODUCTION

To provide an attractive product portfolio to their customers, automotive companies have to offer vehicles with constantly evolving features. Trends like connected vehicles, electric mobility, and autonomous driving lead to an increasing amount of digitization, resulting in more and more software being integrated into vehicles.[1] Still, the underlying foundation of any vehicle remains the hardware platform, based on which comfort and safety features are build to fulfill customer as well as legal requirements—and into which innovative features must be integrated [19]. As a consequence, while most engineering in the automotive industry has focused on hardware and mechanical components in the past, there has been a constant shift towards more and more software-based features.

Due to this shift, software and its interactions with a vehicle's hardware have become key properties of any vehicle to fulfill customer requirements and engineer an innovative product [21, 41]. Consequently, vehicles are transitioning from mechanical products towards software-centered cyber-physical systems; thereby enabling and integrating novel features, such as over-the-air updates or self-driving capabilities, that require interactions between software, hardware, and the environment [13, 28, 65]. While providing tremendous opportunities for innovations, the growing importance of software in the traditional hardware platforms has raised novel challenges, particularly with respect to managing and mapping the variability across all artifacts [4, 8]. In fact, the complexity of vehicles and of their development has led to disproportionately rising expenses and efforts, which is why effective and efficient variant management has become one of the most important success factors in the automotive industry [5, 17].

[1] https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/disruptive-trends-that-will-transform-the-auto-industry/de-de

To manage their variants, automotive companies are using various concepts for structuring their product portfolios, for instance, platform strategies to enable reuse and organize the complexity of modern vehicles [2, 58]. However, current platform strategies focus mainly on mechanical vehicle components, missing out on software as well as electrics/electronics components [2]. Even with the increasing adoption of variant-management concepts from software engineering, such as software product lines [23, 36, 48, 63], a holistic platform perspective that spans all dimensions of a modern vehicle is challenging to achieve. Automotive companies demand for such a holistic platform perspective to improve the integration of hardware and software artifacts, while also considering dependencies between both, interactions with the environment, as well as the artifacts' entire life-cycles [27, 54]. A possible solution that has been proposed in the literature are electrics/electronics platforms, which combine concepts from hardware and software platforms with the goal of creating a holistic vehicle architecture that helps to scale the reuse, efforts, and costs of engineering vehicles [26, 49].

In this paper, we compare hardware, software, and electrics/electronics platforms to understand and map their concepts to each other. Building on this comparison and our expertise in the automotive domain, we discuss concrete challenges of adopting electrics/electronics platforms in practice, and consequent research directions. More precisely, we contribute the following:

- We discuss and compare the concepts of hardware, software, and electrics/electronics platforms to understand their similarities and differences, and how these concepts connect to engineering automotive variant-rich systems.
- We build on our comparison and expertise in the automotive domain to describe challenges of adopting electrics/electronics platforms in practice—for which we focus on challenges regarding the evolution and maintenance of electrics/electronics platforms.
- We discuss what future research on platform engineering as well as platform life-cycle management is required to facilitate the adoption of electrics/electronics platforms in practice by considering how to integrate and extend the concepts of hardware and software platforms.

Our contributions help practitioners obtain an understanding of the different platforms strategies, their concepts, and their relations to the automotive domain. We hope that our contributions further foster novel research with a close connection to industry, particularly in the automotive but also other cyber-physical systems domains.

The remainder of this paper is structured as follows. In Section 2, we describe our research methodology for comparing the different platform strategies and for deriving challenges as well as directions for future research. We then compare the different platform strategies by building on the related work in Section 3. Afterwards, we discuss the challenges and research directions we derived in Section 4. Finally, we conclude this paper in Section 5.

2 METHODOLOGY

In this section, we outline our methodology for comparing the different platform strategies and for deriving adoption challenges as well as research directions for electrics/electronics platforms.

2.1 Comparing Platform Strategies

For our comparison of the different platform strategies, we built on our knowledge of the related work in research and our experiences from practice. Namely, the first two authors are working for multiple years and in different departments for one of the largest, international automotive companies, focusing on the areas of platform engineering, variant management, and life-cycle management. In this context, the authors are investigating novel concepts for improving variant management and how to adopt it in practice. Consequently, they have a detailed understanding of the current practices of variant management as well as platform engineering in the company, related standards, and industrial best practices. Additionally, they are constantly investigating new trends to identify opportunities for improvement, also comparing different strategies and concepts, such as different platform strategies. In contrast, the last two authors are researchers and have a detailed understanding of the related work on (software) platform engineering [33–36, 38, 39, 42]. They contributed their overview of the related work and helped map the existing concepts from practice and research.

To initiate our research, the authors from the company sketched and compared the platform strategies currently employed in industry. Then, all authors reiterated through this comparison cooperatively to map concepts from the related work onto the existing comparison. For this purpose, we used the descriptions of current industrial practices and discussed the underlying concepts, which we then assigned to the concepts of hardware, software, or electrics/electronics platform engineering. Based on the understanding we achieved, we demonstrate how electrics/electronics platforms provide a suitable basis for integrating the concepts needed for engineering automotive variant-rich systems. To exemplify this comparison, we discuss the adoption of electrics/electronics platforms based on real-world experiences.

2.2 Deriving Challenges & Research Directions

Afterwards, the authors from the company identified what concepts, processes, or other properties of electrics/electronics platforms may cause challenges during the adoption of such platforms in practice. Particularly, they focused on recent trends within the automotive industry, and aimed to understand to what extent variant and life-cycle management of artifacts are supported within electrics/electronics platforms—and what concepts of hardware or software platforms may be missing or could be helpful to integrate. Using the identified challenges and the comparison of platform strategies, we derived directions for future research on electrics/electronics platforms in the automotive industry or cyber-physical platforms in general. To this end, we mapped the challenges we identified to their corresponding concepts of the platform strategies, to then identify the underlying conceptual research problems.

3 COMPARISON OF PLATFORMS

Next, we describe the fundamentals of hardware, software, and electrics/electronics platforms. Afterwards, we compare their differences and commonalities to then discuss how particularly electrics/electronics platforms can be of use for the life-cycle and variant management in the automotive industry.

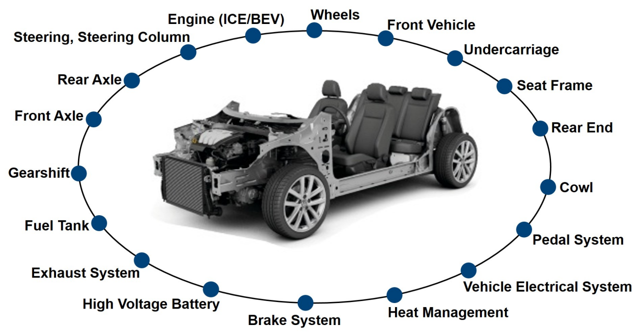

Figure 1: Components of a conventional automotive hardware platform based on Frank et al. [15].

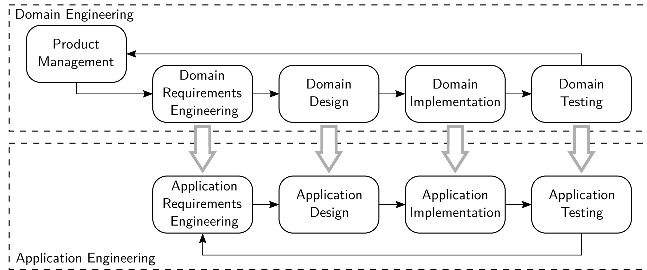

Figure 2: Overview of software-platform engineering based on Pohl et al. [48].

3.1 Hardware Platforms

Hardware platforms have been adopted for a long time in the automotive industry to reduce the complexity, time, and costs of engineering vehicles through standardization and reuse of components. As a consequence, hardware platforms have allowed automotive companies to achieve competitive advantages in terms of mass-engineering customized vehicles, which also enable companies to move to different markets more easily [9, 32, 59]. Unfortunately, the term (hardware) "platform" has been defined in various ways in the scientific literature [7]. However, building on established definitions, we can summarize the following key properties of a hardware platform [24, 44, 55, 64]:

- A platform serves as an overarching foundation for creating different product variants.
- The product variants are derived based on interchangeable modules of the platform.
- A single platform is used for all products of a defined product family, while multiple platforms are used in parallel to fulfill diverging requirements.
- The life-cycle of a platform typically exceeds the product variants' (i.e., vehicles) life-cycles.

Regarding the automotive industry, the term "hardware platform" refers to physical artifacts of a vehicle that define overarching framework conditions for deriving different vehicle models within a product line [45].

According to Hüttenrauch and Baum [25], a hardware platform as a technical basis provides a design framework for the main vehicle dimensions, without directly affecting the exterior design of a vehicle. By building on a hardware platform, between 30 % and 60 % of a product's costs are related to platform components that bundle core vehicle technologies [31]. Frank et al. [15] illustrate the key platform components of current automotive hardware platforms including, for example, the floor assembly, drive train, steering train, and axles (cf. Figure 1). Based on the original understanding of a hardware platform, Frank et al. investigate how to assess the strategic value of platform variants in the automotive industry. As we can see in Figure 1, platform variants in the automotive industry are the consequence of a wide range of vehicle components and their consequent requirements within a product family. The resulting large product portfolio leads to a high number of platform variants, with the portfolio typically evolving and further expanding during the life-cycle of a hardware platform. This poses a significant risk to achieving the key objectives of a platform strategy, namely scaling reuse, standardization, and costs. Consequently, consistent variant management throughout a platform's life-cycle is required to manage hardware platform variants efficiently [15].

3.2 Software Platforms

Due to the growing relevance of software in the automotive industry, there is an increasing demand for concepts to reduce the complexity and increase the efficiency of developing vehicle software [47, 61]. For this reason, the automotive industry is increasingly adopting concepts from computer science, and software engineering in particular. One of the most important concepts in this regard are software platforms build upon software product-line engineering, which enable companies to systematically reuse software artifacts and manage the variants of a software-intensive product portfolio [6, 28, 36, 40, 48, 63]. As we display in Figure 2, product-line engineering is divided into the sub-processes of domain engineering and application engineering [14, 30, 48]. Within the domain engineering, the software platform itself is engineered; involving all software artifacts and the variation points of the product line. The resulting software platform defines all reusable artifacts, their dependencies and constraints, as well as how to derive concrete variants [40, 43, 50]. In the application engineering, the software platform artifacts and constraints are used to derive a concrete product configuration according to specified customer requirements [40, 61]. Similar to hardware platforms, a software platform promises to decrease costs, reduce the time-to-market, and improve software quality by enabling reuse and systematic variant management [11, 12, 35, 60, 63]. Despite the promising benefits, software platforms are no yet fully established in the automotive domain. A particular reason for this are the historical reliance on hardware platforms, as well as dependencies between hardware and software components as well as manufacturers—which demand for a more integrated perspective on and support for engineering vehicles as cyber-physical systems [27].

In automotive systems, electric control units are used to implement components that build upon software. Typically, a vehicle feature is partitioned into different electric control units, with one unit also covering multiple vehicle features—thus, resulting in a high degree of interconnection between the electric control units in

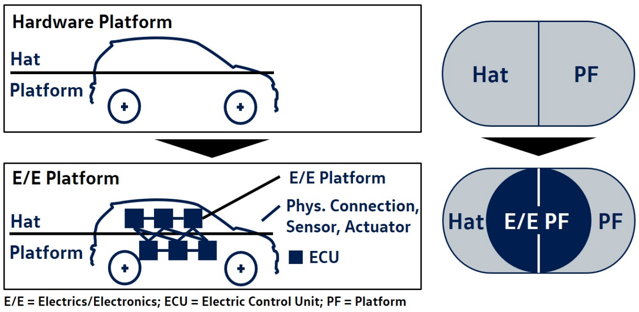

Figure 3: The electrics/electronics platform concept.

a vehicle. Together with sensors and actuators to measure properties of the vehicle and its environment, the various electric control units are accumulated into a vehicle electrics/electronics architecture [3, 53, 57]. Vehicles can therefore be considered as cyber-physical systems in which the electric control units serve as embedded systems to integrate hardware and software [28, 65]. To account for the strong dependency of software artifacts on hardware components as well as the high level of functional connectivity in automotive systems, the electrics/electronics platform concept has been established as an extension to hardware and software platforms.

3.3 Electrics/Electronics Platforms

An electrics/electronics platform is defined as a set of electrics/electronics components providing an overarching basis to derive a vehicle-specific electrics/electronics architecture (cf. Figure 3) [27, 49]. Analogous to hardware or software platforms, the electrics/electronics platform is used as a common basis to create specific applications (i.e., vehicles). As we display in Figure 3, a typical hardware platform serves as the basis on top of which the so-called "hat" (i.e., all design-relevant vehicle components, cf. Figure 1) is placed. The electrics/electronics platform integrates all software artifacts from both hardware platform and hat (i.e., the software platform, cf. Figure 2) as well as their physical implementation within electric control units—forming an interconnected embedded system. So, an electrics/electronics platform can be considered as a connection layer for the close integration of hardware and software within a cyber-physical system. Inherently, the electrics/electronics platform is limited neither to hardware nor software artifacts, but includes all components of the electrics/electronics architecture to optimize standardization and synergies. A key factor for the successful development and implementation of an electrics/electronics platform constitutes a high level of usability regarding different vehicle body styles, equipment lines, or sales markets. In addition, a certain degree of adaptability must be ensured to enable further development of the electrics/electronics platform in line with new innovations and technological changes during its life-cycle [27, 49].

3.4 Interconnections

Engineering an electrics/electronics platform requires the integration of novel concepts into existing platform strategies of automotive companies [27]. Within the automotive industry, the hardware-platform concept is widely used to efficiently develop and manage extensive product portfolios, while software platforms still play a minor role up to this point in time. Electrics/electronics platforms represent a concept for integrating hardware and software platforms, but they do not build on exactly the same concepts as these two. In Figure 4, we display the interaction between an electrics/electronics platform and a hardware platform, as well as the derivation of individual vehicles. As we can see, the implementation of an electrics/electronics platform does not influence the platform strategy itself. Both platform strategies can coexist, keeping the original division of a vehicle into platform and hat (cf. Figure 3). Within this mapping, the electrics/electronics platform introduces a new level of abstraction for structuring products, which contains all electrics/electronics components from both platform and hat to provide a cross-vehicle basis that aims to increase reuse and standardization of software-intensive components. As a consequence, a vehicle continues to be represented by a combination of platform and hat, but the electrics/electronics platform provides additional possibilities to utilize cross-vehicle synergies of the electrics/electronics architecture [18, 49].

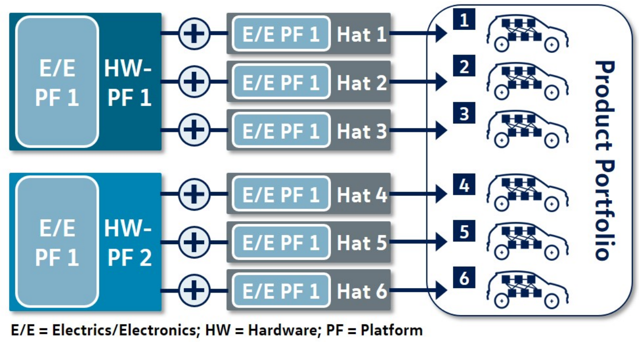

Figure 4: Conceptual interaction of hardware and electrics/electronics platform.

The efficient interaction of hardware and electrics/electronics platform requires a high amount of planning and development effort, which is intensified by the extensive product portfolios of automotive companies and the resulting variability [26, 54]. Similar problems and concepts have been adopted from hardware to software platforms, and particularly software product-line engineering provides concepts to guide the design of electrics/electronics platforms, for instance, feature modeling [1, 29, 46], variant management, or feature interactions. In practice, the diverging vehicle requirements lead to an additional level of variance below the platform, which is referred to as the platform-variant level [15]. For the electrics/electronics platform, this platform-variant level has not yet been assessed. However, strong implications of the electrics/electronics platform on the vehicles' features indicate similar challenges for the electrics/electronics platform regarding standardization and the diverging vehicle requirements.

3.5 Automotive Electrics/Electronics Variants

Platform strategies in the automotive industry aim to optimize synergies and economics of scaling through standardization and systematic reuse. However, in practice, hardware vehicle platforms

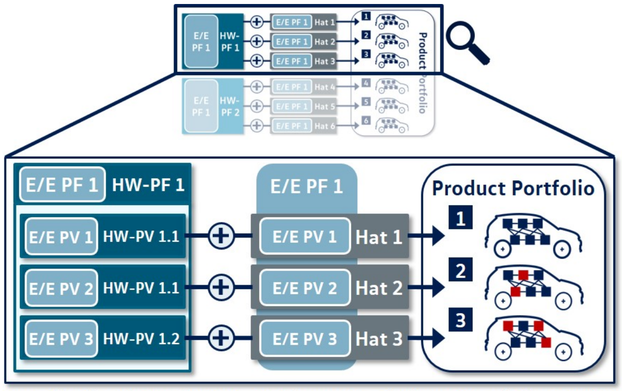

Figure 5: Electrics/electronics platform variant.

are split into individual platform variants, due to extensive product portfolios and the resulting broadly diverging vehicle requirements. We can expect the same mechanism for the implementation of electrics/electronics platforms in the automotive industry. While the literature defines an electrics/electronics platform as a constant basis for deriving different product configurations, in practice, the wide spread of individual vehicle requirements leads to a fragmentation of the electrics/electronics platform into electrics/electronics platform variants. Analogous to a hardware platform variant, the basic structure of the platform, in the case of the electrics/electronics platform the underlying electrics/electronics architecture, remains identical across all platform variants. However, variability of individual electrics/electronics components that violate the interface compatibility within the electrics/electronics architecture lead to electrics/electronics platform variants. Additional electrics/electronics platform variants are thus created as soon as a change to an electrics/electronics component results in adjustments to other electrics/electronics components within the electrics/electronics platform, due to the lack of interface compatibility. Those incompatibilities can be triggered by changes in the hardware as well as software.

In Figure 5, we display the interaction between the hardware platform and the electrics/electronics platform, taking into account the (electrics/electronics) platform variance in practice. We display that, contrary to the original platform definition, both the hardware platform and the electrics/electronics platform contain additional platform variants to fulfil the individual vehicle requirements. Despite building on consistent fundamental properties, individual vehicles demand technical adjustments to the (electrics/electronics) platform, resulting in an intensification of (electrics/electronics) platform variability and complexity.

4 CHALLENGES & RESEARCH DIRECTIONS

Reflecting on the background of platform concepts and the practical exemplification of the platform-variant level (cf. Section 3), we can deduce the control of complexity—in particular software complexity—as a key challenge for automotive companies. The electrics/electronics platform concept addresses this issue by serving as a concept to efficiently develop and manage software-intensive product portfolios. However, different challenges exist for effectively applying the electrics/electronics platform concept in the automotive industry; many of which relate to software, and thus require a better integration of software-platform concepts. In the following, we discuss key challenges for the practical application of electrics/electronics platforms based on our analysis of different platform concepts complemented by the authors' practical expertise. Subsequently, we use the results to derive directions for future research that support a successful implementation of the electrics/electronics platform concept in the automotive industry.

4.1 Electrics/Electronics Platform Challenges

The electrics/electronics platform concept is considered suitable for structuring products in automotive companies to complement the existing variant management, taking into account that today's vehicles are software-intensive cyber-physical systems. As we described, an electrics/electronics platform strategy aims to provide a cross-vehicle electrics/electronics architecture to achieve a low level of complexity through reuse and synergy effects as well as to maintain this architecture throughout the life-cycle of the electrics/electronics platform. However, the vehicles' life-cycles typically exceeds the life-cycle of the individual electrics/electronics components [57]. In addition, vehicles based on the electrics/electronics platform are successively launched and updated several times throughout their life-cycle [52]. Managing the platform complexity while enabling new technologies and taking into account the short (software) life-cycles poses a significant challenge for the practical application of electrics/electronics platforms.

C_1: Life-Cycle Differences

A vehicle as a cyber-physical system combines hardware and software components with varying innovation life-cycles, resulting in the challenge of controlling complexity and innovations throughout an electrics/electronics platform's life-cycle.

Short software life-cycles not only impact the development and production of new vehicles, but also the existing vehicles in the field. To keep the current vehicle fleet up to date, automotive companies are increasingly using over-the-air (OTA) software updates, which provide customers with the latest vehicle software regardless of time and location [20, 22]. For automotive comapnies, there are different use cases for OTA software updates. On the one hand, OTA software updates can be utilized to deliver simple and fast bug fixes without the need for workshop visits or recalls. On the other hand, OTA software updates offer automotive companies the possibility of additional business models through functional enhancements for vehicles in the field, for example, by activating extended driver assistance systems. OTA software updates thus provide customers with several benefits, which is why the technical and structural facilitation of OTA software updates becomes essential for electrics/electronics platforms. [13, 20]

C_2: Software Updates

The reliable implementation of over-the-air updates is increasingly impacting customer satisfaction. Thus, electrics/electronics platforms face the challenge of technically and structurally enabling software updates over-the-air, while also considering variability.

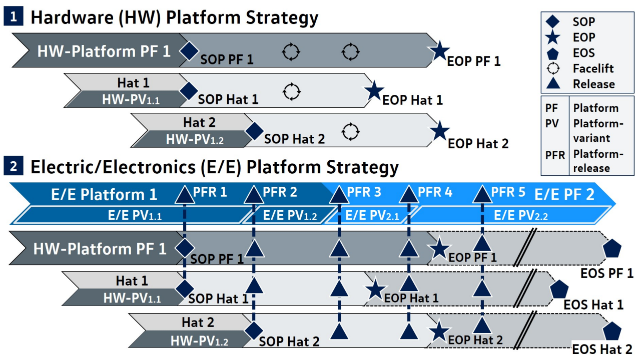

Figure 6: Life-cycle comparison of a hardware platform and an electrics/electronics platform.

In addition to technical requirements, the implementation of OTA software updates also impacts the organizational structure of automotive companies. To demonstrate such impacts, we compare the life-cycles of an electrics/electronics platform and a hardware platform in Figure 6. We can see that the active maintenance period of the hardware platform ends with the "End of Production" (EOP) of the last platform-related vehicle—not considering OTA software updates. The electrics/electronics platform strategy extends the maintenance period to a predefined milestone called "End of Service" (EOS), which marks the termination of supplying vehicles with OTA software updates. As a result, expenses for technical and organizational support of the electrics/electronics platform, in particular between EOP and EOS, are increasing and need to be incorporated as well as evaluated within the electrics/electronics platform strategy. Consequently, the variability of electrics/electronics platforms must be controlled throughout the continuous and life-cycle spanning adoption and evolution of software within a suitable life-cycle management framework

C_3: Extended Platform Life-Cycle

Continuous software updates (over-the-air) extend the vehicle life-cycle, and thus automotive companies require a feasible life-cycle management framework that helps adopt, evolve, and maintain the software of an electrics/electronics platform.

In Figure 6, we also show the more distinct requirements of electrics/electronics platforms with respect to the release dates of individual vehicles. Within a hardware platform strategy, new vehicles and face lifts can be implemented independently as far as the main platform constraints are complied with. The electrics/electronics platform strategy introduces a consistent release logic for all vehicles related to an electrics/electronics platform, which implies that platform-relevant changes need to be performed across all vehicles based on the electrics/electronics platform at fixed release dates. As a consequence, the electrics/electronics platform can maintain its value for variant management by enhancing reuse, reducing complexity, and ensuring technical compatibility between the individual vehicle variants. The implementation of a consistent release logic is a key challenge for the practical application of electrics/electronics platforms.

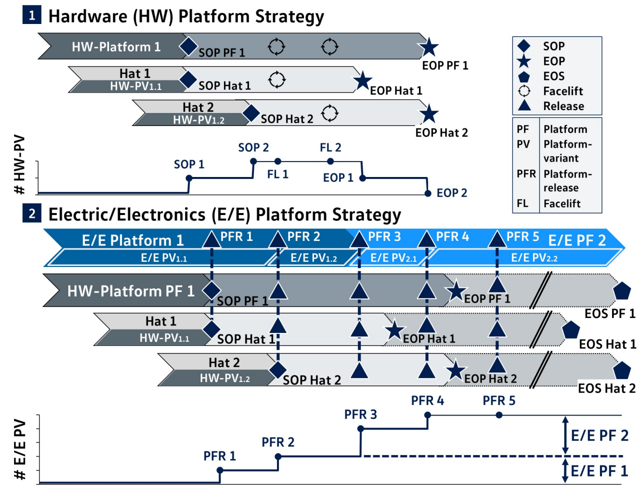

Figure 7: Complexity of hardware and electrics/electronics platforms due to variants.

C_4: Comprehensive Releases

Ensuring interface compatibility and complexity control throughout the life-cycle of an electrics/electronics platform requires synchronized vehicle launches within a comprehensive release logic.

Unfortunately, a consistent release logic impacts the flexibility and reaction time of automobile companies. The independence of changes to platform-related vehicles within the hardware platform enables fast response times and vehicle-specific solutions to arising problems. However, changes to the electrics/electronics platform are implemented in every platform-related vehicle, which is why vehicle-specific solutions must always be evaluated in the context of the whole electrics/electronics platform. While enhancing variability management, a consistent release logic can also lead to decreased flexibility and reaction time for problems related to a single vehicle. The trade-offs between flexibility and control of complexity within the framework of a consistent release logic pose a challenge for automotive companies in the successful implementation of an electrics/electronics platform strategy.

C_5: Decreased Flexibility

Within a consistent electrics/electronics platform release logic, every change to electrics/electronics components needs to be evaluated in the context of all platform-related vehicles, resulting in decreased flexibility.

The main purpose of the electrics/electronics platform concept is to control and manage complexity while taking into account the increasing relevance of software and digitization for vehicles. While this concept addresses key complexity issues for automotive companies, there are still variance-related challenges remaining that hamper the successful implementation of an electrics/electronics platform. To this end, we exemplify the impact of variability and complexity on hardware and electrics/electronics platforms throughout their life-cycles in Figure 7. Regarding hardware platforms, new vehicles may lead to additional platform variants, which increase the overall complexity. However, eliminating vehicle models or consolidating individual vehicle models into a common platform variant allows automotive companies to reduce the number of platform variants during a hardware platform's life-cycle. [15] Within an electrics/electronics platform, automotive companies need to ensure service and maintenance updates for all vehicles until their EOS. As each electrics/electronics platform variant must be maintained throughout its whole life-cycle (e.g., via OTA software updates), the existing electrics/electronics platform variability cannot be reduced. The lack of variant-reduction mechanisms increases the importance of limiting the initial complexity and poses a key challenge for automotive companies for managing variability throughout the life-cycle of an electrics/electronics platform.

C_6: Inability of Variant Reduction

Due to technical limitations, an electrics/electronics platform currently must comprise all variability related to that platform, which challenges the variant management.

4.2 Directions for Future Research

Based on our comparison of hardware platforms, software platforms, and electrics/electronics platforms, we outlined key challenges for the successful application of an electrics/electronics platform in the automotive industry. In the following, we discuss directions for future research that can help address these challenges (cf. Figure 8) and identify fields of action to improve the practical applicability of the electrics/electronics platform concept in automotive companies. We argue that these directions have to build on ideas of platform engineering to integrate the expertise of managing variant-rich software systems into electrics/electronics platforms.

First, the electrics/electronics platform concept must take into account the increasing relevance of software as vehicles are continuously evolving into cyber-physical systems. As we explained, software-intensive components are typically outdated after a brief period of time, resulting in significantly shorter life-cycles compared to an individual vehicle. To allow for technological changes of electrics/electronics components, the electrics/electronics platform needs to ensure a certain degree of adaptability over time. This relates both to vehicle development as well as to vehicles in the field. While the adaptability of an electrics/electronics platform during vehicle development relates to the technical design of the software components, the adaptability of vehicles in the field is primarily related to (OTA) software updates. A certain degree of robustness to changes that ensures the long-term adaptability of an electrics/electronics platform is needed to solve the conflicts of short software life-cycles (C_1) as well as enabling OTA updates (C_2) as key challenges for the successful implementation of electrics/electronics platforms in the automotive industry.

D_1: Ensuring Adaptability

We need concepts for facilitating the technical and structural adaptability of an electrics/electronics platform to enable the implementation of innovative technologies throughout the entire platform life-cycle.

Enabling OTA software updates leads to an extended maintenance period for an electrics/electronics platform (C_3). During this period, automotive companies must ensure that specific software updates are provided for each vehicle in the field. To minimize complexity and expenses of these software updates, reuse and standardization strategies should be applied within the framework of an electrics/electronics platform. This is necessary to advance upon hardware-platform strategies, since OTA software updates eliminate the possibility of subsequent variability reduction (C_6). For this reason, low initial variability poses a fundamental precondition to successfully control and manage complexity throughout an electrics/electronics platform's life-cycle.

D_2: Reducing Variability

We need concepts for reducing the (initial) variability of an electrics/electronics platform to control complexity during a platform's entire life-cycle.

Platform-relevant vehicle changes must be implemented across all related vehicles as well as performed at a comprehensive release time to reduce complexity and ensure standardized vehicle software (C_4). So, software updates can be implemented across all vehicles belonging to an electrics/electronics platform (in production and field via OTA updates), which in itself reduces software complexity and testing efforts. However, the restriction to comprehensive release dates results in reduced flexibility (C_6), since the requirements of an individual vehicle must always be evaluated in the overall context of the electrics/electronics platform and implemented across all vehicles. In particular, the impact on vehicles in the field must be taken into account within the development process of new vehicle models. The successful implementation of the electrics/electronics platform concept demands an appropriate requirements management with a focus on the electrics/electronics platform specifications as major cost and complexity drivers.

D_3: Enabling Requirements Management

We need tool support that helps synchronize between different vehicle releases, their artifacts, and the corresponding requirements on an integrated platform basis to enable better tracing, analyses, management, and control of variability.

In addition to technical and organizational adjustments in automotive companies, an optimization of decision-making processes will also contribute to solving the challenges we identified. Reduced flexibility (C_5) as well as a lack of methods for electrics/electronics platform variant reduction during the life-cycle (C_6) increase the impact of variability on costs and time-to-market as key success factors. Consequently, decision makers must be enabled to adequately assess the impact of any changes of an electrics/electronics platform's variability. There exist concepts that facilitate the quantitative assessment of software and hardware variability within the automotive, but also other cyber-physical, domain. Still, we need to develop and implement integrated methods and tools that support the existing variant management in quantitatively evaluating electrics/electronics platform variability.

D_4: Implementing Quantitative Evaluation Methods

We require tools and methodologies to assess the quantitative impact (e.g., money, time) of electrics/electronics platform variability to support decision makers.

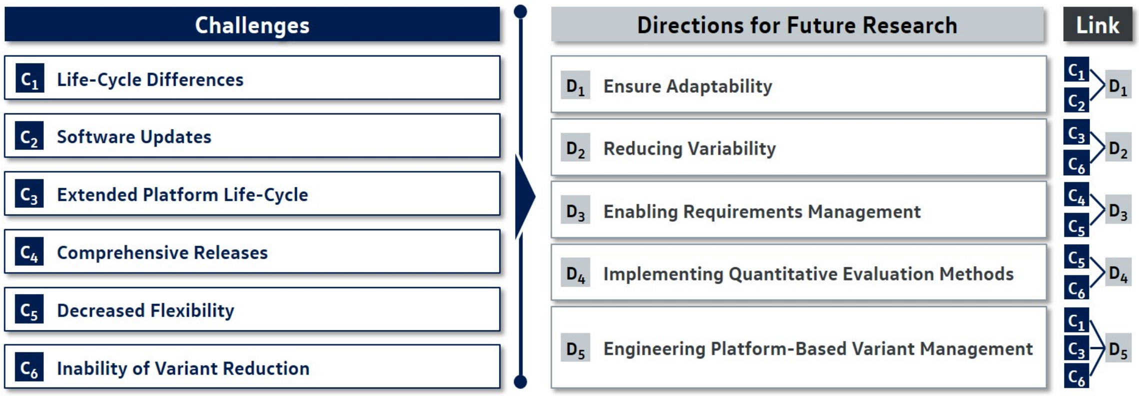

Figure 8: Summary of challenges and directions for enabling the practical application of electrics/electronics platforms.

Several of the challenges we derived for the practical application of electrics/electronics platforms (C_1, C_3, C_6) require a successful control of complexity throughout the electrics/electronics platform's life-cycle. Despite a wide variety of existing variability-management concepts regarding automotive [10, 47, 62] and other cyber-physical systems [37, 51, 56], the full control of electrics/electronics platform complexity—integrating hardware and software components as well as considering the entire platform life-cycle—is missing. To exploit the full potential and benefits of the electrics/electronics platform concept, suitable methods and tools are needed to complement the existing variant management.

D_5: Engineering Platform-Based Variant Management

We need techniques that allow to manage all artifacts in an electrics/electronics platform through a single, integrated management lens and framework, enabling variant management throughout the whole electrics/electronics platform and its life-cycle.

In summary, automotive companies demand concepts to manage complexity and variability throughout the complete vehicle life-cycle, taking into account the increasing relevance of software. The electrics/electronics platform concept enables an efficient management of variant-rich vehicle product portfolios throughout the entire life-cycle, focusing on specific software indicated requirements, such as OTA software updates. However, different challenges must be tackled to effectively implement the electrics/electronics platform concept in the automotive industry. In this context, we derived directions for future research to identify central activities for the successful application of the electrics/electronics platform concept in the automotive industry. We summarize our challenges and directions for future research in Figure 8.

5 CONCLUSION

In this paper, we derived six central challenges and five research directions for the practical application of electrics/electronics platforms in automotive companies (cf. Figure 8) based on a comparison of different platform concepts. We outlined that the electrics/electronics platform concept enables the control of complexity throughout the entire vehicle life-cycle, while considering the increasing importance of software. However, to fully utilize the benefits of electrics/electronics platforms, further research is required to tackle the six challenges we discussed in this paper. We envision that our discussions of the challenges and research directions motivates future work that helps companies in the automotive industry, but also other cyber-physical domains, to advance with feasible variant-management concepts to improve their product development and and life-cycle management. A consequent step for future work is to tackle the challenges we discussed by working on the outlined research directions.

Disclaimer. *The results, opinions, and conclusions of this paper are not necessarily those of Volkswagen AG.*

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