Decision Making for Managing Automotive Platforms: An Interview Survey on the State-of-Practice

Philipp Zellmer
philipp.zellmer2@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

The automotive industry is changing due to digitization, a growing focus on software, and the increasing use of electronic control units. Consequently, automotive engineering is shifting from hardware-focused towards software-focused platform concepts to address these challenges. This shift includes adopting and integrating methods like electrics/electronics platforms, software product-line engineering, and product generation. Although these concepts are well-known in their respective research fields and different industries, there is limited research on their practical effectiveness and issues—particularly when implementing and using these concepts for modern automotive platforms. The lack of research and practical experiences challenges particularly decision makers, who cannot build on reliable evidence or techniques. In this paper, we address this gap by reporting on the state-of-practice of supporting the decision making for managing automotive electrics/electronics platforms, which integrate hardware, software, and electrics/electronics artifacts. For this purpose, we conducted 26 interviews with experts from the automotive domain. We derived questions from a previous mapping study in which we collected current research on product-structuring concepts, aiming to derive insights on the consequent practical challenges and requirements. Specifically, we contribute an overview of the requirements and criteria for (re)designing the decision-making process for managing electrics/electronics platforms within the automotive domain from the practitioners' view. Through this, we aim to assist practitioners in managing electrics/electronics platforms, while also providing starting points for future research on a real-world problem.

CCS CONCEPTS

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

KEYWORDS

automotive, electrics/electronics, product line, life-cycle management, cyber-physical system, product structuring concept, platform management, decision making

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1 INTRODUCTION

To remain competitive, automotive manufacturers must continuously enhance their product portfolios by incorporating novel features into their vehicles. Traditionally, the focus was on hardware components, but technological advancements, new customer preferences, and legal standards demand the integration of a rising number of software features into the existing hardware platforms [5, 6, 26]. This shift is evident from the prevalence of software-centric innovations, which are driven by trends like autonomous driving, driver assistance systems, electrification, and vehicle connectivity. So, vehicles transition towards software-intensive cyber-physical systems, requiring effective collaboration between hardware and software components to deliver innovative features. However, the surge in software features introduces challenges for manufacturers when engineering and managing their vehicle platforms. In particular, the historical development of hardware platforms that integrate mechanical components now poses challenges when trying to integrate software-focused features, such as over-the-air updates or self-driving capabilities.

Managing the complexity of modern vehicle platforms, with the increasing numbers of electrics/electronics components and interconnections between hardware and software artifacts, has become progressively challenging. Consequently, automotive manufacturers face more complex decisions when engineering their platforms, which can easily result in escalating expenses and efforts. To address such problems, the manufacturers are adopting product-structuring concepts [36] that consider vehicles as software-centered cyber-physical systems. For instance, variant-management concepts from software product-line engineering [8, 22, 27] are being integrated into established hardware-platform strategies to incorporate the software perspective [4, 33]. However, despite these adaptations, creating a holistic platform strategy that encompasses all dimensions of modern vehicles remains a challenging problem in practice.

In this paper, we report the results of an interview survey with 26 experts from the automotive domain. With this survey, we aimed to elicit the state-of-practice of making decisions for managing electrics/electronics platforms, collecting requirements and challenges that different stakeholders perceive in this context. Based on the interviews, related research, and our expertise in the automotive domain, we discuss and asses how automotive manufacturers can deal with the temporary challenges they face. More precisely, we contribute the following:

- We report an interview survey we conducted with 26 practitioners to collect requirements and challenges when managing automotive electrics/electronics platforms.
- We discuss how to support decision-making processes for managing electrics/electronics platforms.
- We contribute a set of requirements to guide the development of new techniques that can support the practical implementation of product-structuring concepts.

Our results can guide practitioners in making decisions about adopting product-structuring concepts, particularly electrics/electronics platforms. Researchers can build on the real-world experiences and challenges to design new techniques for supporting practitioners.

2 BACKGROUND AND RELATED WORK

Software-Driven Complexity. Automotive manufacturers face several challenges due to the rapid transformations caused by new trends like digitization and new software features. In fact, software has emerged as a key enabler for introducing innovative features, becoming a dominant factor shaping the competition within the automotive domain [5, 6]. This shift is reflected in the rapid and nearly exponential growth in the amount of software integrated into vehicles each year [9, 26]. As a result, the complexity of modern automotive systems has surged, encompassing a multitude of features aimed at meeting diverse user needs, at accommodating different countries' requirements, and at addressing environmental concerns [1, 7, 35]. This increasing complexity poses challenges, for instance, when analyzing commonalities and managing variations within a vehicle portfolio [19]. Notably, contemporary vehicles are evolving into cyber-physical systems in which physical and software components are intricately interconnected, and interact dynamically based on the operational context as well as environmental factors [20, 28]. This development highlights the increasing integration of digital and physical elements in the automotive domain.

Automotive Electrics/Electronics Platforms. The increasing software-driven complexity also results in a surge of electrics/electronics components in a vehicle, comprising Electronic Control Units (ECUs), sensors, and actuators that enable an interconnected vehicle. This aggregation of electrics/electronics components, referred to as the electrics/electronics platform, forms the fundamental basis for developing a modern vehicle-specific electrics/electronics architecture. By acting as a connection layer, electrics/electronics platforms facilitate the integration of hardware and software within a cyber-physical system [17, 27]. Notably, electrics/electronics platforms extend beyond mere hardware or software artifacts. They encompass all components of the electrics/electronics architecture, optimizing standardization and fostering synergies [17, 27].

Historically, hardware-driven vehicle platforms have been divided into individual platform variants to manage an extensive vehicle portfolio with its diverse requirements for individual vehicles [13]. Today, the same happens for electrics/electronics platforms. Unfortunately, the variations of individual electrics/electronics components can easily lead to interface-compatibility issues within the electrics/electronics architecture, resulting in the creation of electrics/electronics platform variants. These variants are generated whenever a change to an electrics/electronics component necessitates adjustments to other components within the platform. The causing incompatibilities may arise from changes in both hardware and software components [15]. Ideally, the underlying electrics/electronics architecture should remain identical across all platform variants, despite their variations.

Product-Structuring Concepts. In our previous work, we conducted a mapping study of product-structuring concepts that have been researched in an automotive context [36]. We refer to product-structuring concepts as any methodology that attempts to systematically manage a large product portfolio, involving hardware, mechanic, electrics/electronics, and software components. Within our study, we investigated three different concepts: software product-line engineering (SPLE), electrics/electronics platform engineering, and product-generation engineering. SPLE enables organizations to establish reuse and standardization across software artifacts, resulting in synergies between individual product variants [21, 24, 27]. Historically, SPLE structures development along domain engineering (developing the platform) and application engineering (deriving variants) [22, 27]. Today, SPLE is an established variability-management concept for software-intensive systems [19, 24]. While SPLE shows great potential in reducing costs, increasing software quality, and achieving faster time-to-market [21, 34], it lacks the integration of other variability representations (e.g., physical and electrics/electronics components). Moreover, it can be challenging to differentiate physical from functional variability in SPLE [10, 12, 29].

Unlike traditional hardware or software platforms, electrics/electronics platform engineering takes a distinctive perspective by concentrating on the seamless integration of software and hardware components within an overarching electrics/electronics architecture [15, 17, 27]. Serving as a key connection layer, an electrics/electronics platform establishes a foundational electrics/electronics architecture. The idea is to create a close interconnection between software and hardware components, while accounting for a vehicle as a cyber-physical system. This concept aims to optimize the characteristic benefits of hardware platforms, such as enhanced reuse and overall synergies, also across software-related vehicle components. In essence, the proposal of electrics/electronics platforms promotes a holistic concept for designing a vehicle platform in which the synergies between software and hardware are prioritized to improve performance and efficiency across a vehicle portfolio [36].

Product-generation engineering is a concept for systematically developing mechatronic systems across generations by evolving from an existing product (the reference product) [2, 3, 11]. In this concept, engineers create new technical product generations by combining specific carryovers with newly developed system parts [2]. Two key hypotheses guide product-generation engineering: (1) Products are defined based on a reference system, drawing from existing or planned socio-technical systems. (2) Subsystems are crafted through activities like carryover, embodiment, and principle variation. Recent research has extended this concept to address the growing importance of software and digitization in systems. To handle system evolution, product-generation engineering uses overarching functional roadmaps, mapping the functional evolution across the entire product portfolio and life cycle [3, 11].

In our systematic mapping study [36], we observed that each of these concepts has the potential to align with current trends in the automotive domain. However, we also identified various challenges and issues associated with implementing these concepts in practice. Most prominently, we found that all three concepts lack adequate tool support, a proper integration of all components that constitute modern vehicles, and practically usable knowledge management to support decisions. With this paper, we aim to provide practical insights that can guide practitioners as well as researchers in tackling these challenges, particularly to support organizations in deciding how to implement a holistic platform management.

Related Work. We found few publications that are concerned with the decision-making for contemporary platform management in the automotive domain. Reddy et al. [30] conducted a literature review to assess the optimal decision-making technique for developing a make-buy decision framework that can be applied to the so-called product introduction process within automotive manufacturing. Siyun et al. [32] discuss three conceptions of purchasing quality, encompassing various decision-making patterns. Their goal is to establish a comprehensive framework for purchasing quality management. Kaluza et al. [18] present a starting point and requirements for developing tools that can provide usable and robust decision bases throughout the development of components. However, none of these publications offers a thorough and systematic analysis of the state-of-practice regarding the decisions needed to manage complex electrics/electronics platforms.

Other researchers discuss current automotive challenges, including topics related to product-structuring concepts. Broy [6] provides an overview to the state-of-practice, including issues, challenges, and opportunities regarding automotive software engineering. Hohl et al. [14] identified challenges of combining agile software development and SPLE, contributing recommendations for a hybrid development process for vehicles. Holsten et al. [16] conducted an interview survey to elicit insights on the challenges of transitioning towards electrics/electronics platforms. Thiel et al. [33] and Holsten et al. [15] contributed overviews of temporary challenges faced by automotive manufacturers, focusing on different product-structuring concepts. While Thiel et al. [33] investigated SPLE, Holsten et al. [15] compared and discussed the concepts of hardware, software, and electrics/electronics platforms to sketch directions for future research. Although these studies are related to ours, we are not aware of any being concerned with how to support decision makers who are responsible for managing platforms in the automotive domain .

3 METHODOLOGY

To start addressing the challenges we identified in our mapping study [36], we conducted an interview survey following the guidelines by Nair and Prem [25] and by Rong et al. [31]. Based on these guidelines, we defined the methodology that we describe in this section. We provide an overview about the individual steps in Figure 1.

3.1 Research Questions

With our interview survey, we aimed to elicit the state-of-practice regarding the decision making for managing electrics/electronics platforms. So, our goal was to establish a basis for developing decision-making techniques that support the management of electrics/electronics platforms within the automotive industry. To guide this goal, we defined three research questions (RQs):

- RQ_1 *How do which current challenges and requirements in the automotive domain impact variant management?*
  First, we aimed to obtain an overview of the challenges and requirements that practitioners experienced to influence the variant management in automotive practice.
- RQ_2 *What is the state-of-practice for the decision making regarding platform management in the automotive domain?*
  Second, we aimed to understand how practitioners make decisions in the context of managing automotive platforms, particularly with respect to the challenges and requirements we identified before.
- RQ_3 *What support does the decision making need to effectively manage automotive electrics/electronics platforms?*
  Finally, we aimed to understand what requirements new tools and techniques for supporting the decision making of practitioners would need to support to effectively manage an automotive electrics/electronics platform.

Tackling these research questions contributes valuable insights from automotive practice. Primarily, our contributions can help automotive manufacturers understand the challenges and requirements connected to their decision making for electrics/electronics platforms. Moreover, these insights can guide future research on how to improve practice, particularly how to implement and use product-structuring concepts to effectively support the implementation of large cyber-physical product portfolios.

3.2 Interview Design

To collect relevant insights for answering our research questions, we employed semi-structured interviews with experts from different fields of activity. At the beginning of our interview survey, we prepared a short interview guide involving a few questions and the methodology for identifying relevant statements. Except for some closed background questions, we primarily used a few open-ended questions to initiate discussions around our research questions. We exemplify these questions in Section 4, emphasized by italic font and a label (Q_x). This way, we aimed to offer our interviewees time for detailed and nuanced answers, thereby providing depth and context on the interview questions while also exploring what our interviewees perceived as most relevant. We iteratively developed our interview guide among all authors to improve its effectiveness and completeness. To ensure a reasonable length for the interviewees, we eliminated and consolidated potentially redundant questions through multiple iterations. Moreover, we defined optional questions that could be skipped if the schedule was behind. Before starting with the actual interviews, we conducted several pilot runs with employees of Volksawagen AG to enhance the quality of the designed questions and ensure that our interview survey captured all necessary information. Please note that we also had to limit our questions to prevent confidentiality and ethical violations. Through these meanse, we received internal approval by the communications department and the union of employees ("Betriebsrat") of Volkswagen AG to conduct our interviews.

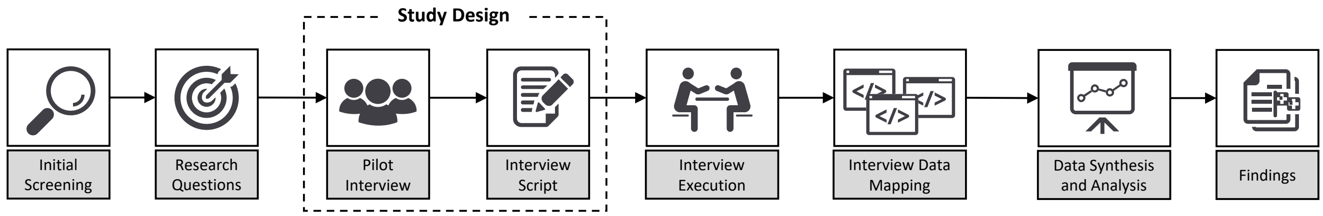

Figure 1: Overview of our research methodology.

3.3 Conduct

Our target group of interviewees involved employees from different brands of Volkswagen AG, including Volkswagen, CARIAD, and Volkswagen Nutzfahrzeuge. We display an overview of their respective fields of activity and their experiences in Table 1. In total, we sent 30 invitations, with 26 employees agreeing to participate in our study. Please note that participation was completely voluntarily and we anonymized all collected data to protect the interviewees' privacy and avoid any negative consequences. Moreover, they could stop their interview at any point without consequences.

Then, the first author of this paper conducted the actual interviews in with each interviewee individually. During an interview, we allowed participants to deviate from our defined questions to obtain additional and more in-depth information. The interviews had varying lengths, most lasting around 65 minutes while a few lasted only 30 minutes and the longest took 90 minutes. To collect the data, we utilized an Excel spreadsheet to document the interviewees' answers for each of our questions.

3.4 Data Synthesis and Analysis

To analyze our data, we used qualitative data analysis methods, particularly open coding and card sorting. Initially, the first author built on their experiences from practice to add codes to the spreadsheet. The first author is working for several years at one of the biggest automotive companies, Volkswagen AG. In this time, he has accompanied projects in various departments, focusing on topic such as, variant management, platform engineering, and software-portfolio management. In this context, the author used his expertise to arrange and classify all collected data, by card sorting. We further refined the codes based on all authors' knowledge from previous research [36, 37]. Subsequently, we organized the collected statements by card sorting their labels into themes and structuring these within mind maps. We illustrate the most prominent statements and their overarching themes regarding our research questions within the three mind maps in Section 4.

4 RESULTS

Next, we report the main results from our interviews. To this end, we present and discuss the most relevant themes we identified related to each of our research questions.

4.1 Variant-Management Challenges (RQ_1)

First, we aimed to gather an overview of challenges and requirements that impact the variant management for automotive platforms. We display a concise mind map of the most important statements and themes in Figure 2.

Challenges. *We elicited several challenges associated with electrics/electronics platforms and architectures within the automotive domain (Q_1).* The most frequent responses included dealing with the increasing software focus in functions (5), providing a failure-free architecture and system (4), and balancing requirements between platform, brands, and body (4). All of these challenges are important to tackle to achieve customer satisfaction as the central challenge for automotive manufacturers. These challenges become increasingly important due to the growing digital affinity of customers and the individualization through software. In this context, some interviewees also specified that the security claims of costumers are increasing alongside the digitization.

The next repeatedly reported challenge is connected to increasing complexity along various dimensions. Some interviewees stated that the increasing number of software-driven functions, ECUs, and dependencies is leading to much more complex vehicles. These complex systems are hard to manage over their life cycle, while this complexity will continue to increase in the future—even beyond an individual vehicle:

> "*Software-focused systems and their interconnections are increasing to the point of dependencies beyond the vehicle*"

Table 1: Participants of our semi-structured interviews.

Field of Activity	Number	Percentage
Product Management	10	38.5
Technical Project Management	4	15.4
Portfolio Management	3	11.5
Requirements Management	2	7.7
Configuration Management	2	7.7
Life-Cycle Management	2	7.7
Roll-Out Management	1	3.8
Systems Engineering	1	3.8
E/E Platform Engineering	1	3.8
Experience in the Field		
< 1 year	1	3.8
1–3 years	13	50
3–10 years	5	19.2
> 10 years	7	26.9
Automotive Experience		
3–10 years	7	26.9
> 10 years	19	73.1
Sum	**26**	**100**

Lastly, the growing efforts in testing, validation, and safety (5) are also a consequence of the rising number of ECUs, amount of dependencies, general complexity within vehicles.

In general, we found that software emerged as one of the biggest challenges for automotive experts. While some interviewees see the challenge predominantly in the increased costs and additional skills or tools required for software development, others perceive the harmonization between software and hardware as the central challenge. Many participants agreed that the hardware has remained the pivotal focus and needs to be much more synchronized with the software life cycle. Thereby, automotive manufacturers could enable longer lifetimes of hardware components within an electrics/electronics platform. This need for harmonizing would also reflecting the development process of an electrics/electronics platform itself.

Requirements. *To address the above challenges, we collected requirements for software-focused electrics/electronics platforms and architectures during our interviews (Q_2).* Many participants reported considering software maintenance over the whole life cycle (8), especially for critical components within a vehicle, to ensure compliance with new regulations and to meet customer demands as a fundamental requirement. At the same time, customer demands for functions within vehicles are increasingly oriented towards mobile devices, highlighting the growing importance of software features and functional orientation within vehicles (5). In turn, this requires flexible deployment strategies for software that include all stakeholder within the decision process. Additionally, software must be able to change quickly and short-term changes must be transferable to a vehicle via OTA updates. As a consequence, OTA update capabilities of modern vehicles must also be thoroughly tested and validated:

> "*Software maintenance, OTA update ability, and compatibility of vehicles must be ensured since software features play a key role in the future.*"

In this context, some participants highlighted that compatibility must be ensured within the electrics/electronics platform, and a standardized software can bring significant benefits for scaling.

New business models like function-on-demand require strict variant management to restrict complexity within the electrics/electronics platform and to ensure a systematic management of hardware adaptability during updates. Some participants also noticed the necessity for a strategic plan for the electrics/electronics platform as an additional requirement. This plan should encompass systematically planned functional enhancements over the whole life cycle.

Subsequently, we sought to know which requirements are already addressed in practice, and which demand changes or optimization (Q_3). Interestingly, the ability to update vehicles within a platform is already an integral part of the electrics/electronics platform. Also, an understanding of the change to software-focused electrics/electronics platforms and architectures is present among our interviewees. While some of them reported that such new requirements are adopted into existing processes and tools, others mentioned that they are only partially addressed and that the transformation of processes, methods, and tools is an ongoing transformation. For example, many mentioned that more focus must be put on defining criteria that transparently present the effects of variants to enable life-cycle maintenance.

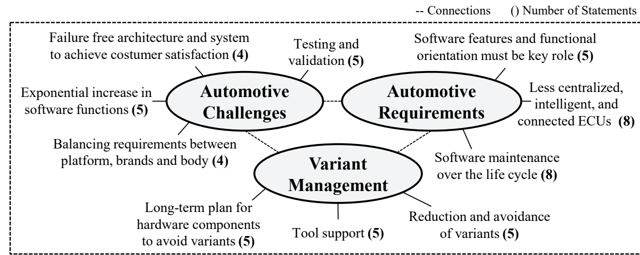

Figure 2: Our high-level mind map with statements on challenges and requirements (RQ$_1$).

Variant Management. *Lastly, we investigated how the increasing relevance of software in electrics/electronics platforms impacts variant management (Q_4).* Five interviewees reported that variant management is becoming more and more important, and plays a key role in managing automotive platforms. In this context, they highlighted the importance of avoiding and reducing hardware variations that influence platform variants in a negative way to keep the complexity manageable. As mentioned, software maintenance and testing are heavily dependent on these hardware variants, increasing the necessity for a manageable number variants within the electrics/electronics platform. Besides, new business models like function-on-demand or continuous software maintenance OTA depend on systematic variant management throughout the platform's and vehicles' entire life cycles. The respective hardware components need long-term planning to minimize and avoid variants (5), while software is subject to frequent updates and bug fixes. So, five participants explicitly mentioned that the software variance is becoming more important and that the tool support is currently limited in the existing processes and system landscape.

4.2 Decision-Making Practices (RQ$_2$)

Next, we analyze the state-of-practice in managing and deciding upon electrics/electronics platforms. We display a concise mind map of the most important statements and themes in Figure 3.

Platform Management. *First, we asked each participant what they understand under the term electrics/electronics platform management and how it would ideally look like (Q_5).* The answers contained four different themes. Six interviewees mentioned a centralization of hardware, software, and functions into a cohesive functional unit. Another six expanded on this by emphasizing the need for reducing the complexity across vehicles releases, the combination of hardware and software in cross-brand usage, and the avoidance of "wild growth" within an electrics/electronics platform. Some of them mentioned that this also involves synchronization between releases and continuous development to deliver fixed software packages at specific dates. However, all these interviewees agreed that electrics/electronics platform management ensures compatibility, and thus also the functionality of all components for a specific platform release:

> "*E/E platform management aims to ensure compatibility between all components within the electrics/electronics platform and their interaction with each other without errors.*"

Subsequently, we aimed to assess the current level of integration of electrics/electronics platform management into decision-making processes

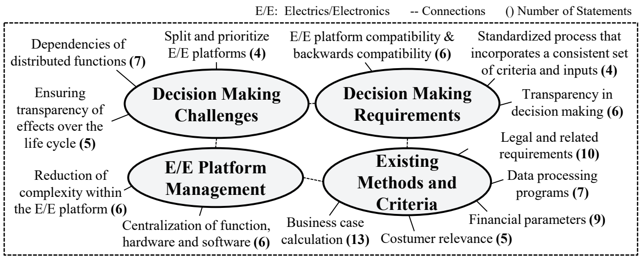

Figure 3: Our high-level mind map with statements on decision making practices (RQ$_2$).

(Q$_6$). While some interviewees mentioned that this management is fully integrated, most indicated that it is mostly implemented on top of the existing process and could be optimized to ensure an efficient integration into the decision-making. Although the electrics/electronics platform management mindset is present across all departments, the majority of our interviewees expressed the need to further strengthen the integration between processes, methods, and tools to fully benefit from it.

Decision-Making Challenges. *We collected various statements on challenges for decision making within the automotive industry (Q$_7$).* The most common ones included dependencies of distributed software-based functions (7), ensuring transparency over all inputs, data, and effects over the life cycle (5), and effective splitting and prioritizing of electrics/electronics platforms for a specific release (4). Dependencies of distributed functions extend into the hardware, as well as the time dependency between platform, hardware, and software development.

Variant management emerges again as a key challenge in the evolving landscape of automotive platforms, with emphasis on the increasing importance of software variance. One challenge is the choice between avoiding variants and developing new ones. According to most interviewees, the goal should always be to keep the number of variants, and thus complexity low. Still, innovative features must be offered to the customer in parallel. So, the overall challenge for decision making is to establish an affordable vehicle portfolio that originates from a controlled process. This includes describing new requirements, evaluating these technically and financially, as well as implementing the requests via relevant decision-making bodies.

Subsequently, we asked the interviewees how the increasing software focus has changed decision-making. In fact, software has becoming the defining feature for decisions (Q$_8$). There is consensus among our interviewees that decisions that do not consider the software are no longer viable. In parallel, including software adds a new layer of complexity to evaluating changes and makes it more intricate to determine impact, the timing of implementation, as well as the interfaces involved. Moreover, introducing new software often necessitates elevated performance standards for hardware, increasing the importance of backwards compatibility and update-ability within an electrics/electronics platform:

> "*Requirements in terms of backward compatibility are contrary to new, innovative hardware and thus to competitiveness*"

Additionally, our interviewees mentioned that software can change more often and in more spontaneous intervals compared to hardware [23]. This poses a challenge for decision making and highlights the need for a sped-up process, also requiring new decision criteria. OTA updates stand out as a distinctive feature that must be considered within decision-making processes.

Decision-Making Requirements. *Next, we asked our interviewees about the most important requirements in decision making (Q$_9$).* The most frequent answer was to ensure (backwards) compatibility within the platform to reduce complexity (6). Identically, six interviewees mentioned a fixed and transparent road map with fixed release intervals as essential to increase transparency in decision making. Lastly, four interviewees stated that the decision-making process must be adapted by implementing a group-wide standardized methodology that utilizes a consistent set of criteria and inputs:

> "*Decisions across electrics/electronics platforms should be made only based on a standardized set of premises.*"

Such an adaptation aims to improve the validity of decisions in managing software-focused platforms and to maintain consistency across the criteria used.

Existing Methods and Tools. *Then, we collected statements on how decision making is currently supported via methods, processes, and tools (Q$_{10}$).* The most common methods are business-case calculation (13) followed by various data processing programs (7). Additionally, electrics/electronics platform management was referred to as one of the methods for decision-making for software-intensive vehicle platforms. Other mentioned methods and tools include benefit-cost calculation, workshops, and engineering teams. In summary, only a few advanced methods that comprehensively address decision-making for electrics/electronics platforms are used. Most of these methods and tools are applied through various meetings, leading to decentralized information and thus limited transparency.

Afterwards, we sought to understand the extent to which the current methods and tools align with emerging challenges and requirements (Q$_{11}$). Several interviewees highlighted that the current committee structures could benefit from simplification, involving fewer rounds to reduce the time required to come to a decision. Furthermore, it is key to enhance the relevance of software in decision-making. Even greater attention must be paid to the transparency of decision-making processes, which includes accounting for the impact of software and hardware variance over the entire life cycle of a vehicle platform up to its end-of-software-service:

> "*Processes and methods originate from the time when decisions were made about hardware without dependency on software - this is no longer sufficient for the future.*"

We remark that, even though electrics/electronics platform management was one of the most frequently mentioned methods, many interviewees highlighted the need to strengthen the respective platform mindset. So, the effective integration of this platform management into existing processes and methods must be advanced.

Lastly, we aimed to determine whether the decision-making process today places a stronger focus on hardware or on software (Q$_{12}$). While many interviewees noted that software has broader coverage due to its more frequent changes, the majority indicated that hardware still boasts stronger coverage due to the mechanical background of the process structures and better transparency in terms of costs. Only few interviewees said that software and hardware are equally covered in today's decision-making processes.

Existing Inputs and Criteria. *We asked our interviewees about the criteria and inputs they find important for decision-making, and whether some criteria need stronger focus (Q_{13}).* Nine interviewees mentioned financial parameters (e.g., material costs), ten legal and related requirements, and five customer relevance as well as release type including the release interval as a common criterion employed today. Furthermore, the criteria software compatibility and backwards compatibility, build ability issues including hardware availability within production, as well as the functional implementation were mentioned repeatedly. In contrast, only individual interviewees stated that criteria like OTA update ability, installation rates and volumes, development effort, and cross-user synchronization within the platform are being considered.

Contrary to current use, numerous participants emphasized the importance of factors like technical affordability, competitive comparisons, as well as the costs and revenues associated with electrics/electronics platform variants over the life cycle. This suggests that these criteria should take a more prominent role in the decision-making process:

> "*The maintenance effort and variety over life cycle are underestimated.*"

Furthermore, our interviewees emphasized the importance of integrating criteria like a multi-supplier strategy and the key properties of battery electric vehicles with their charging time, range, and efficiency into the decision-making process.

4.3 Future Decision Making (RQ$_3$)

Finally, we gathered our interviewees' opinions regarding the potential of adopting or recreating decision-making methods for software-intensive systems. We display a concise mind map of the most important statements and themes in Figure 4.

Reasons. *First, we collected opinions on why and how to (re)design decision making within the automotive industry (Q_{14}).* The majority of our interviewees saw potential in optimizing and expanding existing processes, methods, and tools:

> "*The (re)design of methods is mandatory to effectively and transparently map the increasing complexity in decision-making.*"

In particular, five of them mentioned revising the existing structures and methods by enhancing links between systems and processes as an improvement. Thereby, it is possible to avoid decentralized and hidden information by adding adequate tools. Considering that architectural decisions made today will only become visible later in the life cycle, four interviewees highlighted the need to integrate respective criteria to raise the users' awareness of this fact. These criteria could include the dimensioning of hardware components until the end-of-software-service with improved transparency and accounting for the tangible effects of each decision. In addition, three interviewees noted that the evolving functional orientation and increasing speed of (software) changes may require a generally new approach to decision-making.

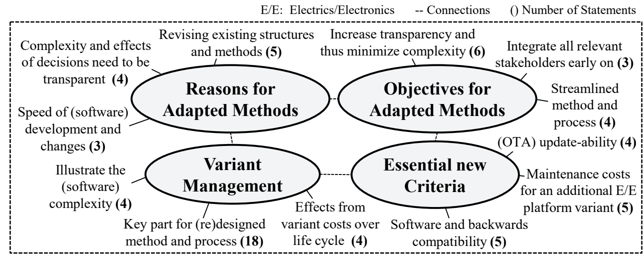

Figure 4: Our high-level mind map with statements on support for decision making (RQ$_3$).

Subsequently, we aimed to understand the importance of implementing changes to address the challenges and requirements of software-intensive systems (Q_{15}). All interviewees stated that changes are crucial and mentioned a broad range of reasons for their opinions. The majority emphasized that it is important to change to meet customer requirements, stay competitive, and efficiently manage the impact of software maintenance throughout the life cycle. Additionally, our interviewees highlighted reasons like avoiding incorrect decisions, enhancing capacity planning, and improving data handling from various sources.

Objective. *Next, we inquired about how our interviewees would describe the primary objective of a new decision-making method (Q_{16}).* Key themes for formulating a target, as highlighted by most interviewees, include transparency (6), acceleration, integration (3), and synchronization. Additionally, four participants highlighted the importance of standardization, a methodical and streamlined method, as well as customer-centricity as focal points.

Based on the assumption that variant management plays a decisive role in decisions, we asked the interviewees how important they consider it to be (Q_{17}). A majority of our interviewees (18) rated variant management as particularly crucial. Especially, four highlighted affordability and transparency on the costs of variants also while maintaining them throughout the life cycle and the evaluation of changes (including testing, validation, and maintenance) as key elements. Four of them emphasized the need for variant management as part of the priority rating to support the transparency of dependencies in decision-making. In addition, some participants highlighted the significance of extending variant considerations to mobility systems (systems of systems). This emphasizes the importance of addressing how additional requirements from a mobility system can be implemented with a minimum number of variants.

New Criteria. *Finally, we asked our interviewees about new criteria and inputs they find important for addressing the increasing software focus in electrics/electronics platform and (re) redesigning decision-making methods and tools (Q_{18}).* The most mentioned criteria include the update-ability (4), architectural synergies, software and backwards compatibility (5), as well as maintenance costs for an additional electrics/electronics platform variant over its life cycle (5). Further relevant criteria encompass the strategic relevance for future projects, customer usage behavior and feedback, additional business cases (including OTA and function-on-demand), cyber security relevance, affordability of technical development, as well as the impact on mobility systems. Moreover, some interviewees mentioned that synergies with other architectures and the transfer to future projects are insufficiently considered and need to be strengthened to better leverage synergies. To summarize, the new criteria must efficiently support decisions by avoiding or reducing variants that have a negative impact on the overall electrics/electronics platform. This aims to simplify testing and the validation while facilitating the roll-out of updates.

5 DISCUSSION

In this section, we analyze and discuss our results. For this purpose, we consolidate our findings to emphasize key insights that we enrich based on our experiences in the automotive domain.

5.1 Challenges and Requirements

We gathered insights into numerous challenges associated with software-focused electrics/electronics platforms and architectures in the automotive domain. Commonly mentioned challenges, such as managing the increasing software focus, ensuring a flawless system, and establishing architecture for customer satisfaction, are not surprising. This aligns with the ongoing transformation of modern vehicles into cyber-physical systems, necessitating efficient interaction between hardware and software to deliver innovative vehicles. These challenges also shed light on the increased security concerns among customers due to the advanced digitization, with larger networks of vehicles representing potential cyber-security risks. The reported complexity-induced challenges, such as the spread of software-driven functions, ECUs, and dependencies, increase efforts in testing, validation, and safety throughout the life cycle of electrics/electronics platforms. In this context, many participants highlighted the need for harmonizing hardware and software life cycles, including the respective development processes. Moreover, coordination within the platform is key to balance requirements among stakeholders, adding another layer of complexity.

In response to these challenges, we collected and analyzed various requirements for electrics/electronics platforms and architectures. Our interviewees emphasized that considering OTA software maintenance, especially for critical components, is important to comply with regulations and meet evolving customer demands over the vehicle's life cycle. This aligns with the reported trend of customer demands shifting towards functions oriented around mobile devices. While some participants noted that the integration of new requirements into existing processes and tools is in a pilot phase, others highlighted that these changes are only partially addressed. So, there is currently an ongoing transformation in processes, methods, and tools within the automotive domain. This also suggests differences in the degree to which requirements are considered among interviewees from different departments. In turn, we emphasize the need for a comprehensive, transparent, and platform-spanning decision making.

Our findings on variant management underpin its increasing importance and pivotal role in managing electrics/electronics platforms in the automotive domain. The interviewees emphasized the need to avoid and reduce hardware variants that negatively influences the electrics/electronics platform variants, highlighting the necessity of maintaining manageable complexity. Software maintenance, including testing, was identified as heavily dependent on hardware variants over the life cycle, underpinning the need for a manageable number of variants within electrics/electronics platforms. Emerging business models like function-on-demand or continuous software maintenance OTA are highly dependent on systematic variant management throughout the life cycle. Our interviewees mentioned that, while hardware components are more stable with fewer changes, software variations, including updates and bug fixes, are becoming more frequent. The growing importance of software variance while tool support is lacking clearly indicates a need for research to develop novel methods and techniques for facilitating the management of electrics/electronics platforms.

RQ_1: Variant-Management Challenges

Variant Management has become a key challenge in the automotive industry. It is influenced by factors like the continuously growing importance of software, continuous software maintenance, and interconnected hardware variants within vehicles. Software introduces an additional layer of complexity that demands for pivotal attention in platform management.

5.2 State-of-Practice Platform Decision-Making

Our interviewees had diverse perspectives on the aim of electrics/electronics platform management, resulting in a diverse set of tasks that characterize an ideal electrics/electronics platform management. While all statements included the centralization of hardware, software, and functions into a cohesive functional unit, other interviewees expanded on this by emphasizing the need for a reduction in complexity across projects during releases or the combination of hardware and software for cross-brand usage and to avoid "wild growth" within an electrics/electronics platform. A similar picture emerged with regard to the implementation of electrics/electronics platform management. While some interviewees mentioned that electrics/electronics platform management is fully integrated, most participants indicated that it is currently mostly implemented on top of existing processes. This demands for further optimizations to efficiently integrate relevant criteria into transparent decision-making processes. We found that this is evident in a majority of responses, signifying the widespread presence of the electrics/electronics platform management mindset across all interviewees. However, there is an opportunity to further align current processes, methods, and tools with the electrics/electronics platform concept to enhance the integration and effectiveness.

We gathered various perspectives on the general challenges associated with decision-making in the automotive industry. Common responses highlighted the importance of involving all affected brands and users in the decision-making process. Furthermore, it is necessary to ensure transparency by considering all inputs, data, and the final decision; achieving a timely decisions in alignment with the desired standard operating procedure to incorporate the risk of high maintenance costs. Additionally, our interviewees noted the critical problem of electrics/electronics platform compatibility and backwards compatibility. These are key to offer customer benefits and facilitate vehicle maintenance through OTA updates throughout the whole life cycle of the platform and its individual vehicle variants—which otherwise co-evolve and may not be compatible anymore. Moreover, decision-making must account for the numerous dependencies of distributed functions, including hardware and software, and navigate the time dependencies between platform, hardware, and software development. This complexity significantly influences the effective splitting and prioritizing of electrics/electronics platforms for a specific release. Thus, in the evolving landscape of automotive development, variant management emerges as another key challenge, with a specific emphasis on the increasing significance of software variance. Our interviewees also noted the challenge of deciding between avoiding variants and developing new ones. The overarching goal is to maintain a low number of variants and achieve reduced complexity, while still offering innovative vehicles to customers. In summary, the overarching challenge regarding decision-making processes is to enable an affordable function portfolio that stems from a controlled process. Such a process involves describing new requirements, conducting technical and financial evaluations, and seeking implementation approval from relevant decision-making bodies.

There has been a consensus among our interviewees that decisions without considering software are no longer viable. Consequently, software is becoming the dominant factor in decision-making processes and leads to more complexity within the decision making. Especially, determining the scope of impact, the timing of implementation, and the interfaces of electrics/electronics platform variants is a current practical challenge that needs to be addressed in research. Moreover, our interviewees mentioned that software can change more often and in spontaneous intervals, posing a particular challenge for decision making. This supports the identified need for an accelerated decision-making process, which involves reevaluating established criteria.

To address these challenges, our interviewees reported various requirements. As the most frequent responses, electrics/electronics platform compatibility and backwards compatibility are not surprising, since these reduce the overall complexity within the electrics/electronics platform. Logically, this requirement was also mentioned as a general automotive requirement. Nevertheless, given that OTA updates have been highlighted as one of the key challenges for the future, we can assume that update-ability and backwards compatibility will be crucial criteria for decision-making in the future. This also aligns to the mentioned issue of implementing fixed and transparent road maps with fixed release intervals. We anticipate the management of such complex road maps as am opportunity for future research.

Only a few methods for comprehensively addressing decision-making for software-intensive platforms were mentioned by our interviewees. Most of the methods and tools, such us business case calculation, data processing programs, workshops, and engineering teams, have only limited transparency regarding the derived decisions. Identically, the inputs for decision-making are partly decentralized, negatively impacting the workload, quality of decisions, and transparency. This was also supported by the majority of our interviewees, who reported several opportunities for enhancing transparency. Particularly, the effects of software and hardware variance over the life cycle of the platform and its vehicle variants up to end-of-software-service are important. Although electrics/electronics platform management was one of the most frequently mentioned methods, many participants emphasized the need to enhance integration. This underpins the necessity to either adopt or redesign

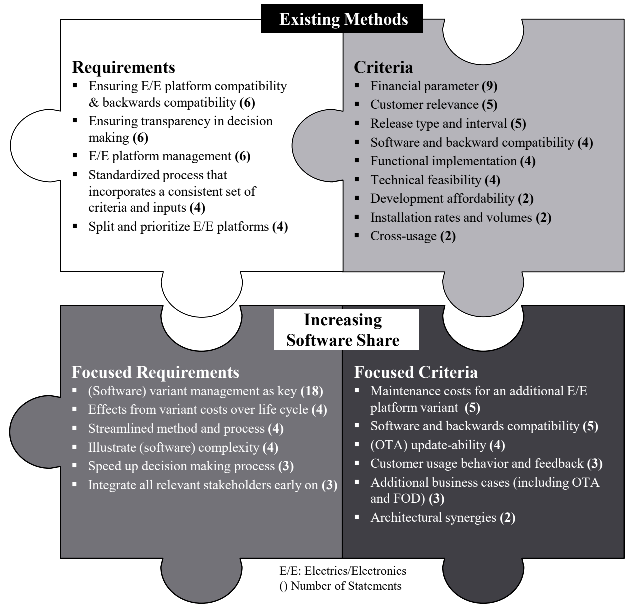

Figure 5: Most mentioned requirements and criteria in decision making for automotive platforms.

existing processes and tools to effectively address software-focused challenges in decision-making. In turn, researchers can support practice concretely by proposing new means for this purpose.

The most mentioned initial criteria, such as financial parameters (e.g., equity, material costs), management requests, legal and similar requirements, customer relevance, release type, or release interval, indicate that parameters with a mechanical background are still more prominent than criteria derived from software in decision-making. Only a few criteria, including update-ability, proof of software compatibility, backwards compatibility, and functional implementation, are currently part of today's decision-making processes and methods. Many participants highlighted the need to expand existing criteria, including costs and revenues associated with electrics/electronics platform variants over the life cycle, key properties of battery electric vehicles (e.g., charging time, range, and efficiency), and competitive comparisons.

RQ_2: Platform Decision-Making Practices

Current processes, methods, and tools face the challenge of meeting the increasing demands of the growing software focus within the automotive platform, which is also reflected in the complexity of decision-making. According to the majority of our interviewees, there is an opportunity to enhance transparency, speed, and establish a consistent, methodical approach for the effective integration of software into decision-making.

5.3 Future Decision-Making Techniques

The majority of the interviewees affirmed the potential to optimize and extend existing processes, methods, and tools for decision-making. In parallel, all interviewees also rated these change as particularly crucial to address software induced challenge and requirements. Several reasons were reported, including the integration of new criteria that consider both hardware and software effects over the life cycle, the evolving functional orientation, and the These factors underpin the need for further advancements in decision-making methods and techniques.

In the context of (re)building decision-making methods, various key objectives were mentioned, including transparency, acceleration, and synchronization, aligning with the previously discussed challenges and requirements in the automotive domain. Additionally, the interviewees emphasized the importance of standardization, a methodical approach, customer-centricity, and the incorporation of mobility systems. *Based on the assumption that variant management is another key objective, we asked the participants for their assessment, whereby all interviewees rated these aspects as particularly crucial (Q_{17}).* They particularly emphasize affordability and transparency on costs of variants in the case of software maintenance over the life cycle and the evaluation of changes including testing, validation and maintenance as part of the priority rating to support the transparency of dependencies in decision-making.

The most frequently reported criteria within the interview survey included update-ability, architectural synergies, software and backwards compatibility, maintenance costs for an additional electrics/electronics platform variant over the life cycle, and others. These can serve as crucial components for (re)designing decision-making methods. At the end, all these criteria, along with others, must be detailed, agreed upon by all relevant stakeholders, and incorporated into a standardized, transparent, and methodical decision-making procedure. As a starting point, we present all the mentioned requirements and criteria for (re)designing the decision-making process of managing electrics/electronics platforms in the automotive domain in Figure 5.

RQ_3: Requirements for (re)designing Decision Making

The majority of our interviewees see potential in (re)designing decision-making processes, tools, and methods to address customer demands, stay competitive, and effectively manage the impact on software maintenance over the life cycle. To achieve this, systems and processes need to be transparently integrated, accelerated, and augmented with new criteria, especially those related to software.

6 THREATS TO VALIDITY

In this section we discuss several validity risks due to which our interview survey may be compromised.

Internal validity. First, we acknowledge that internal validity may be compromised by personal biases in the interpretation of the interview data. Specifically, the open card sorting was conducted by a single author, potentially influencing the results through subjectivity. To counteract this risk, we performed an iterative strategy as part of the data synthesis and analysis. More precisely, we discussed the interpretations across all authors and cross-checked our results, mitigating the threats from personal bias.

External validity. The external validity of our study could be impacted by the representativeness of the interviewees. In separate meetings, we conducted interviews with 26 participants from Volkswagen AG. Therefore, the results and findings may not fully encompass the entire landscape of decision making for managing automotive platforms. To mitigate this validity risk, we expanded the scope of our interview study, involving interviewees from different departments and brands. This effort aimed to enhance the representativeness of our study, with 26 interviewees from various fields of activity accross different brands reducing the risks to the external validity of our findings.

Construct validity. Finally, there is a potential risk to the construct validity, specifically related to the appropriateness of survey questions in the interview script. To mitigate this risk, we incorporated pilot surveys during the design phase of our interview script. Through discussions with the interviewees, we aimed to further enhance the quality of the designed questions and ensure that the interview survey captured all necessary information. This proactive approach helped to mitigate the threat to construct validity.

7 CONCLUSION

In this paper, we presented a interview study on the state-of-practice of making decisions for managing electrics/electronics platforms. Our study provides an overview of the requirements and criteria for (re)designing the decision-making process for managing electrics/electronics platforms within the automotive domain. We interviewed 26 participants from different fields of activity and departments. Drawing from the given statements, we identified and discussed various automotive challenges and requirements that influences decision making for managing electrics/electronics platforms and derived an overview of requirements and criteria for the (re)design of methods, processes and tools. Within our analysis, we identified several interesting findings regarding automotive challenges and requirements, especially to decision making. First, software is becoming a dominant factor in terms of complexity and needs to pay attention in decision making process. In this context, factors like the growing emphasis on software, continuous software maintenance, and interconnected hardware and software variants within vehicles, emerge as key challenges for tomorrows (software) variant management. Second, there was a common consensus on the potential benefits of (re)designing decision-making processes, tools, and methods, such as staying competitive or managing the impact on software maintenance over the life cycle. In this regard, we gathered many promising enhancements to address these challenges, focusing on transparency, speed, and integration, aiming to establish a consistent, methodical approach that facilities the effective integration of software into the decision-making process. Lastly, by consolidating all statements on requirements and criteria, we presented an overview that can serve as the foundation for (re)designing the decision-making process of managing software-intensive electrics/electronics platforms in the automotive domain.

To pursue this line of research, we intend to utilize the identified requirements and criteria to develop a comprehensive decision-making method for the effective management of electrics/electronics platforms in the automotive industry. We anticipate that standardized and comprehensive processes and methods will be key to enhance transparency and speed in decision making. So, this is also a promising direction for research directly benefiting practitioners.

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

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