Insights into Transitioning towards Electrics/Electronics Platform Management in the Automotive Industry

Lennart Holsten
lennart.holsten@volkswagen.de
Volkswagen AG & Harz University
Wolfsburg & Wernigerode, Germany

Jacob Krüger
j.kruger@tue.nl
Eindhoven University of Technology
Eindhoven, The Netherlands

Thomas Leich
tleich@hs-harz.de
Harz University
Wernigerode, Germany

ABSTRACT

In the automotive industry, platform strategies have proved effective for streamlining the development of complex, highly variable cyber-physical systems. Particularly software-driven innovations are becoming the primary source of new features in automotive systems, such as lane-keeping assistants, traffic-sign recognition, or even autonomous driving. To address the growing importance of software, automotive companies are progressively adopting concepts of software-platform engineering, such as software product lines. However, even when adapting such concepts, a noticeable gap exists regarding the holistic management of all aspects within a cyber-physical system, including hardware, software, electronics, variability, and interactions between all of these. Within the automotive industry, electrics/electronics platforms are an emerging trend to achieve this holistic management. In this paper, we report insights into the transition towards electrics/electronics platform management in the automotive industry, eliciting current challenges, their respective key success factors, and strategies for resolving them. For this purpose, we performed 24 semi-structured interviews with practitioners within the automotive industry. Our insights contribute strategies for other companies working on adopting electrics/electronics platform management (e.g., centralizing platform responsibilities), while also highlighting possible directions for future research (e.g., improving over-the-air updates).

CCS CONCEPTS

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

KEYWORDS

Automotive, Electrics/electronics, Platform, Cyber-physical system

ACM Reference Format:

Lennart Holsten, Jacob Krüger, and Thomas Leich. 2024. Insights into Transitioning towards Electrics/Electronics Platform Management in the Automotive Industry. In *Companion Proceedings of the 32nd ACM International Conference on the Foundations of Software Engineering (FSE Companion '24), July 15–19, 2024, Porto de Galinhas, Brazil.* ACM, New York, NY, USA, 12 pages. https://doi.org/10.1145/3663529.3663837

FSE Companion '24, July 15–19, 2024, Porto de Galinhas, Brazil

ACM ISBN 979-8-4007-0658-5/24/07
https://doi.org/10.1145/3663529.3663837

1 INTRODUCTION

Similar to other industries, innovations in the automotive domain are driven more and more by digital features that build on software. The consequent trends emerging in the automotive industry (e.g., autonomous driving, digitization, electrification) have amplified the speed of new customer demands, forcing automotive companies to continuously evolve their portfolio by developing new features for their vehicles [3, 34]. Due to this situation, more than 80 % of current automotive innovations are software-driven. In turn, the amount of software in a vehicle is increasing and the importance of software to efficiently develop and manage an automotive vehicle portfolio is growing [19, 52].

In the past, automotive vehicle portfolios were built on hardware platforms and modules to facilitate reuse and achieve overarching synergies. However, to fulfill contemporary customer and regulatory requirements, vehicles have to rely on the efficient interaction between hardware, software, and the surrounding environment—thereby evolving into software-intensive cyber-physical systems [6, 45]. Integrating more and more software into existing hardware platforms remains a challenging task for automotive companies. Especially managing the variability of all artifacts (hardware, software, mechanics, electronics) and their interconnections has become increasingly complex [7, 11]. As a way to tackle this growing complexity introduced by software, automotive companies are proactively adopting principles and methodologies from the software-engineering domain [10, 14, 26, 53]. In this context, the concept of electrics/electronics platforms has gained a lot of attention in the industry. An electrics/electronics platform combines software and hardware platforms into a holistically used vehicle architecture, aiming to enhance reusability, establish standardization, and achieve scaling effects [24, 36].

While promising to facilitate the management of automotive vehicle (or other cyber-physical) portfolios, introducing an electrics/electronics platform also poses challenges. For example, to efficiently control the complexity of an electrics/electronics platform throughout its entire life-cycle, it has become more important to systematically manage the operational phase of vehicles. Specifically, automotive companies are progressively exploiting the possibilities of software over-the-air (OTA) updates [14, 17]. Consequently, managing an automotive vehicle portfolio based on electrics/electronics platforms necessitates to implement strategic release management to determine the functional and temporal evolution of the platform and its users throughout all life-cycle phases [31, 56]. However, integrating the possibilities of updates while a vehicle is operated into the design and management of an electrics/electronics platform is only one challenge—and even this one is, to the best of our knowledge, not well-explored.

In this paper, we aim to contribute to a better understanding of this and other challenges that are connected to transitioning from hardware-oriented platforms towards electrics/electronics platforms as a holistic concept for managing hardware, software, and electronics. For this purpose, we conducted 24 interviews with practitioners in the automotive domain, primarily from Volkswagen AG—one of the largest automotive companies with vehicle portfolios of various independent brands (e.g., Audi, Bentley, Porsche, MAN, Scania). During the interviews, we elicited the challenges these experts experienced with this transitioning, the key success factors for solving these, and activities to implement corresponding solutions. More precisely, we contribute the following:

- We report the results of 24 semi-structured interviews to provide insights from practitioners into the transitioning towards electrics/electronics vehicle platforms.
- We summarize challenges and success factors of managing and releasing electrics/electronics vehicle platforms.
- We discuss activities for successfully transitioning towards an electrics/electronics vehicle platform with integrated release management.

By building upon the experiences and recommendations of practitioners with expertise on the topic, we hope that the insights we contribute are helpful to practitioners in other companies or domains facing the same challenges. Moreover, we sketch directions for new research based on the challenges we identified, aiming to thereby foster the alignment between software-engineering research and practice on automotive and other cyber-physical systems.

2 BACKGROUND AND RELATED WORK

In this section, we first introduce electrics/electronics platforms and release management as core concepts within this paper. Afterwards, we discuss the related work for our contributions.

2.1 Electrics/Electronics Platforms

Aiming to efficiently manage their vehicle portfolios, automotive companies have developed and utilized different platform strategies to complement their existing variability-management strategies [4, 44]. The fundamental strategy of automotive companies involves consolidating key vehicle components into a single hardware platform. A hardware platform is developed iteratively and subsequently deployed across multiple vehicle models to, for instance, foster reuse, reduce costs, and speed up the time-to-market [12, 22, 32, 38, 46, 51]. Despite the ongoing digitization in the automotive domain, mechanical vehicle components remain the dominant decomposition criterion in vehicle platforms.

To account for the digitization, recent efforts of automotive companies went into adopting concepts from software engineering [10, 15]. In fact, software product lines are based on similar concepts, namely combining various reusable software artifacts and their variations within a software platform to efficiently manage variant-rich software systems [9, 29, 35]. The resulting software platforms help organizations to systematically decrease the time-to-market, reduce costs, and improve software quality through artifact reuse and standardization [27, 28, 42, 50].

While promising considerable advantages, implementing a software platform consistently across an automotive vehicle portfolio

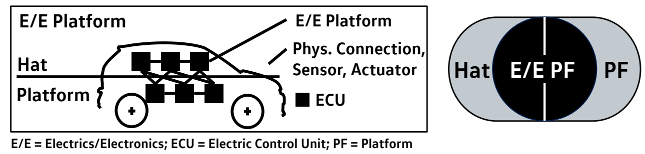

Figure 1: The electrics/electronics platform strategy based on our previous work [21].

remains challenging, due to the persistent reliance on hardware platforms. Moreover, the extensive interconnections that exist between mechanics, hardware, and software components as well as the environment emphasize the need for a more integrated strategy. To this end, the electrics/electronics platform strategy has been proposed in the literature [21, 25, 36]. This strategy consolidates hardware, software, and electrics/electronics components across multiple hardware platforms to provide a cross-vehicle electrics/electronics architecture.

More specifically, in contrast to traditional hardware or software platform strategies, electrics/electronics platform engineering revolves around combining hardware and software components into one comprehensive electrics/electronics architecture. In Figure 1, we illustrate how such an electrics/electronics platform can look like in practice [21]. We display the electrics/electronics platform and its connections to the hardware platform and "hat" strategy, which is often applied in the automotive industry today. Rather than segregating mechanical components (the hardware platform) from components directly impacting the customer (designated as the "hat"), the electrics/electronics platform strategy consolidates all components of a vehicle into a unified layer. That layer encompasses all software components along with their physical counterparts as electronic control units (ECUs). Functioning as an overarching framework, the electrics/electronics platform establishes a basic electrics/electronics architecture, facilitating close integration between hardware, software, and ECU components while acknowledging the vehicle as a complex cyber-physical system.

Overall, electrics/electronics platforms promise to achieve the advantages typically associated with hardware and software platforms across the entire life-cycle of a vehicle portfolio, such as enhancing reuse, optimizing synergies, and reducing costs. To ensure that an electrics/electronics platform leads to such benefits, two factors are crucial [21, 25, 36]: First, the electrics/electronics platform must be highly adaptable to diverse customer requirements, including various equipment configurations and market segments. Second, the electrics/electronics platform must remain flexible and responsive to an evolving technological landscape with emerging innovations.

2.2 Release Management

Another concept automotive companies are adopting from software engineering is systematic release management. For software development, release management is widely practiced to enhance a system's performance throughout its development and life-cycle [23, 31]. On a strategic level, release management primarily aims to streamline the planning of system improvements, which encompasses the implementation of new features, bug fixes, or performance enhancements [40, 41]. Key drivers and goals of release management include [23, 56]

- consolidated development, testing, and implementation activities within the development phase;
- harmonized change-management processes;
- refined variant adaptations; and
- integrated innovations to enhance features and enable life-cycle-supporting updates.

So, release management serves as a strategic method to manage a system's entire life-cycle, emphasizing a sustained focus on fulfilling market demands and achieving business success [43, 56].

Operationally, release management organizes the product development within an agile framework, dividing development tasks into smaller, manageable pieces to facilitate incremental development [40]. Consequently, operational release management focuses on the detailed planning of individual releases by considering their content, timing, and deployment. More specifically, on this operational level, the above goals of release management are achieved by specifying feature selections, aggregating these into release units, and determining their release timing [31, 56].

With the growing importance of software within the automotive domain, the respective companies increasingly acknowledge the possible benefits of implementing a comprehensive release management that encompasses software and hardware artifacts. Moreover, as vehicles' connectivity continues to expand, customized release plans can help address legal and technical constraints like the possibility of software updates at the customer's premises (e.g., OTA updates). So, for automotive companies, implementing release management promises to save costs, improve capacity allocation, and accelerate the times-to-market [18, 23, 31, 41].

While implementing release management is considered pivotal for the success of automotive companies, limited research has focused on the integration of release plans within the automotive domain [31]. In their works, Guissouma et al. [18] and Sax et al. [41] have investigated current and future challenges of automotive release management, focusing on the impact of introducing OTA software-updates. Inkermann et al. [23] have examined opportunities and challenges associated with the implementation of release management in domains characterized by prevailing mechanical engineering, such as the automotive industry. This study has put particular emphasis on the necessary adjustments needed for the successful application of release management beyond its conventional domain. To the best of our knowledge of the state-of-practice and research, the influence of release management on the portfolio management of automotive companies and its interactions with electrics/electronics platforms are yet to be researched in-depth and observed in practice. We aim to provide a steppingstone for such research by contributing practitioners' experiences on the topic.

2.3 Related Work

Within our previous research [21, 54], we have discussed the boundaries of research regarding the implementation of electrics/electronics platforms—particularly for the automotive industry. In these two studies, we have reflected on the connections between the different platform concepts [21] and elicited the state-of-research on product-structuring concepts for vehicle platforms [54]. For this paper, we built on these works to conduct interviews that contribute in-depth insights of practitioners into the use and challenges of electrics/electronics platforms for automotive companies. In another interview survey [55], we have elicited the state-of-practice regarding decision making for electrics/electronics platforms. Next, we discuss other related research on implementing automotive electrics/electronics platform management.

Wallin and Axelsson [52] conducted an in-depth case study based on semi-structured interviews to investigate issues and challenges inherent to the development of an electrics/electronics architecture at Volvo Car Corporation. The study identified a total of 12 challenges, categorized into four distinct domains: architecture, organization, processes & methods, and management & business. Subsequently, three overarching strategies have been proposed at a conceptual level, while specifics of the operational implementation within the automotive industry were not the focus of this study.

In another case study, Eklund and Gustavsson [13] examined the development and maintenance of electrics/electronics-based product lines, studying Volvo Car Corporation and Scania as illustrative examples. The study built upon interviews with experts representing both organizations, facilitating a comparative assessment of electrics/electronics-based product lines. This analysis resulted in considerations for process, organization, technology, and tool dimensions, with emphasis on the concrete responsibilities of system architects involved in the development and maintenance of these electrics/electronics-based product lines.

Lastly, Braun et al. [5] performed a literature review in conjunction with semi-structured interviews, aiming to offer a comprehensive perspective on contemporary vehicle electrics/electronics architectures and their evolution. The study dug into practical challenges and future requirements for developing electrics/electronics architectures, identifying challenges centered primarily around developing vehicle architectures. However, the study did not focus on cross-vehicle strategies throughout the electrics/electronics architecture life-cycle within platform or portfolio-management strategies.

These studies are concerned with issues and challenges of developing electrics/electronics platforms for vehicle portfolios, and thus related to our work. Besides contributing complementary insights regarding challenges and practices of implementing electrics/electronics platform management, we also contribute novel insights by exploring strategies for mitigating these challenges. By building on the expertise of 24 practitioners from different companies compared to the previous studies, we obtained additional and more recent empirical evidence that expands and supports this research. In contrast to the previous works, we put distinct emphasis on formulating efficient and synergistic life-cycle management strategies for electrics/electronics architectures in the automotive industry.

3 RESEARCH METHOD

In this section, we describe the individual steps of our research method, for which we display an overview in Figure 2. Our interview study has been approved internally by the communications department and the union of employees ("Betriebsrat") of Volkswagen AG to prevent confidentiality and ethical violations.

3.1 Research Questions

In our previous works [21, 54], we outlined several key challenges automotive companies are currently facing due to the increasing

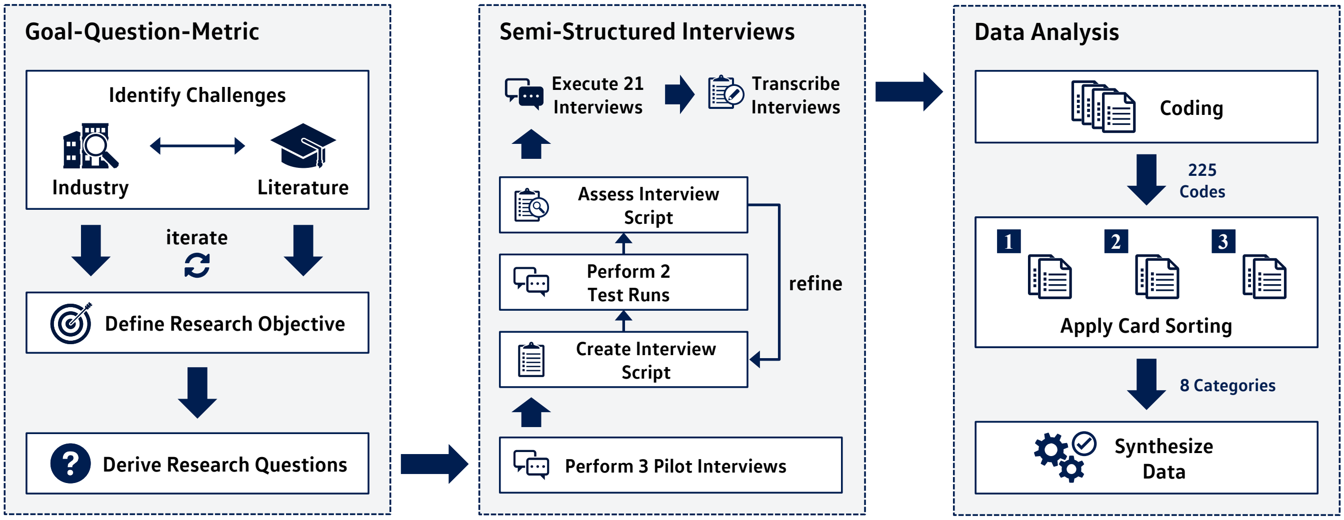

Figure 2: Overview of our research method.

digitization of vehicles and the growing importance of software. We further proposed steps to tackle these challenges, but our findings have been based primarily on scientific publications on cyber-physical systems and insights we obtained from our experience of working in the automotive domain (the first author working at Volkswagen AG). With this study, we aimed to deepen our understanding of contemporary challenges that automotive companies face by eliciting insights from other practitioners. Specifically, we defined our goal as moving towards tailored activities and guidelines that support practitioners in adopting electrics/electronics platform management.

To scope our interview study as a step into this direction, we first applied the goal-question-metric method (GQM) [2]. Consequently, we defined our research objective as well as corresponding research questions as follows: *To investigate and analyze* challenges, success factors, and potential solutions for transitioning towards automotive electrics/electronics platform and release strategies. *For the purpose of* understanding current practical challenges and providing dedicated activities to tackle these. *In the context of* multi-brand automotive companies operating on a global level and engineering extensive vehicle portfolios.

Based on this objective, we defined three research questions:

RQ$_1$ *What electrics/electronics platform and release management challenges do automotive companies face currently?*
First, we aimed to elicit what challenges practitioners in the automotive domain are currently facing regarding the transitioning towards electrics/electronics platforms. Particularly, we focused on challenges connected to strategic portfolio planning, platform management, release management, and their cohesive coordination. Our findings provide insights into critical challenges our interviewees in the automotive domain encounter, informing other practitioners and serving as a starting point for subsequent research.

RQ$_2$ *What factors are critical for the success of electrics/electronics platform and release management?*
After understanding the current challenges, we aimed to elicit what factors or goals a company would need to aim for to resolve these challenges. So, we aimed to identify what areas of improvement our interviewees perceive as important and what solutions would be or have been useful. By tackling this question, we contribute a concise overview of prerequisites needed to bridge the gap between the challenges reported and guidelines for resolving these.

RQ$_3$ *How can automotive companies improve their strategic electrics/electronics platform and release management?*
Lastly, we dug in more depths into recommendations for supporting organizations to implement strategic electrics/electronics platform management. Drawing on the challenges, success factors, and further responses by our interviewees, we aimed to formulate activities that help organizations transition towards this overarching goal. Our proposed activities are not confined to the automotive industry, but offer versatile strategies for many cyber-physical domains to help adapt to the increasing relevance of software and digital components within originally hardware-oriented domains.

Through these contributions, we hope to help other practitioners experiencing similar challenges in adopting electrics/electronics platforms, and to define a steppingstone for research on the electrics/electronics platform strategy.

3.2 Pilot Interviews

As a step to scope our work, refine the interview guide, and ensure that our results contribute a broader picture of the automotive industry (outside of Volkswagen AG), we first conducted a series of three pilot interviews with experts from other automotive companies (cf. Table 1 IDs A–C). Each of these interviewees had more than 10 years of experience in the automotive domain, spanning various roles within automotive electrics/electronics-platform and product-management strategies. The first author of this paper conducted these semi-structured interviews with a set of basic questions. Specifically, we formulated 16 questions to gain a better understanding of the development, management, and life-cycle handling of automotive electrics/electronics platforms. In this context, we focused on aspects of the organization and process, encompassing decision-making, change-management, and strategies for effectively controlling complexity throughout the platform's life-cycle. During the interview sessions, we did not follow a rigid script. Instead, we opted for a flexible method that allowed us to tailor each interview to capture critical insights and practical experiences unique to an interviewee. This semi-structured method allowed us to adjust and improvise during the interviews to improve our comprehension and obtain more nuanced perspectives.

In spite of their varying positions, roles, and companies, the three interviewees remarkably aligned with each other and our experiences regarding the challenges and practices of transitioning towards automotive electrics/electronics platforms. Notably, centralizing organizational structures, processes, and the decision-making for an electrics/electronics platform has been reported as a recurrent challenge. Identically, all agreed that establishing a unified requirements-management framework for electrics/electronics architectures is a pivotal success factor. However, to enable centralized processes effectively, decision-makers require support by electrics/electronics-oriented Key Performance Indicators (KPIs) [33, 48, 49]. These encompass not only financial KPIs, but also KPIs that measure impact on customers and the complexity throughout the entire electrics/electronics platform's life-cycle, dimensions the interviewees reported as lacking.

Moreover, facilitating OTA software updates poses a challenge, since it requires early-stage technical enhancements to vehicles. In parallel, the backwards compatibility throughout a vehicle's life-cycle must be guaranteed. This challenge arises particularly from the dual demand of meeting not only evolving customer expectations but also legal requirements. Overall, the outcomes of the three pilot interviews substantiated our initial understanding of prevalent challenges and practices within the automotive industry. Furthermore, the agreement underpins the importance of researching innovative platform and release strategies that integrate hardware, software, and electronics—a novel perspective that we built upon as foundation for our interview study.

3.3 In-Depth Interviews

To answer our research questions, we conducted semi-structured expert interviews following established guidelines [37, 39]. As interviewees, we recruited 21 volunteering employees from different subsidiary brands of the Volkswagen Group, such as Volkswagen, Audi, Scania, or Porsche. This way, we aimed to improve the generalizability of our findings by gathering insights from independently operating brands within the automotive industry. We tried to cover a broad range of perspectives on planning, developing, and maintaining automotive vehicle portfolios by interviewing employees with a large variety of roles and experiences. Consequently, we interviewed experts from several departments, such as development, product management, strategy management, sales & marketing, production, and in-house consulting. We provide an overview of the roles and experiences of each interviewee in Table 1 (IDs 1–21).

Based on our pilot interviews and aligned to our research questions, we derived a script to guide the interviews, comprising open-ended questions thematically clustered into five categories. Within each category, we supplemented our core questions with a number

Table 1: Overview of the interviewed experts.

ID	Role	Experience
A	E/E Systems Manager	>10 years
B	Product & Portfolio Manager	>15 years
C	System Architect	>10 years
1	Architecture Release Manager	>15 years
2	Architecture Release Manager	>5 years
3	Architecture Strategy Manager	>10 years
4	Brand Strategy Manager	>10 years
5	Business Architect	>10 years
6	Business Architect	>30 years
7	Change Manager	>10 years
8	Change Manager	>10 years
9	Cyber Security Expert	>5 years
10	Digitization Expert (Consultant)	>5 years
11	Portfolio Strategy Manager	>20 years
12	Product Manager	>10 years
13	Product Manager	>10 years
14	Product Manager	>15 years
15	Product Strategy Manager	>5 years
16	Ramp-Up Manager	>15 years
17	Software Platform Expert (Consultant)	>15 years
18	System Architect	>5 years
19	System Architect	>10 years
20	Update Manager	>10 years
21	Update Manager	>15 years

of in-depth questions to encourage discussions with the interviewees on specific topics. Before executing the interviews, we performed two test runs to iteratively assess and refine the interview script. The resulting script contained a total of 24 open-ended questions complemented by 17 optional in-depth questions. However, following the concept of semi-structured interviews, we adjusted our pattern of questioning to react to more interesting responses to specific topics and issues mentioned during the conversation.

To account for the distance to and availability of the experts, the first author performed most interviews online using Microsoft Teams. During these online interviews, we tried to recreate a face-to-face environment by turning cameras on. Due to the internal data-privacy policies of Volkswagen AG, only the first author was permitted to conduct the interviews, we cannot share the questions in our interview guide (since these may reveal details of the brands' operations), and we were not allowed to record the interviews. Instead, the first author took notes during the interviews to create a transcript and subsequently validated that transcript directly afterwards with the interviewees. The average interview duration was 58 minutes.

As an impression of how we conducted the interviews, this was the typical procedure: We started with a short introduction about ourselves and our research project, followed by a few questions regarding the role, expertise, and experience of the interviewee. Subsequently, we moved on to asking the questions in our interview script. The sequence of questioning, what optional questions we asked, and which questions we discussed on what level of detail

Table 2: Example for our evaluation matrix.

	C1. Customer Satisfaction
RQ_1: Challenge	*Decisions lack customer orientation; technical requirements often lead decision-making.*
RQ_2: Success Factor	*Successful product design and development depends on satisfying customer wishes.*
RQ_3: Activity	*Implement a centralized and customer orientated requirements engineering for electrics/electronics platforms.*

varied significantly between the interviews, depending on the expertise and responses of the interviewees. However, regardless of the sequence, every interviewee answered our core questions to ensure a comparable dataset for our analysis. At the end of each interview, we reserved time for an open discussion, encouraging the interviewees to further elaborate on the topic or whatever they found important to discuss. We concluded the interviews by validating the transcribed notes with each interviewee.

3.4 Data Analysis

Deciding when enough information has been collected to terminate the interviews is a key issue for any expert study. Instead of focusing on a minimum or specific number of interviews to reach a critical target group, we focused on achieving saturation to ensure the validity of our results [1]. Therefore, we iteratively extracted and analyzed the relevant data from each interview transcript, aligning that data to our previously collected data and examining its novelty. From the 16^{th} interview onwards, we noticed that we obtained at most one new statement per interview—which did not result in new categories. After the last five interviews, we reasonably assumed that we reached saturation and decided to terminate our study.

To gather relevant data, we employed an open-coding method [8] combined with card sorting [47]. So, we started by extracting key statements from each transcript, which included the three pilot interviews to improve the generalizability of our study (cf. Table 1). We extracted a total of 225 statements, which we then coded and sorted into subject-specific categories and assigned to the research question they refer to. By re-iterating this process, we aimed to condense similar categories into a few broader categories and to consolidate statements within one category to eliminate repetitions. In the end, we constructed a results matrix that mapped the key statements to each of the resulting eight categories and to the research question for which these were relevant. To illustrate this results matrix, we display an example in Table 2. The category is *customer satisfaction*, and we exemplify three statements, one for each of our research questions.

4 RESULTS

In this section, we present the results of our interview study, which we summarize in Table 3. From the categories we derived, we identified three primary topics for implementing and improving electrics/electronics platform management. For each, we outline the associated challenges (**RQ_1**), success factors (**RQ_2**) and activities for improvement (**RQ_3**).

4.1 Centralized Management

As the first and most prominent topic in the interviews, we identified challenges surrounding the actual transition towards an electrics/electronics platform. Consequently, the following challenges, success factors, and activities are closely related, emphasizing the need for centralizing all management tasks on the platform level.

Challenge 1 (RQ_1): Platform Transition. To address the increasing complexity of hardware and software components, as well as their interconnections, 19 of 21 interviewees reported the need for a strategic shift from hardware platforms towards an electrics/electronics architecture. In this context, especially transitioning to a centralized decision-making authority at the electrics/electronics platform level has been suggested—a transition that is currently progressing at Volkswagen. To illustrate a concrete example, implementing a novel feature in the electrics/electronics platform requires modifications to various ECUs. This can be rather challenging, as every ECU is assigned to either the hardware platform, a module, or the "hat," each of which involve independent processes, stakeholders, and decision-making authorities. As a consequence, emphasizing reuse and standardization has primarily revolved around mechanical components, intensifying the challenge of managing the extensive electrics/electronics variability by transitioning to a full-fledged electrics/electronics platform.

Challenge 2 (RQ_1): Responsibilities. In connection to the platform transition, 18 interviewees raised concerns about the primarily vehicle release ("Start Of Production" (SOP)) driven strategic orientation of the vehicle and platform management. The separation of new vehicle projects and life-cycle management has created a situation in which platform and portfolio management lack comprehensive goals and objectives. For the interviewees, this highlights the need for consolidating release strategies at the electrics/electronics architecture level. In practise, decision-making tends to revolve around financial and technical considerations that influence the release of a single vehicle or platform. To transition towards a successful electrics/electronics platform, it is important to implement overarching decision-making competencies to encourage collaborative solutions that benefit the platform as a whole.

Challenge 3 (RQ_1): Knowledge Management. Lastly, 18 interviewees highlighted notable deficiencies in transparency, communication, and cross-divisional knowledge sharing concerning the electrics/electronics architecture as a major challenge within the existing corporate structures and hierarchies. In particular, consistent product-management responsibilities at the electrics/electronics architecture level are still under development. Improving the knowledge management helps to optimize the complex assessment and decision-making processes involving a multitude of stakeholders and interfaces. Due to decentralized information systems providing limited value to developers and product managers, our interviewees emphasized the need for organizational centralization of electrics/electronics architecture knowledge management. Thereby, the time-to-market cycles and vehicle roll-outs of the platform can be improved, which would positively impact customer satisfaction.

Success Factor 1 (RQ_2): Platform-Level Decision Making. Considering the three previous challenges, it is not surprising that 17 of 21 interviewees see a platform-level decision making as a key success factor for transitioning towards electrics/electronics platforms. Specifically, establishing coherent and transparent decision-making processes and allocating the respective responsibilities at the electrics/electronics platform level were highlighted as critical prerequisites for efficiently managing vehicle portfolios and their releases. The interviewees anticipated considerable improvements by centralizing vehicle projects and life-cycle management under a unified electrics/electronics platform responsibility. In turn, this would guide cohesive strategic decisions and allow to formulate comprehensive objectives for the whole platform. Besides also fostering cross-divisional knowledge sharing, a centralization of platform responsibilities would further streamline decision-making processes, thereby speeding up the time-to-market.

Success Factor 2 (RQ_2): Platform-Level KPIs. To facilitate life-cycle oriented decision-making even more, 12 interviewees indicated a demand for an integrated KPI-framework. This framework should involve financial assessments throughout the entire life-cycle of the platform as well as parameters that consider factors impacting customer satisfaction, complexity, and compatibility. For reasoning about decisions and allocating resources, the KPI-framework must be implemented at the electrics/electronics platform level, serving as an overarching decision-support system for change requests. Adopting a life-cycle-oriented assessment facilitates the strategic integration of essential technical prerequisites for OTA updates, rectifying gaps typically overlooked in traditional SOP-based assessments. Furthermore, proactively managing the complexity of an electrics/electronics platform throughout its life-cycle can be enabled, ensuring long-term OTA update capabilities and minimizing maintenance overhead.

Success Factor 3 (RQ_2): Platform-Level Information Sharing. Accompanying the previous success factors, 20 interviewees suggested to introduce a centralized information system for the electrics/electronics platform to increase the availability, consistency, and transparency of data. This would facilitate cross-divisional knowledge sharing. Since data is becoming a core business asset of modern (automotive) companies, and thus possesses significant economic value, the interviewees consider the rapid processing and provisioning of data via information systems a key success factor. As an example, low failure-rates strongly determine the success of automotive OTA-update campaigns, as each failed update causes expensive and inconvenient workshop visits for the customer. Consequently, providing consistent and transparent data about previous update campaigns allows to optimize future OTA-update strategies.

Activity 1 (RQ_3): Implement Platform Release Management. As a logical consequence of the challenges and their success factors, 14 interviewees proposed to centralize and consolidate electrics/electronics architecture-related processes, responsibilities, and decision-making at the electrics/electronics platform level. This consolidation should span not only newly developed vehicles, but also those currently in production or being part of the existing vehicle fleet. So, a coherent and holistic electrics/electronics platform management throughout all vehicles' entire life-cycles can be implemented. On the operational level, an overarching release management system at the electrics/electronics platform level is needed, which helps determine the content and frequencies of releases homogeneously across all vehicles. The logic and hierarchy of decision-making would then be transferred towards an electrics/electronics platform-based portfolio management rather than being isolated between vehicle-centred decisions and changes affecting the electrics/electronics architecture.

Activity 2 (RQ_3): Implement Platform Requirements Engineering. According to another 14 interviewees, the electrics/electronics platform release management should be complemented by an overarching platform requirements engineering to further stimulate a holistic yet customer-centric point of view. Specifically, such a requirements engineering can consolidate customer-sourced vehicle requirements and seamlessly incorporate these into the development process. In fact, given the diversity of customer demands in the automotive industry, stemming from various brands, regions, and market segments, often multiple electrics/electronics platforms are concurrently developed and maintained. To address this complexity, besides consolidating processes and decisions at electrics/electronics platform level, it is necessary to establish a platform-spanning management, which plans and coordinates cross-platform initiatives to achieve additional synergies. For instance, envision a novel and innovative feature destined for deployment spanning various vehicles, brands, and global regions that impacts multiple electrics/electronics platforms. Traditional practices would lead to the independent development of similar features within each platform to meet individual requirements (similar to clone & own development [27, 28]), resulting in redundant efforts. To optimize cost-efficiency and the allocation of resources, a streamlined platform strategy should consolidate all requirements. Consequently, the feature would only be developed once, with subsequent deployment into the respective electrics/electronics platform and vehicle release plans. In the future, the most effective strategy would be to integrate requirements management on two levels: for individual electrics/electronics platforms and across these.

Activity 3 (RQ_3): Implement Life-Cycle Platform Management. To establish effective early-phase requirements engineering, 12 interviewees find it essential to incorporate suitable KPIs to assess individual change projects. In practice, finite financial resources and development capacities necessitate judicious allocation. A comprehensive KPI-framework must meticulously consider and weigh diverse decision aspects, such as influences on finances, complexity, and compatibility, to ensure a holistic evaluation of the impact of changes across the entire vehicles' life-cycles. By adopting this strategy, individual change projects can be systematically prioritized based on objectives and life-cycle-oriented criteria to optimize the allocation of financial resources and development capacities. Also, requirements engineering and the subsequent release management should be supported by centralized information systems, enhancing data consistency and simplifying knowledge exchange.

Insight: Centralized Platform Management

To centralize responsibilities for an electrics/electronics platform, our interviewees suggest to establish a platform release management, which should be complemented by life-cycle-oriented requirements engineering. This highlights the need to research supporting techniques for guiding automotive companies in implementing holistic electrics/electronics platform management.

4.2 OTA Software Updates

As a second independent topic, we identified the issue of OTA updates, which are gaining more and more traction among automotive companies to facilitate life-cycle software updates for customers.

Challenge 4 (RQ_1): Strategizing OTA Updates. Decentralized financing structures and individualized incentives diminish the motivation to engage in collective investments into an electrics/electronics architecture. So, as 14 interviewees reported, a focus on short-term revenues is favored compared to long-term strategic advancements of the platform. Particularly, the strategic planning of OTA software updates across an electrics/electronics platform is currently posing a challenge for automotive companies. Illustratively, the absence of strategic planning in one example case resulted in additional errors, infrequent deployment, and diminished the customer value of the employed OTA software updates. This particular case exemplifies the substantial challenges caused by current decision-making processes and methodologies for reaching agreement between individual electrics/electronics platforms and the overarching corporate success.

Success Factor 4 (RQ_2): Evolvable Electrics/Electronics Platform. Effectively managing the complexity caused by electrics/electronics components as well as innovative vehicle features that are tailored to evolving customer demands throughout the entire vehicle and platform life-cycles is a pivotal success factor for automatoive companies—as recognized by 12 interviewees. In this context, it is key to develop a durable electrics/electronics platform by ensuring a high degree of evolvability through the integration of technical enablers (e.g., OTA update). However, backwards compatibility muse also be ensured in parallel. This way, complexity can be managed throughout a platform's life-cycle and electrics/electronics synergies can be achieved. By decoupling hardware and software, automotive companies can independently update specific components. Consequently, they can account for varying innovation cycles between hardware and software to reduce the time-to-market and facilitate modularity. The resulting stronger focus on processes and strategies on electrics/electronics platform level can further help fulfill customer demands, especially in today's rapidly changing competitive environment.

Activity 4 (RQ_3): Implement Dedicated OTA Strategy. To address the growing importance of software in automotive companies' processes and strategies, 12 interviewees proposed to emphasize OTA updates within the release management for an electrics/electronics platform. Given the distinct requirements for developing and testing as well as the varying innovation life-cycles between pure software updates and combined releases, introducing separate release scenarios [30] with correspondingly shorter update frequencies for software updates has been proposed. As a consequence, it is essential to plan for OTA updates as an addition to existing vehicle releases that are part of regular maintenance. In parallel, automotive companies must aim to enhance customer benefits with each update. Beyond considering the release content and update frequency, a dedicated OTA strategy should proactively ensure that the technical prerequisites for each update are ensured already during the early development of an electrics/electronics platform. Also, it must systematically address variability and compatibility concerns to ensure the continued usability of OTA updates.

Insight: OTA Software Updates

The strategic planning of OTA updates requires a shift from SOP-driven processes towards a life-cycle-oriented electrics/electronics platform management. Thus, the technical capabilities and compatibility of the platform to support continuous OTA updates during its whole life-cycle is key to fulfill customer demands. To support automotive companies in establishing an OTA strategy, we see the need for research on the impact of OTA updates on the electrics/electronics platform and its processes.

4.3 Software Expertise

Challenge 5 (RQ_1): Software and Electrics/Electronics Expertise. Finally, 11 interviewees indicated that a consistent understanding regarding software and electrics/electronics related issues that may impact a platform has not been universally reached across all departments. This challenge is likely rooted in the mechanical-engineering background prevalent in the automotive domain. To respond to the growing importance of software for all automotive companies, recruiting software-engineering experts and implementing in-house programs to enhance software and electrics/electronics competences pose persistent challenges for such companies. Further underpinning this challenge is that the interviewees repeatedly mentioned the associations between an absence of software expertise with inadequate release and update strategies or vehicle-oriented with SOP-driven decision making.

Success Factor 5 (RQ_2): Software Understanding. Contemporary challenges in the automotive industry and evolving digital trends are stretching the limits of conventional mechanical engineering. Consequently, 10 interviewees considered establishing software and electrics/electronics competences, including educating both staff and management, as a pivotal catalyst for substantial performance improvements of automotive companies. In particular, the strategic platform, portfolio, and release management are increasingly impacted by software-related challenges, such as developing and validating innovative features for autonomous driving or devising effective OTA update strategies. Such challenges increase the demand for understanding software among engineers, strategists, and managers. As a result, reaching a comprehensive understanding of software and electrics/electronics related issues as well as practices is becoming more and more crucial to guide the strategic direction of automotive companies.

Activity 5 (RQ_3): Implement Training. To address the lack of software expertise, 15 interviewees proposed in-service training, sensitizing employees and managers for the importance and use of software and electrics/electronics in modern vehicle platforms. Particular emphasis should be placed on the impact of software changes during an electrics/electronics platform's life-cycle, especially regarding compatibility and OTA updates. Besides helping managers formulate effective platform and release strategies, a fundamental software and electrics/electronics understanding is also crucial for engineers and product managers. In fact, several interviewees attributed a majority of decisions that deviated from the overall electrics/electronics platform strategy in the past to a lack of awareness for the decision's impact—particularly on the software.

Table 3: Summary of results with the high-level themes in bold and short explanations below.

Sec.	Challenges (RQ_1)	I	Success Factors (RQ_2)	I	Activities (RQ_3)	I
4.1	**Transition to Electrics/Electronics Platform** Transition from hardware and software based platforms towards a single electrics/electronics platform based product management.	19	**Have Electrics/Electronics Platform Decision Making** Have a centralized electrics/electronics platform decision-making authority.	17	**Implement Electrics/Electronics Platform Release Management** Implement comprehensive and life-cycle-oriented knowledge management and decision making for electrics/electronics platforms.	14
	Unite Responsibilities for New Vehicles and Life-Cycle Management Integrate new vehicles and the life-cycle management into a holistic electrics/electronics platform responsibility.	18	**Have Electrics/Electronics Platform-Level KPIs** Have comprehensive assessment methods through a life-cycle-oriented KPI-framework.	12	**Implement Electrics/Electronics Platform Requirements Engineering** Foster both the customer-centric and synergistic development of innovative features and their effective cross-platform deployment.	14
	Provide Comprehensive Knowledge Management Ensure efficient sharing of knowledge despite a high number of stakeholders and interfaces.	18	**Have Consistent and Transparent Information Sharing** Have cross-divisional knowledge provisioning through client-friendly information systems.	20	**Implement Life-Cycle Oriented Electrics/Electronics Platform Management** Improve data consistency by implementing integrated information systems supporting the electrics/electronics platform management.	12
4.2	**Strategize OTA Software-Updates** Moving from SOP-driven processes towards efficient OTA software updates.	14	**Have an Evolvable Electrics/Electronics Platform** Have the technical capabilities and guarantee compatibility during the life-cycle of an electrics/electronics platform.	11	**Implement a Dedicated OTA Software Update Strategy** Strategically determining (OTA) release content and timings throughout the electrics/electronics platform life-cycle.	12
4.3	**Acquire Software and Electrics/Electronics Expertise** Obtaining software and electrics/electronics competences requires automotive companies to gather the corresponding expertise.	11	**Have Software Understanding** Have a consistent software and electrics/electronics understanding across different departments and roles.	10	**Implement Training for Software and Electrics/Electronics Issues** Create a comprehensive awareness of how decisions impact the electrics/electronics platform.	15

Sec.: Section with detailed explanations — I: Number of the 21 in-depth interviews with respective statements

Insight: Software Expertise

Achieving a consistent company-wide understanding about the importance of software and electrics/electronics in contemporary vehicle platforms is critical for the success of transitioning towards an electrics/electronics platform. Researchers can support the respective training by identifying key differences between platform strategies and designing guidelines on such transitions that can serve as educational material.

5 DISCUSSION

As we summarize in Table 3, we identified five key challenges for transitioning towards electrics/electronics vehicle platforms based on practitioners' experiences (**RQ_1**). We structured those challenges along three topics and elicited five matching success factors that can serve companies as objectives to solve the challenges (**RQ_2**). To contribute concrete steps in this direction, we have also derived five respective activities to guide companies in their endeavours (**RQ_3**). In this section, we further contextualize the results for each research question by introducing an electrics/electronics platform management framework, which we display in Figure 3. Specifically, we derived and tailored this framework to address the challenges we identified based on the success factors and activities. We remark that this framework is a high-level vision that requires future research into the individual levels and dimensions to make it operational—which we aim to do in our own future work.

The framework revolves around the integration of a primary electrics/electronics platform release plan (middle of Figure 3), which specifies the frequency and content of releases (addressing the first row in Table 3). Within the electrics/electronics platform release plan, each release is strategically designed to incorporate the collective features of all vehicle models, thus representing a "150 % platform" [16]. Simultaneously, the release plan defines a binding commitment for all related vehicle models, demanding vehicle releases to match with designated electrics/electronics platform release intervals and predefined release contents (bottom of Figure 3). Such a design would effectively help the involved engineers manage the complexity of an electrics/electronics platform across all components, and allow a company to achieve synergies in development and validation processes.

Next, the framework covers an electrics/electronics platform requirements-engineering process that accompanies the release plan (addressing the second row in Table 3). This process consolidates the individual vehicle requirements that originate from customer demands on the electrics/electronics platform level, facilitating their integration into development, maintenance, and delivery processes. Based on the requirements, the development department constructs a strategic functional road-map (top of Figure 3), which represents all development initiatives concerning the integration of novel or refined features. Thus, the functional roadmap serves as a key artifact for managing the release plans.

Note that an efficient requirements-engineering process also requires a company to implement a comprehensive KPI framework [20, 49] and respective knowledge management (addressing the third row in Table 3). Such a KPI framework should cover factors on all relevant business dimensions and should be oriented towards the entire electrics/electronics platform life-cycle. This enables the systematic prioritization of individual vehicle requirements to guide decision-making processes related to their eventual implementation within an electrics/electronics platform release.

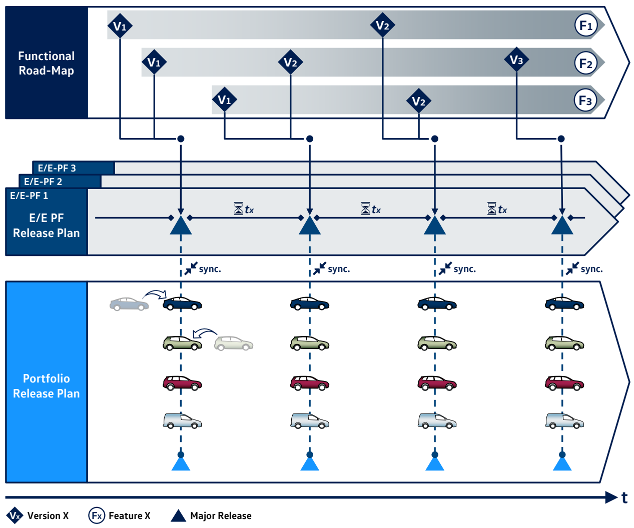

Figure 3: Portfolio strategy based on centralized electrics/electronics platform release planning and functional road-maps.

To ensure the universality of the electrics/electronics release plan and to further reduce complexity, releases should be strategized independently of the deployment type (addressing row four in Table 3). This means that releases, depending on type and content, may be executed either in production or directly at a customer's location via OTA updates. Consequently, the strategic planning of OTA updates gets integrated within the electrics/electronics platform release management. By adopting this strategy, the entire electrics/electronics platform's complexity is mitigated, enhancing synergies among development and validation endeavors. Additionally, well-defined release parameters in common releases simplify compatibility maintenance throughout the electrics/electronics platform's life-cycle.

Finally, a foundational requirement for implementing such a comprehensive electrics/electronics platform management framework is that all involved stakeholders understand software and electrics/electronics issues (addressing row five in Table 3). Thus, it is necessary to involve stakeholders in training activities and onboard them onto the electrics/electronics platform to involve them and share knowledge. Additionally, upon the successful implementation of the electrics/electronics platform management framework, we anticipate a continuous and persistent sensitization of decision-makers for ongoing software and electrics/electronics related challenges.

6 THREATS TO VALIDITY

Like any empirical study, our work faces potential threats to validity. First, *internal validity* assesses the degree to which a study establishes a reliable cause-and-effect connection between the investigated factors. For our interviews, the primary threat regarding internal validity revolves around potential personal bias stemming from our interviewees' experiences and our interpretation of the collected data. Given the flexible nature of semi-structured interviews and the absence of predefined data extracts, we had to transcribe, code, and interpret free-text responses to open-ended questions. While the subjectivity of our interviewees is inherent to the methodology, we aimed to mitigate our personal biases by following the established methods of open coding and card sorting for analyzing free-text responses.

Second, *external validity* pertains to the generalizability of the findings. Ensuring the representativeness of the interviews is a potential and inherent threat to the validity of our study. In fact, we conducted 21 interviews exclusively among employees of Volkswagen AG, potentially limiting the generalizability of our findings to the broader automotive industry. To mitigate this threat, we conducted three pilot interviews with experts from other automotive companies and compared between these two sets, which indicated that our findings should be transferable. Additionally, Volkswagen AG spans various brands that operate independently, for instance, Audi, Porsche, Scania, or MAN. To improve the generalizability of our findings, we interviewed employees from different brands, regions, and roles within Volkswagen AG.

Third, *construct validity* is concerned with the alignment between the researchers' intended measurements and the actual ones. Our study's commitment to internal privacy and legal regulations mandated that the first author conducted the interviews without recording them. Instead, the interviewer carefully took notes. In turn, a threat may arise from individual notes representing misinterpretations or overlooks by the interviewer. To mitigate such threats, we implemented post-interview discussions and protocol validation with each interviewee, enhancing the overall quality of our notes. Finally, the construct validity may be threatened by the suitability of the interview script, as the interview questions substantially influence the acquired insights. To address this concern, we repeatedly discussed the questions among the authors and conducted pilot interviews as well as test runs to iteratively evaluate and refine the questions, thereby limiting this threat.

7 CONCLUSION

In this paper, we presented an interview study with 24 practitioners in which we investigated challenges, success factors, and activities of transitioning towards electrics/electronics platforms in the automotive industry. To consolidate our findings and guide research towards an operational framework for engineering electrics/electronics platforms, we have derived and sketched an electrics/electronics platform management framework. At its core, this framework builds on an platform-spanning release management including respective requirements engineering, responsibilities, life-cycle management, and knowledge sharing as well as training activities. Our insights can help practitioners aiming to introduce electrics/electronics platforms, while also highlighting potential directions for future research. In the future, we plan to build upon this framework to design and implements its individual parts in more detail. We plan to then instantiate these parts in practice to evaluate to what extent these help to tackle the challenges we identified.

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

ACKNOWLEDGMENTS

We thank all interviewees who participated in this study and shared their invaluable experiences with us.

REFERENCES

[1] Khaldoun Aldiabat and Carole-Lynne Le Navenec. 2018. Data Saturation: The Mysterious Step in Grounded Theory Methodology. *The Qualitative Report* 23 (2018), 245–261. https://doi.org/10.46743/2160-3715/2018.2994

[2] Victor Basili. 1994. Goal, Question, Metric Paradigm. *Encyclopedia of Software Engineering* (1994), 528–532.

[3] Stephan Baumgart, Xiaodi Zhang, Joakim Fröberg, and Sasikumar Punnekkat. 2014. Variability Management in Product Lines of Safety Critical Embedded Systems. In *International Conference on Embedded Systems (ICES)*. ACM, 98–103. https://doi.org/10.1109/EmbeddedSys.2014.6953098

[4] Damir Bilic, Etienne Brosse, Andrey Sadovykh, Dragos Truscan, Hugo Bruneliere, and Uwe Ryssel. 2019. An Integrated Model-Based Tool Chain for Managing Variability in Complex System Design. In *International Conference on Model Driven Engineering Languages and Systems Companion (MODELS-C)*. IEEE, 288–293. https://doi.org/10.1109/MODELS-C.2019.00045

[5] Lisa Braun, Michael Armbruster, and Frank Gauterin. 2015. Trends in Vehicle Electric System Design: State-of-the Art Summary. In *Vehicle Power and Propulsion Conference (VPPC)*. IEEE, 1–6. https://doi.org/10.1109/VPPC.2015.7353035

[6] Manfred Broy. 2006. Challenges in Automotive Software Engineering. In *International Conference on Software Engineering (ICSE)*. ACM, 33–42. https://doi.org/10.1145/1134285.1134292

[7] Harald Bucher, Kevin Neubauer, and Jürgen Becker. 2019. Automated Assessment of E/E-Architecture Variants Using an Integrated Model- and Simulation-Based Approach. In *World Congress Experience (WCX)*. SAE International, 1–14. https://doi.org/10.4271/2019-01-0111

[8] Philip Burnard. 1991. A Method of Analysing Interview Transcripts in Qualitative Research. *Nurse Education Today* 11, 6 (1991), 461–466. https://doi.org/10.1016/0260-6917(91)90009-Y

[9] Paul C. Clements and Linda M. Northrop. 2001. *Software Product Lines: Practices and Patterns*. Addison-Wesley.

[10] Yanja Dajsuren and Mark van den Brand (Eds.). 2019. *Automotive Systems and Software Engineering*. Springer. https://doi.org/10.1007/978-3-030-12157-0_1

[11] Joseph D'Ambrosio and Grant Soremekun. 2017. Systems Engineering Challenges and MBSE Opportunities for Automotive System Design. In *International Conference on Systems, Man, and Cybernetics (SMC)*. IEEE, 2075–2080. https://doi.org/10.1109/SMC.2017.8122925

[12] Olivier L. de Weck, Eun S. Suh, and David Chang. 2003. Product Family and Platform Portfolio Optimization. In *International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (DETC)*. ASME, 175–185. https://doi.org/10.1115/DETC2003/DAC-48721

[13] Ulrik Eklund and Håkan Gustavsson. 2013. Architecting Automotive Product Lines: Industrial Practice. *Science of Computer Programming* (2013), 2347–2359. https://doi.org/10.1016/j.scico.2012.06.008

[14] Kaneez Fizza, Nitin Auluck, Akramul Azim, Md. Al Maruf, and Anil Singh. 2019. Faster OTA Updates in Smart Vehicles Using Fog Computing. In *International Conference on Utility and Cloud Computing Companion (UCC-Companion)*. ACM, 59–64. https://doi.org/10.1145/3368235.3368842

[15] Sebastian Graf, Sebastian Reinhart, Michael Glaß, Jürgen Teich, and Daniel Platte. 2015. Robust Design of E/E Architecture Component Platforms. In *Design Automation Conference (DAC)*. IEEE, 1–6. https://doi.org/10.1145/2744769.2747941

[16] Hans Grönniger, Holger Krahn, Claas Pinkernell, and Bernhard Rumpe. 2008. Modeling Variants of Automotive Systems Using Views. In *Workshop Modellbasierte Entwicklung von Eingebetteten Fahrzeugfunktionen (MBEFF)*. se-rwth, 76–89.

[17] Houssem Guissouma, Axel Diewald, and Eric Sax. 2019. A Generic System for Automotive Software Over the Air (SOTA) Updates Allowing Efficient Variant and Release Management. In *International Conference on Information Systems Architecture and Technology (ISAT)*. Springer, 78–89. https://doi.org/10.1007/978-3-319-99981-4_8

[18] Houssem Guissouma, Heiko Klare, Eric Sax, and Erik Burger. 2018. An Empirical Study on the Current and Future Challenges of Automotive Software Release and Configuration Management. In *Euromicro Conference on Software Engineering and Advanced Applications (SEAA)*. IEEE, 298–305. https://doi.org/10.1109/SEAA.2018.00056

[19] Håkan Gustavsson and Jakob Axelsson. 2008. Evaluating Flexibility in Embedded Automotive Product Lines Using Real Options. In *International Software Product Line Conference- (SPLC)*. IEEE, 235–242. https://doi.org/10.1109/SPLC.2008.9

[20] Khan Habibullah, Hans-Martin Heyn, Gregory Gay, Jennifer Horkoff, Eric Knauss, Markus Borg, Alessia Knauss, Håkan Sivencrona, and Polly Li. 2024. Requirements and Software Engineering for Automotive Perception Systems: An Interview Study. *Requirements Engineering* 29 (2024), 25–48. https://doi.org/10.1007/s00766-023-00410-1

[21] Lennart Holsten, Christian Frank, Jacob Krüger, and Thomas Leich. 2023. Electrics/Electronics Platforms in the Automotive Industry: Challenges and Directions for Variant-Rich Systems Engineering. In *International Working Conference on Variability Modelling of Software-Intensive Systems (VaMoS)*. ACM, 50–59. https://doi.org/10.1145/3571788.3571796

[22] Katja Hölttä-Otto. 2005. *Modular Product Platform Design*. Dissertation. Helsinki University of Technology. http://lib.tkk.fi/Diss/2005/isbn9512277670/isbn9512277670.pdf

[23] David Inkermann, Tobias Huth, and Thomas Vietor. 2018. Towards Cross-Domain Release Engineering-Potentials and Challenges for Automotive Industry. *International Conference on Adaptive and Self-Adaptive Systems and Applications (ADAPTIVE)* (2018), 93–99.

[24] Martin Jaensch. 2012. *Modulorientiertes Produktlinien Engineering für den modellbasierten Elektrik/Elektronik-Architekturentwurf*. Dissertation. Karlsruhe Institute of Technology. https://edocs.tib.eu/files/e01fn12/73179205X.pdf

[25] Martin Jaensch, Bernd Hedenetz, Markus Conrath, and Klaus D. Müller-Glaser. 2010. Transfer von Prozessen des Software-Produktlinien Engineering in die Elektrik/Elektronik- Architekturentwicklung von Fahrzeugen. In *INFORMATIK*. GI, 497–502. In German.

[26] Eun-Young Kang, Dongrui Mu, Li Huang, and Qianqing Lan. 2017. Verification and Validation of a Cyber-Physical System in the Automotive Domain. In *International Conference on Software Quality, Reliability and Security Companion (QRS-C)*. IEEE, 326–333. https://doi.org/10.1109/QRS-C.2017.62

[27] Jacob Krüger. 2021. *Understanding the Re-Engineering of Variant-Rich Systems: An Empirical Work on Economics, Knowledge, Traceability, and Practices*. Ph. D. Dissertation. Otto-von-Guericke University Magdeburg. https://doi.org/10.25673/39349

[28] Jacob Krüger and Thorsten Berger. 2020. An Empirical Analysis of the Costs of Clone- and Platform-Oriented Software Reuse. In *Joint European Software Engineering Conference and Symposium on the Foundations of Software Engineering (ESEC/FSE)*. ACM, 432–444. https://doi.org/10.1145/3368089.3409684

[29] Jacob Krüger, Wardah Mahmood, and Thorsten Berger. 2020. Promote-Pl: A Round-Trip Engineering Process Model for Adopting and Evolving Product Lines. In *International Systems and Software Product Line Conference (SPLC)*. ACM. https://doi.org/10.1145/3382025.3414970

[30] Elias Kuiter, Jacob Krüger, and Gunter Saake. 2021. Iterative Development and Changing Requirements: Drivers of Variability in an Industrial System for Veterinary Anesthesia. In *International Systems and Software Product Line Conference (SPLC)*. ACM, 113–122.

[31] Kristina Marner, Stefan Wagner, and Guenther Ruhe. 2022. Release Planning Patterns for the Automotive Domain. *Computers* (2022), 1–26. https://doi.org/10.3390/computers11060089

[32] Marc Meyer and Alvin Lehnerd. 1997. The Power of Product Platforms: Building Value and Cost Leadership. *Journal of Product Innovation Management* (1997), 526–529. https://doi.org/10.1016/S0737-6782(97)80157-9

[33] David Parmenter. 2015. *Key Performance Indicators: Developing, Implementing, and Using Winning KPIs*. Wiley.

[34] Patrizio Pelliccione, Eric Knauss, Rogardt Heldal, Magnus Ågren, Piergiuseppe Mallozzi, Anders Alminger, and Daniel Borgentun. 2016. A Proposal for an Automotive Architecture Framework for Volvo Cars. In *Workshop on Automotive Systems/Software Architectures (WASA)*. IEEE, 18–21. https://doi.org/10.1109/WASA.2016.9

[35] Klaus Pohl, Günter Böckle, and Frank Van Der Linden. 2005. *Software Product Line Engineering*. Springer. https://doi.org/10.1007/3-540-28901-1

[36] Alexander Poth. 2009. Product Line Requirements Engineering in the Context of Process Aspects in Organizations with Various Domains. *Software Process: Improvement and Practice* (2009), 315–323. https://doi.org/10.1002/spip.427

[37] Michael Quinn Patton. 2002. *Qualitative Research and Evaluation Methods*. Sage.

[38] David Robertson and Karl Ulrich. 1998. Planning for Product Platforms. *Sloan Management Review* (1998), 19–31. https://repository.upenn.edu/handle/20.500.14332/42182

[39] Herbert Rubin and Irene Rubin. 2011. *Qualitative Interviewing: The Art of Hearing Data*. Sage.

[40] Günther Ruhe. 2010. *Product Release Planning: Methods, Tools and Applications*. CRC Press.

[41] Eric Sax, Ralf Reussner, Houssem Guissouma, and Heiko Klare. 2017. *A Survey on the State and Future of Automotive Software Release and Configuration Management*. Technical Report. https://doi.org/10.5445/IR/1000075673

[42] Klaus Schmid and Martin Verlage. 2002. The Economic Impact of Product Line Adoption and Evolution. *IEEE Software* 19 (2002), 50–57. https://doi.org/10.1109/ms.2002.1020287

[43] Günther Schuh and W. Eversheim. 2004. Release-Engineering—an Approach to Control Rising System-Complexity. *CIRP Annals* (2004), 167–170. https://doi.org/10.1016/S0007-8506(07)60670-2

[44] Günther Schuh and Michael Riesener. 2017. *Produktkomplexität Managen*. Hanser. https://doi.org/10.3139/9783446453340.fm In German.

[45] Günther Schuh, Stefan Rudolf, Christian Tönnes, and Sasa Aleksic. 2016. Release Frequency for Technical Changes of Modular Product Platforms: How to Synchronise Technical Changes and Product Releases During the Lifecyle of a Product Platform. In *International Conference on Industrial Technology (ICIT)*. IEEE, 1045–1050. https://doi.org/10.1109/ICIT.2016.7474898

[46] Timothy Simpson. 2004. Product Platform Design and Customization: Status and Promise. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* (2004), 3–20. https://doi.org/10.1017/S0890060404040028

[47] Donna Spencer and Todd Warfel. 2004. Card Sorting: A Definitive Guide. *Boxes and Arrows* (2004), 1–23.

[48] Miroslaw Staron and Wilhelm Meding. 2018. *Software Development Measurement Programs*. Springer. https://doi.org/10.1007/978-3-319-91836-5

[49] Cem Sürücü, Bianying Song, Jacob Krüger, Gunter Saake, and Thomas Leich. 2020. Establishing Key Performance Indicators for Measuring Software-Development Processes at a Large Organization. In *Joint European Software Engineering Conference and Symposium on the Foundations of Software Engineering (ESEC/FSE)*. ACM, 1331–1341. https://doi.org/10.1145/3368089.3417057

[50] Frank Van der Linden, Klaus Schmid, and Eelco Rommes. 2007. *Software Product Lines in Action: the Best Industrial Practice in Product Line Engineering*. Springer. https://doi.org/10.1007/978-3-540-71437-8

[51] Thomas Vietor and Carsten Stechert. 2013. *Produktarten zur Rationalisierung des Entwicklungs- und Konstruktionsprozesses*. Springer, 817–871. https://doi.org/10.1007/978-3-642-29569-0_17 In German.

[52] Peter Wallin and Jakob Axelsson. 2008. A Case Study of Issues Related to Automotive E/E System Architecture Development. In *International Conference and Workshop on the Engineering of Computer Based Systems (ECBS)*. IEEE, 87–95. https://doi.org/10.1109/ECBS.2008.46

[53] Daniel Work, Alexandre Bayen, and Quinn Jacobson. 2008. Automotive Cyber Physical Systems in the Context of Human Mobility. In *National Workshop on High-Confidence Automotive Cyber-Physical Systems*. NITRD, 1–3. https://lab-work.github.io/download/WorkAutoCPS2008.pdf

[54] Philipp Zellmer, Lennart Holsten, Thomas Leich, and Jacob Krüger. 2023. Product-Structuring Concepts for Automotive Platforms: A Systematic Mapping Study. In *International Systems and Software Product Line Conference (SPLC)*. ACM, 170–181. https://doi.org/10.1145/3579027.3608988

[55] Philipp Zellmer, Jacob Krüger, and Thomas Leich. 2024. Decision Making for Managing Automotive Platforms: An Interview Survey on the State-of-Practice. In *International Conference on the Foundations of Software Engineering (FSE)*. ACM. https://doi.org/10.1145/3663529.3663851

[56] Tarik Şahin, Tobias Huth, Joachim Axmann, and Thomas Vietor. 2020. A Methodology for Value-Oriented Strategic Release Planning to Provide Continuous Product Upgrading. In *International Conference on Industrial Engineering and Engineering Management (IEEM)*. IEEE, 1032–1036. https://doi.org/10.1109/IEEM45057.2020.9309756