A Methodology for Electrics/Electronics Platform Release Management in the Automotive Domain

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ABSTRACT

Platform strategies, originating from pure hardware platforms, have proven effective in optimizing development processes in the automotive domain. Over time, software-driven innovations have emerged as the primary origin of novel features in automotive systems, as exemplified by functionalities like lane-keeping assistants, traffic-sign recognition, and the prospect of autonomous driving. To address the growing importance of software, automotive manufacturers progressively incorporate principles of software-platform engineering, for instance, by adopting software product lines. However, a notable gap still persists in thoroughly managing all facets of a cyber-physical automotive system, which involves hardware, software, electronics, variability, and their complex interactions. Efforts to address this gap and to achieve holistic platform management have resulted in electrics/electronics platforms to emerge in the automotive domain; but these platforms and transitioning towards them have not been fully worked out, yet. In this article, we contribute to addressing this gap by proposing a methodology for holistic electrics/electronics platform release management. We present detailed explanations of our methodology and its individual guidelines, which we derived from practical requirements and subsequently validated through expert assessments. Specifically, we conducted a series of workshops involving eight practitioners at a large international automotive manufacturer. Our methodology and insights can help other researchers and practitioners who work on adopting electrics/electronics platform management and emphasize possible directions for future research.

1. Introduction

Innovation and change in the automotive domain are increasingly driven by digitization, and software-driven functionalities have become a primary source of value and distinction (Guissouma et al., 2018; Pelliccione et al., 2016). Traditionally, automotive vehicle portfolios have been structured around hardware platforms and modules, which allowed reuse across vehicle models to achieve overarching synergies (Graf et al., 2014). However, as the scope, size, and complexity of vehicle software grew, integrating software-based features within established hardware platforms has proven challenging. In turn, automotive manufacturers are increasingly adopting software-engineering practices to address the challenges associated with the complexity of their now software-intensive cyber-physical systems (Broy, 2006; Ignaim and Fernandes, 2019; Schuh et al., 2016).

Most recently, the concept of electrics/electronics platforms has emerged as a promising framework for managing the growing digital dimension of modern vehicles, expanding beyond the ideas of pure hardware or software platforms (Jaensch, 2012; Poth, 2009). Electrics/electronics platforms define a unified architecture that integrates hardware, software, and electronic components, thereby enhancing cross-model compatibility, enabling faster updates, and facilitating the addition of digital features. Logically, implementing an electrics/electronics platform induces its own set of challenges (Holsten et al., 2023). One particular challenge is the need for coordinated release management to guide the functional and temporal development of a platform through a vehicle's lifecycle (Holsten et al., 2024).

In this article, we contribute to addressing this challenge by presenting a systematic methodology for implementing electrics/electronics platform release management. We designed this methodology based on real-world requirements that we elicited from the domain as well as based on our experiences of working for and with a large international automotive manufacturer, Volkswagen AG. Moreover, we iteratively validated our methodology through expert workshops. In more detail, we contribute the following:

- We define requirements for enabling effective electrics/electronics platform release management that we derived from our previous interview study (Holsten et al., 2024) and related work (Section 4).
- We propose our electrics/electronics platform release management methodology, describing its core guidelines and fundamental principles (Section 5).
- We report our findings from a series of workshops that we conducted with eight automotive experts to validate our methodology and contribute practical insights regarding its first implementation in the automotive industry (Section 6).

Through these contributions, we aim to provide a reusable methodology for practitioners working on electrics/electronics platforms, particularly in the automotive domain.

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In addition, our methodology supports bridging the gap between software-engineering research and its application to automotive and other cyber-physical systems. Thereby, we sketch directions for future software-engineering research on novel platform concepts like electrics/electronics platforms.

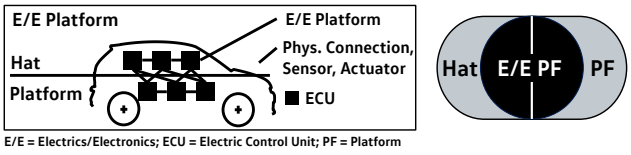

Figure 1: The electrics/electronics platform strategy based on our previous work (Holsten et al., 2023).

2. Background and Related Work

In this section, we first introduce the principles of electrics/electronics platforms and release management as core concepts within this article. Afterwards, we discuss the related work with respect to our contributions.

2.1. Electrics/Electronics Platforms

To effectively and efficiently manage vehicle portfolios and to enhance their variability management, automotive manufacturers have employed different platform strategies (Bilic et al., 2019; Schuh and Riesener, 2017). The core strategy involves consolidating vehicle components into a single hardware platform, which is iteratively developed and deployed across multiple vehicle models to enhance reuse, reduce costs, and accelerate the time-to-market (Hölttä-Otto, 2005; Meyer and Lehnerd, 1997; Robertson and Ulrich, 1998; Simpson, 2004; Vietor and Stechert, 2013; de Weck et al., 2003). Today, despite the ongoing digitization in the automotive domain, mechanical components remain the dominant concern for engineering vehicle platforms.

To adapt to the increasing importance of digitization, automotive manufacturers are incorporating more and more software-engineering concepts into their platforms (Dajsuren and van den Brand, 2019; Graf et al., 2015). Interestingly, software product-line engineering has been inspired by hardware platforms, and thus follows similar principles. Essentially, a software product line consolidates reusable software artifacts and their variations into a unified platform to systematically manage a variant-rich system (Chimalakonda and Lee, 2021; Clements and Northrop, 2001; Krüger et al., 2020; Pohl et al., 2005). Similar to hardware platforms, these software platforms reduce the time-to-market, decrease costs, and improve software quality through artifact reuse and standardization (Chimalakonda and Lee, 2021; Krüger, 2021; Krüger and Berger, 2020; van der Linden et al., 2007; Schmid and Verlage, 2002).

Despite their potential benefits, consistently deploying software platforms across an automotive vehicle portfolio remains challenging, due to the continued dependence on hardware platforms. In addition, complex interconnections among mechanical, hardware, and software components along with environmental interactions highlight the necessity for a more integrated platform strategy. Accordingly, the so-called electrics/electronics platform strategy has been advocated in the literature, which aims to consolidate hardware, software, and electrics/electronics components into a single cross-vehicle electrics/electronics platform architecture (Holsten et al., 2023; Jaensch et al., 2010; Poth, 2009).

In Figure 1, we illustrate how the electrics/electronics platform strategy works in practice (Holsten et al., 2023). We show the electrics/electronics platform and its connections to the hardware platform and "hat" strategy commonly used in the automotive industry. Instead of separating mechanical components (the hardware platform) from customer-related components (the "hat"), the electrics/electronics platform strategy integrates all of these as electrics/electronics components into a unified layer. Consequently, that layer encompasses software components and electronic control units (ECUs) as their physical counterparts. Functioning as an integrative framework, the electrics/electronics platform forms an overarching electrics/electronics architecture, enabeling close integration of hardware, software, and ECU components while conceptualizing the vehicle as a complex cyber-physical system.

2.2. Release Management

Another strategy automotive manufacturers are incorporating from software engineering is systematic release management. In software engineering, release management is extensively utilized to enhance a system's performance during its development and throughout its lifecycle (Inkermann et al., 2018; Marner et al., 2022). At a strategic level, release management focuses on planning system improvements, including new features, bug fixes, and performance upgrades (Ruhe, 2010; Sax et al., 2017). Key drivers and subsequent goals of strategic release management are (Inkermann et al., 2018; Şahin et al., 2020)

- consolidated development, testing, and implementation activities during the development process;
- harmonized change-management processes;
- refined variant adaptations; and
- integrated innovations to enhance features and enable lifecycle-supporting updates.

Thus, strategic release management is a method to efficiently manage the entire lifecycle of a system, focusing on satisfying market demands and obtaining business value (Şahin et al., 2020; Schuh and Eversheim, 2004).

At an operational level, release management organizes product development through an agile process, splitting tasks into smaller manageable units to support incremental development (Ruhe, 2010). As a result, the focus of operational release management is on the detailed planning of an individual system release. Consequently, this requires a release manager to consider the content, scheduling, and deployment of each system release (Marner et al., 2022; Şahin et al., 2020).

With software-engineering methods becoming more important and established within the automotive domain, manufacturers are increasingly recognizing the possible advantages of systematic release management. Particularly, integrating both software and hardware artifacts into a unified architecture and management system promises to facilitate development and maintenance. Furthermore, expanding vehicle connectivity requires customized release plans to meet legal and technical requirements, most importantly software updates at the customer premises through over-the-air (OTA) updates. So, adopting release management promises benefits for automotive manufacturers, for instance, reduced costs, enhanced capacity allocation, and accelerated time-to-market (Guissouma et al., 2018; Inkermann et al., 2018; Marner et al., 2022; Sax et al., 2017). However, current research and practice primarily focus on release plans for individual features or vehicle models. In contrast, we are working on a more unified release management methodology at electrics/electronics platform level to cover the development and maintenance of all vehicles stemming from a platform—requiring the efficient integration of OTA software updates (Holsten et al., 2024).

2.3. Related Work

Only a few previous studies have examined the application of electrics/electronics platform strategies and release management within the automotive domain. In their work, Jaensch et al. (2010) propose a module-oriented product-line engineering framework for vehicle development. Their framework involves developing an overarching electrics/electronics platform (domain engineering) that provides the foundation for deriving individual vehicle models (application engineering). Similarly, Brandt (2016) proposes a reference model for developing a module-oriented electrics/electronics architecture in the automotive domain. The model focuses on harmonizing the electrics/electronics wiring architecture and the modularized electrics/electronics platform as an overarching framework for developing individual vehicle models. Both works address the challenge of streamlining the development of automotive electrics/electronics platforms. However, contemporary problems, such as lifecycle-oriented electrics/electronics platform management, systematic release strategies, and OTA software updates, are out of their scope. These are the problems we focus on with our new methodology, thereby complementing such works and contributing new practical insights.

As release management has gained increasing interest in the automotive domain, other studies have focused on its integration into automotive processes and methods. Raubold (2011) has developed a basic structural model for the efficient integration of lifecycle management practices into existing organizational structures of automotive manufacturers. Şahin et al. (2020) have addressed the strategic level of release management, proposing a methodology for value-oriented strategic release planning that can be applied to different manufacturing domains. In their research, Sax et al. (2017) and Guissouma et al. (2018) have addressed challenges associated with automotive release management, particularly related to the adoption of OTA software updates. Inkermann et al. (2018) have analyzed both the potential benefits and challenges of applying release-management practices in domains with a strong focus on mechanical engineering, such as the automotive domain. Consequently, the application of release management in the automotive domain has been thoroughly examined. However, to the best of our knowledge of the state-of-practice and research, the impact of release management on the portfolio management of automotive manufacturers and the implications for electrics/electronics platforms are yet to be analyzed. In fact, we have conducted literature reviews (Zellmer et al., 2024a, 2023) and empirical studies with practitioners (Holsten et al., 2023, 2024; Zellmer et al., 2024b) that highlight this gap in research and practice. Through our methodology and its validation, we contribute towards addressing this gap.

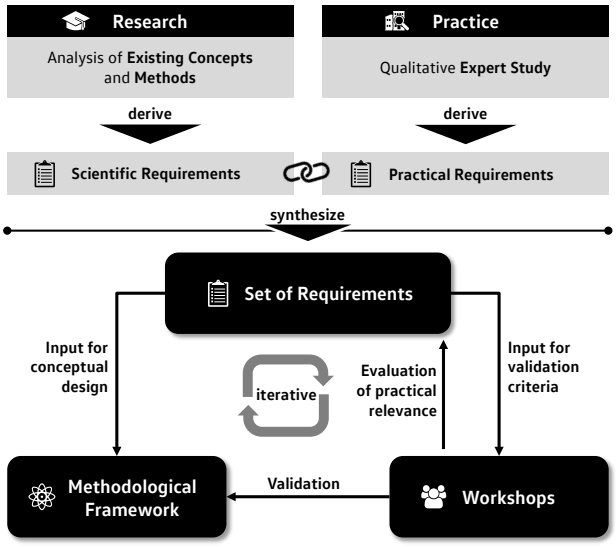

Figure 2: Overview of our research method.

3. Research Method

In this section, we first define our research objectives and then outline the individual steps of our research method, for which we illustrate an overview in Figure 3.

3.1. Research Objectives

With our work, we aimed to contribute a methodology for establishing electrics/electronics platform release management, focusing on the automotive domain. To refine this goal, we defined three research objectives (ROs):

RO_1 *Define requirements for implementing electrics/electronics platform release management.*

First, we defined requirements for electrics/electronics platform release management based on temporary challenges practitioners in the automotive domain

face. To this end, we built and expanded on our previous work in which we elicited the state-of-practice and research on portfolio, platform, and release management (Holsten et al., 2023, 2024; Zellmer et al., 2024a, 2023, 2024b). By synthesizing requirements from such sources, we provided the starting point for developing our methodology and a basis for validating it. The requirements further enable researchers and practitioners to understand the transferability of our methodology, and to adjust it to their specific needs.

RO_2 *Design a methodology for electrics/electronics platform release management.*

Second, we built on our requirements to design a methodology for electrics/electronics platform release management, addressing the practical challenges in the automotive domain and delivering real-world benefits. By defining a series of guidelines, we identified and refined key activities required for implementing electrics/electronics platform release management. While customized to the automotive domain, the resulting methodology represents guidance that should be transferable to other cyber-physical domains, too. The methodology can help practitioners in such domains that focused on hardware to address the growing relevance of software.

RO_3 *Validate the methodology in a real-world context.*

Lastly, we validated the operational value and applicability of our methodology in a practical environment. For this purpose, we conducted a series of workshops with experts from different roles within the automotive domain, utilizing their suggestions and insights to iteratively refine our methodology. Moreover, we have implemented selected elements of our methodology in practice, allowing us to derive insights on its usability. Through this validation, we outline the usefulness of our methodology, its alignment to practice, and improvements to investigate in future research.

Our contributions primarily target practitioners, providing concrete guidelines, recommendations, and experiences for them to transfer to their use cases. We also share insights on temporary challenges and potential improvements on our methodology for future research.

3.2. Method: Engineering Research

To design our methodology, we followed the idea of engineering (also called design-science) research, using a case study (for an empirical evaluation) and interviews (for a conceptual evaluation) for its validation (Wieringa, 2014). Please note that, to the best of our knowledge, we propose a fully novel artifact. No previous research has focused on a methodology for implementing electrics/electronics platform release management, which is not surprising as electrics/electronics platforms have only recently gained traction in practice. Thus, benchmarking or comparisons against other artifacts are not possible or reasonable. For these reasons, we employ a case study and interviews to validate our methodology within the context for which we designed it (i.e., the automotive domain).

Designing a methodology for electrics/electronics platform release management requires a set of defined requirements that capture practitioners' respective challenges. To define such requirements as the basis for our methodology, we integrated scientific and practical criteria for the automotive domain (cf. Figure 2). For this purpose, we relied on our previous research (Holsten et al., 2024; Zellmer et al., 2024a,b), particularly our analyses of temporary automotive challenges in practice (Holsten et al., 2023) as well as shortcomings of existing product-structuring concepts (Holsten et al., 2024; Zellmer et al., 2023). We complemented our studies through further related work (Becerril et al., 2019; Gericke et al., 2017; Guertler, 2018), refining the requirements based on an extensive set of practical and scientific insights. By combining scientific and practical views, we aimed to derive a comprehensive, temporary, and usable set of requirements. To define the requirements, we have extracted key phrases on requirements mentioned in the previous studies, employed card sorting to categorize these, and prioritized them based on our (practical) experiences. We present an overview of the final requirements we identified as key for electrics/electronics platform management on the left side of Figure 3, which we explain in detail in Section 4.

Then, we iteratively designed our methodology, combining design and validation steps to collect intermediate feedback (cf. Figure 2). Specifically, we proposed concrete guidelines (cf. Section 5) that practitioners could apply in their daily work, customized to the first author's work at one of the world's largest automotive manufacturers. We conducted workshops in which we used our requirements as basis for validation criteria to guide discussions with experts in the domain. So, we aimed to collect experts' feedback regarding the comprehensibility and usefulness of each guideline, while maintaining the discussions' focus through our requirements and derived criteria. Afterwards, we refined the guidelines based on the experts' feedback, which we explain in more detail in Section 6. Lastly, we implemented selected guidelines in practice to collect empirical insights on their practical feasibility and limitations.

4. Requirements (RO_1)

In this section, we detail the requirements we derived from the literature and our practical experiences. We further ensured the requirements' relevance by using them to validate our methodology during expert workshops. At the end, we categorized the requirements along four categories (cf. Figure 3): *Practical Applicability*, *Automotive Context*, *Lifecycle-Related*, and *Decision Support*.

4.1. Practical Applicability

The primary goal of a new methodology is to provide concrete value, which is why it is essential to ensure its practical applicability (Şahin, 2022). Since we focus on the automotive domain, it is thus crucial to ensure our

Category	ID	Requirement
Practical Applicability	1.1	Ensure applicability within automotive industry
	1.2	Provide reproducible results
	1.3	Produce traceable results
	1.4	Consider existing product structuring concepts
Automotive Context	2.1	Include different abstraction layers (product, platform, portfolio)
	2.2	Provide an assessment and prioritization of different stakeholder preferences
	2.3	Consider various release types, release timings and release contents
Lifecycle-Related	3.1	Consider all life cycle phases
	3.2	Ensure continuous application across entire life cycle
	3.3	Ensure strategic planning of OTA-Updates
Decision Support	4.1	Support the consolidation of platform responsibilities across all life cycle phases
	4.2	Support strategic platform release management activities
	4.3	Support platform variability management

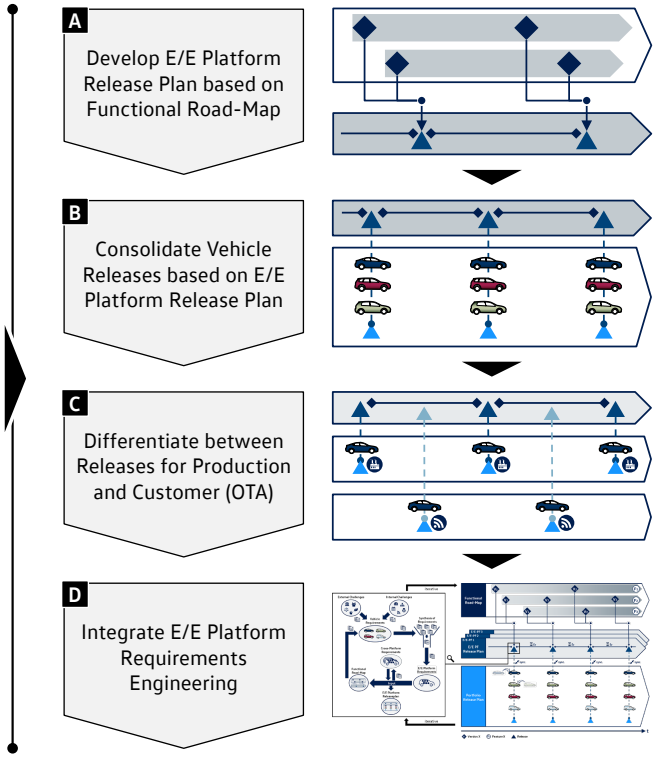

Figure 3: Overview of the requirements and the guidelines we subsequently derived as part of our methodology.

methodology's *applicability within the specifications of the automotive industry* (requirement 1.1) (Holsten et al., 2023). These specifications include basic properties, such as large-scale production combined with a high degree of vehicle individualization (i.e., mass customization) or long product lifecycles, which lead to substantial overall complexity (Brandt, 2016; Reiser, 2009). Requirement 1.1 further accounts for temporary factors like the growing significance of software and electrics/electronics components or the high level of connectivity within modern vehicles and their interactions with the environment (Brandt, 2016; Dajsuren and van den Brand, 2019; Graf et al., 2015). Subsequently, the requirements on the practical applicability of our methodology must also cover that its results are *reproducible* (requirement 1.2) and *traceable* (requirement 1.3) to ensure it can be used reliably (Becerril et al., 2019). Finally, to design centralized platform release management, it is essential to *consider existing product-structuring concepts* (requirement 1.4) to ensure that our methodology can be integrated into current automotive processes and practices (Holsten et al., 2024; Zellmer et al., 2023). Since automotive manufacturers already use combinations of such product-structuring concepts (e.g., platform and modular strategies), at least short-term implementations of our methodology require that it is compatible with these concepts (Holsten et al., 2023, 2024).

4.2. Automotive Context

Beyond practical applicability, when developing our methodology, we also had to account for the automotive context on a content level (Holsten et al., 2024). To support comprehensive release planning, it is essential to consider the various planning dimensions of releases (Şahin, 2022). For instance, the release planning of a vehicle project heavily depends on the release planning of the underlying electrics/electronics platform, which is, in turn, functionally tied to cross-platform development road-maps (Holsten et al., 2023). Thus, our methodology must *include multiple abstraction layers* (requirement 2.1) that consider products, platforms, and the entire portfolio (Holsten et al., 2023, 2024). Next, our methodology should facilitate the *evaluation and prioritization of different stakeholder preferences* (requirement 2.2) to effectively address the multitude of requirements within the automotive domain (Holsten et al., 2024; Zellmer et al., 2023). For example, while a sales department may continuously seek new customization options for customers, the resulting variety can become increasingly difficult and resource-intensive for the technical development to manage. So, our methodology should facilitate the comprehensive consolidation and processing of different requirements (Holsten et al., 2024). Overall, it is important that our methodology *accounts for diverse automotive release cycles, which involves integrating different types of releases, timings, and contents* (requirement 2.3) into an overarching release strategy (Şahin et al., 2020; Schuh et al., 2016).

4.3. Lifecycle-Related

The automotive domain faces continuous change through technological innovations (e.g., OTA updates) and new regulations (e.g., on cyber security) (Guissouma et al., 2018). For this reason, automotive manufacturers are increasingly

focusing their development and deployment efforts on vehicles at the customer's premises (Holsten et al., 2023). Thus, it is essential for electrics/electronics platform release management to *address all stages of the product lifecycle* (requirement 3.1) and to *be applicable across all of these stages* (requirement 3.2) (Guissouma et al., 2022; Holsten et al., 2023, 2024). Subsequently, our methodology cannot only consider vehicles while they are produced, but must facilitate the *strategic planning* and management of releases for vehicles deployed at the customers' premises (Guissouma et al., 2022)—re-emphasizing the need for *over-the-air updates* (requirement 3.3).

4.4. Decision Support

Our analyses of current practical challenges related to product-structuring concepts in the automotive domain (Holsten et al., 2023, 2024; Zellmer et al., 2023) have highlighted limitations regarding temporary decision-making processes and their consequences. In fact, we found that decisions are often made with a narrow focus on optimizing the technical or financial aspects of individual vehicle models or functions. This can lead to suboptimal results in the broader context. To address such suboptimal decisions, electrics/electronics platform release management must provide a basis for a decision-making authority and establish *consolidated platform responsibilities across all lifecycle phases* (requirement 4.1). Thereby, our methodology can enable users to make informed decisions and to continuously evaluate their impact on the platform level, ensuring a comprehensive and systematic assessment. As a result, our methodology should facilitate an organization's capabilities for *strategic platform release management* (requirement 4.2) and support corresponding measures and activities, such as developing overarching platform release plans (Holsten et al., 2024). An important aspect of strategic platform release planning is *platform variability management* (requirement 4.3), which we have identified as a major challenge in both the literature and in practice (Holsten et al., 2024; Ignaim and Fernandes, 2019; Zellmer et al., 2023). Thus, variability management should play a central role in our methodology.

4.5. Summary

Based on our own previous work on product-structuring concepts, related work, and practical experiences as well as studies with experts, we have derived a set of 13 requirements for centralized electrics/electronics platform-release management. We have grouped these requirements into four main categories. The categories cover generic quality-related aspects (e.g., reproducibility, traceability) as well as content-specific needs. Some existing methodologies and product-structuring concepts (cf. Section 2.3) fulfill some of these requirements, particularly if these methodologies or concepts are more general. However, an effective and industry-relevant solution requires a methodology that holistically addresses all of the requirements we have elicited. Since we did not identify a comprehensive methodology that fits temporary industry needs according to these requirements, we designed our new methodology.

5. Methodology (RO_2)

In this section, we describe the methodology we have designed to address the requirements for centralized electrics/electronics platform release management. We first provide a general overview of the individual guidelines we have defined for our methodology. Afterwards, we detail the individual guidelines to describe how these can be operationalized. We provide a high-level overview of our methodology in Figure 4, which includes references to our respective guidelines. Moreover, the structure and guidelines map to the visual elements on the right side of Figure 3.

5.1. Methodological Overview

We derived four guidelines (A–D) as a structural framework for our methodology to address our 13 requirements (c.f. Figure 3). Combined, these guidelines represent our methodology and support practitioners in implementing electrics/electronics platform release management. Please note that the guidelines are cross-cutting the categories of requirements we derived, they are not a one-to-one mapping. To clarify the connections, we add references to the relevant requirements to each guideline. Moreover, requirements 1.1 (practical applicability), 1.2 (reproducibility), and 1.3 (traceability) are not addressed by specific guidelines, but by the combination of all guidelines as our entire methodology.

Guideline A: Develop Electrics/Electronics Platform Release Plan (Requirements 1.4, 2.1, 2.3, 4.3). Our first guideline involves formulating electrics/electronics platform release plans based on a cross-vehicle and cross-platform functional road-map. The functional road-map comprises the entirety of technological and functional development activities, and should be independent of specific vehicle projects or platforms. Consequently, the functional road-map includes all future functional enhancements arising from innovations as well as generational advancements of existing vehicle functions. In essence, the functional road-map aims to reflect the strategic-functional perspective of the technical development department. The electrics/electronics platform release plan relies significantly on the functional road-map, since it dictates the available release contents at each point in time. To avoid redundant development activities and achieve cross-vehicle as well as cross-platform synergies, it is essential to aim for a high degree of alignment between the electrics/electronics platform release plan and the functional road-map—ensuring temporal and decision-making consistency.

Guideline B: Consolidate Vehicle Releases (Requirements 1.4, 2.1, 3.2, 4.1, 4.3). Our second guideline addresses the connection between the electrics/electronics platform and vehicle releases. To optimize synergies between different vehicle models and minimize complexity as well as efforts, vehicle releases should consistently follow the electrics/electronics platform release plan in timing and content. In this context, it is irrelevant whether new or existing vehicle models are involved; a common electrics/electronics platform release should consistently be utilized.

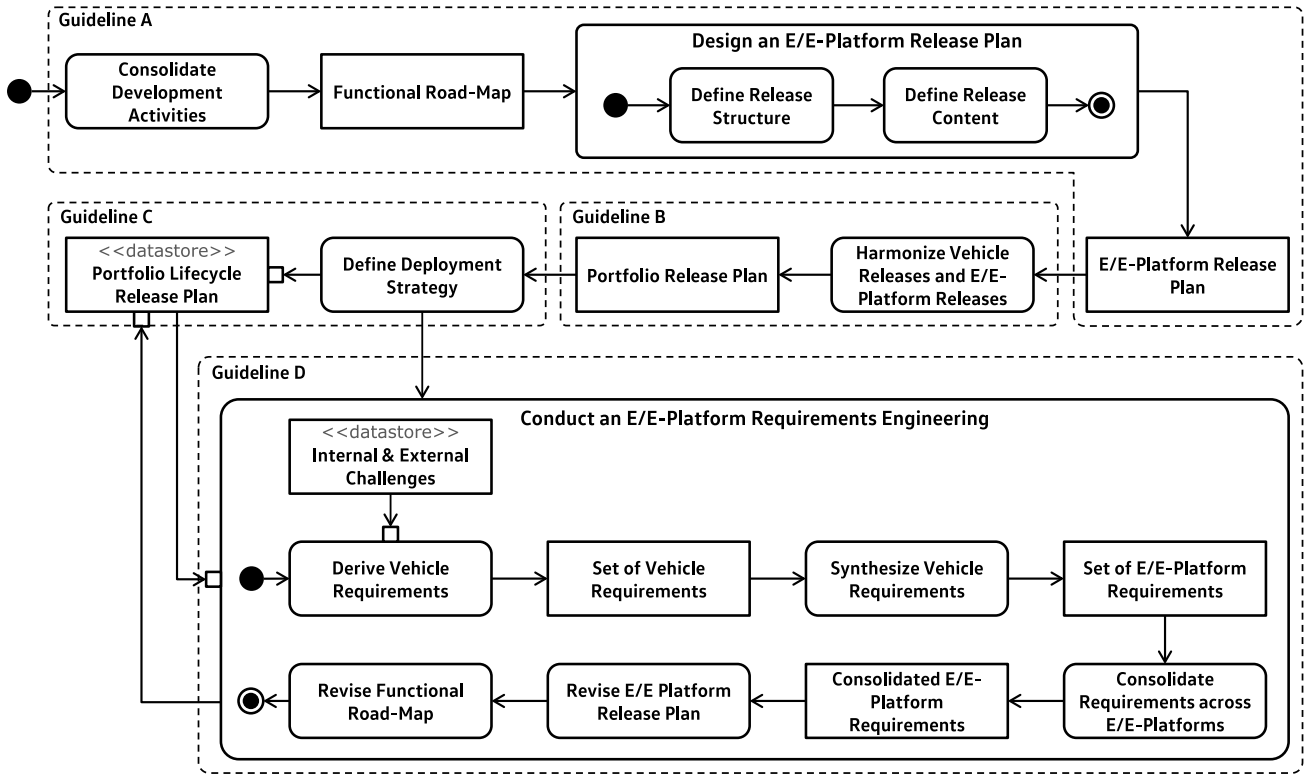

Figure 4: UML activity diagram of our methodology for centralized electrics/electronics platform release management. Please note that the requirements engineering is supposed to run continuously. For simplicity and readability, we do not make this explicit. The core output artifact generated and continuously updated by our methodology is the *portfolio lifecycle release plan*. We represent this plan as a datastorage to demonstrate its continuous interconnection with the requirements engineering (Guideline D).

The required compatibility between the electrics/electronics platform releases of each individual vehicle model, which is a central requirement, should already be considered during the early phases of developing a vehicle.

Guideline C: Define Vehicle Deployment Strategy (Requirements 3.1, 3.3, 4.2). After integrating the dependencies between the functional road-map, electrics/electronics platform release plan, and vehicle releases into our methodology, our third guideline is intended to emphasize the lifecycle perspective. To address the entire vehicle lifecycle, the electrics/electronics platform release plan and, consequently, the release plans of each individual vehicle, should categorize the releases into the different types of deployment. Specifically, users should differentiate at least between production-only releases, OTA-only releases, and combined releases. Since these types of release deployment directly impact key attributes of the associated releases (e.g., content, scheduling, extent of changes), they should be incorporated as a crucial input criterion into the electrics/electronics platform release plan.

Guideline D: Integrate Electrics/Electronics Platform Requirements Engineering (Requirements 2.2, 4.1, 4.2). Our last guideline deals with the challenge of evaluating and balancing the extensive number of vehicle requirements. Here, practitioners have to balance between requirements originating from external (e.g., market demands, legal regulations) and internal sources (e.g., cost-saving measures, complexity-reduction goals). For the electrics/electronics platform release plan to work effectively as the primary control artifact for portfolio release management, it is important to consolidate and synthesize vehicle requirements at the electrics/electronics platform level. So, each electrics/electronics platform release should be preceded by an iterative requirements-engineering process. This process facilitates cross-platform synchronization while also informing the functional road-map and future releases about the latest vehicle requirements. Integrating comprehensive electrics/electronics platform requirements-engineering processes completes our methodology and connects our guidelines.

5.2. A: Platform Release Plan

With our first guideline, we focus on formulating an electrics/electronics platform release plan, which serves as the structuring element in the subsequent guidelines of our methodology. To develop the electrics/electronics platform release plan, we built on established methods for strategic release planning (Inkermann et al., 2018; Marner et al., 2022; Ruhe, 2010; Şahin, 2022; Schuh et al., 2016) and adapted them to meet the specific demands of automotive electrics/electronics platforms. So, it is necessary that an

organization *consolidates its development activities*, essentially meaning that all departments should coordinate to develop a *functional road-map*. The functional road-map is a documented plan of which features are to be developed for the organization's product portfolio (cf. Figure 5).

When to develop and deploy these features is planned by *designing an electrics/electronics platform release plan*. We divided this step along two sub-steps (explained in more detail below): First, a user *defines the release structure*, addressing the available release types and their dependencies regarding the release strategy (e.g., planning horizon, frequency, and rhythm). Second, the user has to *define the content of each release*, primarily based on the features defined in the functional road-map. Combined, these two steps result in a centralized electrics/electronics platform release plan. Such a release plan is a document (cf. Figure 5) that defines the overarching release structure and functional enhancements for all vehicle models at the electrics/electronics platform level. The specific setup of the electrics/electronics platform release plan (e.g., the selected release types or the specified release timing) remains variable within our methodology, and can be adapted to the requirements of the individual user.

5.2.1. Defining a Release Structure

In the following, we explain the individual release types for defining a release structure. Thereby, we contribute guidance on how these release types are or can be utilized within an automotive electrics/electronics platform release plan. However, the specific structure of the electrics/electronics platform release plan is not predefined by our methodology. Instead, our methodology offers guiding principles to support user-specific applications.

Platform Generation Releases represent the most extensive type of change, essentially updating the entire platform. These releases provide considerable potential for incorporating fundamentally new technologies, product concepts, features, or architectures. At the same time, platform generation releases require considerable lead times and cause significant expenditures as well as efforts. Consequently, platform generation releases should follow a release strategy that revolves around well-defined deployment dates that are mandatory for all vehicles using the platform. Furthermore, platform generation releases should be scheduled at low frequency and provided with a corresponding budget allocation well in advance to achieve the intended development objectives. For vehicle projects utilizing the platform, a platform generation release is a prime occasion for launching a new vehicle generation or facelift.

Major Releases represent typical model-year changes in the automotive domain. They are intended to generate new market impulses for current models or to introduce new product upgrades. Therefore, major releases incorporate customer-perceivable changes, such as functional, visual, or performance enhancements, impacting both the software and hardware of a vehicle. While it is possible to generate new electrics/electronics platform variants if necessary, maintaining compatibility with the core electrics/electronics architecture is a primary imperative for major (or smaller) releases to effectively control the overall complexity. Compared to a platform generation release, major releases offer fewer possibilities for changes, but the associated costs and efforts are typically significantly lower. Consequently, major releases are scheduled more frequently than platform generation releases, with reduced planning horizons and budgets. The specific release timings should always align with a market's typical model-year change.

Minor Releases represent enhancements of customer value through software-only changes during a vehicle's lifecycle, improving software-based functions and features. In turn, effectively deploying OTA software updates is essential for minor releases, offering customers fast and convenient access to the enhancements provided. A crucial requirement for applying OTA software updates is compatibility. Compatibility encompasses not only technical but also legal aspects (e.g., compliance to approval standards). Consequently, there are functional and architectural limitations for the scope of changes in minor releases compared to major releases. The associated release strategy of minor releases should, therefore, account for compatibility, necessitating fixed deployment dates and established lead times. Due to the reduced scope of changes, higher release frequencies can be pursued. However, it is essential to ensure that the changes are substantial enough for customers to actively experience the added value to support long-term customer satisfaction.

Patch Releases represent the release type with the smallest scope of changes. They are intended for bug-fixing or function-neutral modifications aimed at reducing costs or enhancing performance. Additionally, patch releases can be used to address cyber-security vulnerabilities, which are becoming increasingly likely due to the growing digitization of vehicles. So, patch releases can be used as a frequent and routine bug-fixing mechanism as well as a means to implement unplanned changes to the electrics/electronics platform that must be deployed quickly due to a time-critical nature. As such, the planning horizon as well as deployment rhythm and frequency of patch releases is more flexible and adapted to practical conditions rather than being rigidly defined in advance. To ensure rapid deployment, a certain budget should always be allocated for patch releases.

5.2.2. Defining the Release Content

After establishing the fundamental structure of the electrics/electronics platform release plan, the next step requires detailing the contents of each release. To enhance synergies between vehicle models and platforms within an automotive portfolio, manufacturers typically develop innovative functions and features on an overarching level. For instance, when introducing a new driver-assistance system, the required software is developed and tested independently, and subsequently deployed across different vehicle models and platforms. Besides reduced development and testing efforts, this strategy results in lower maintenance and evolution costs for such functionalities throughout the vehicles' lifecycles.

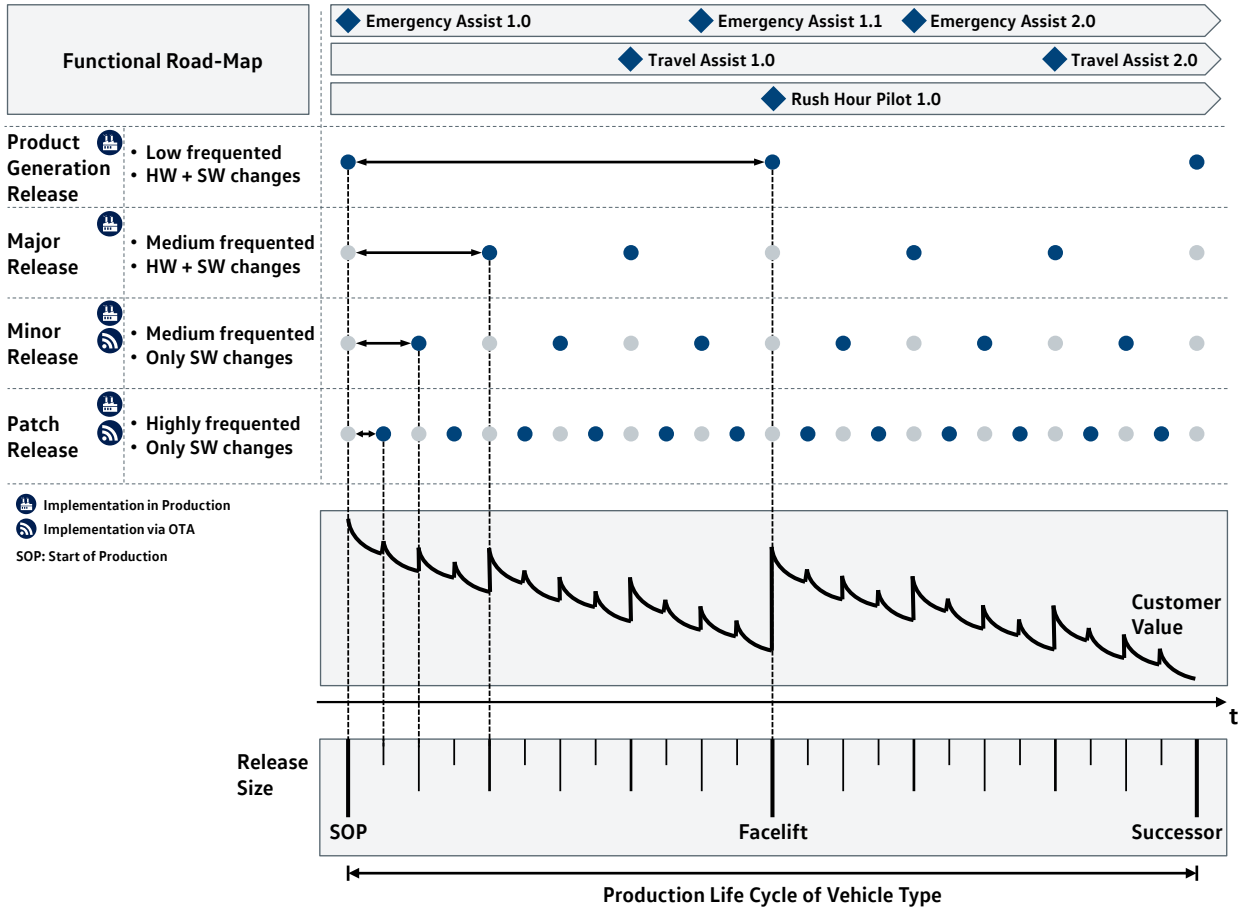

Figure 5: Example of an electrics/electronics platform release plan based on Şahin et al. (2020) and Schuh et al. (2016).

In fact, automotive practice shows that this is a particularly crucial consideration. Also, innovations are often introduced by incrementally enhancing existing features and adding or improving individual functionalities.

By aggregating individual development efforts, the *electrics/electronics platform release plan* can be derived. In the end, the release plan is intended to be a document that provides a comprehensive overview of which new and ongoing features shall be integrated into which upcoming releases and vehicle generations (cf. Figure 5). To develop the release plan, users have to synchronize with the functional road-map, which encomasses

1. current functions,
2. functions nearing market launch,
3. functions currently being developed, and
4. plans for future functions that are yet to be developed.

In combination, the functional road-map and release plan reflect the operational perspective of vehicle development as well as strategic features that have the potential to define future vehicle generations. So, due to its overarching nature, the functional road-map serves as the key input for defining release contents of all release types for the electrics/electronics platform release plan.

5.3. B: Consolidated Vehicle Releases

After developing the electrics/electronics platform release plan within Guideline A, Guideline B details how that release plan is used for specific vehicle releases. To achieve our goal of creating actual added value, our methodology has to incorporate the overarching synergies of the release plan into individual vehicle models. Within matrix structures, vehicle models are typically managed as independent development projects; which, not surprisingly, typically focus on optimizing temporal and financial performance at that project level. To establish the electrics/electronics platform as the central layer for achieving synergies, it is essential to shift responsibilities and decision-making authority from vehicle projects to the electrics/electronics platform. This creates a more hierarchical relationship between the electrics/electronics platform and individual vehicle projects.

In this context, a key aspect is to *harmonize vehicle releases and electrics/electronics platform releases*. To reduce additional release activities and the associated costs, the individual vehicle projects within an electrics/electronics platform must be harmonized to align with the shared release cycles. This applies not only to vehicle projects currently in

production, but also to those already at the customer—which receive release content via software updates. So, decisions related to the electrics/electronics platform are consistently assessed with respect to the entire platform, instead of focusing on optimizing individual projects. In addition to reducing efforts, such a consolidated methodology also supports maintaining compatibility over time by minimizing the number of release versions and potential software variants in the field. Finally, consolidating electrics/electronics platform releases and vehicle releases results in a harmonized *portfolio release plan*, which must be documented and made available to the respective projects.

5.4. C: Vehicle Deployment Strategy

Next, Guideline C is concerned with *defining a deployment strategy* for individual releases based on the functional road-map and the release plans. As we explained, the centralized electrics/electronics platform release plan should cover both vehicles in production and those already at the customer to achieve overarching synergies. Logically, we can distinguish different deployment strategies: In the first strategy, changes are implemented solely for vehicles currently in production, leaving vehicles at the customer unaffected. Possible reasons for this deployment strategy are changes in hardware and mechanics or incompatibilities between different hardware and software configurations. Such changes cannot be implemented at the customer's premises via OTA updates, or not at all in a produced vehicle. The second deployment strategy covers compatible software updates that can be applied both in production and at customer vehicles, either through OTA updates or, if necessary, via workshop visits. This deployment strategy allows to benefit from synergies at the electrics/electronics platform level. All vehicles receive the same software version, preventing breaks in compatibility. The third deployment strategy involves changes that are implemented exclusively in vehicles already at the customer. Such cases include post-production bug fixes that have been resolved in new production runs, but must be addressed in customer vehicles through a dedicated software update.

To detail the existing portfolio release plan, each release should be assigned to one of the three deployment strategies. Given the extent of changes associated with product generation releases and major releases, it is apparent that they typically belong to the first deployment strategy. However, for minor and patch releases, it is crucial to consciously assign the appropriate deployment strategy to scope the content and required compatibility of each release. Thus, categorizing each release into one of the three deployment strategies is key in refining the portfolio release plan.

Overall, developing a portfolio release plan includes defining the release structure, content, and deployment, focusing on incorporating the entire vehicle lifecycle. So, ultimately, the result is a *portfolio lifecycle release plan*, which provides an overview of planned electrics/electronics platform and vehicle releases with respect to content, timing, deployment, and scope of changes.

In Figure 5, we sketch an example for such a finalized electrics/electronics platform release plan that we derived based on the works of Şahin et al. (2020) and Schuh et al. (2016). At the top, the functional road-map defines new features and their updates (e.g., "Emergency Assistant 1.0"). Throughout the platforms' and vehicles' lifecycles, few product generation releases are scheduled, which align to typical facelifts and new model releases in the automotive domain. Below, and more and more frequently, major, minor, as well as patch releases are scheduled. As we display in the bottom, each of these releases aims to improve customer value, depending on its extent.

As such, the electrics/electronics platform release plan provides the basis for deriving dedicated portfolio lifecycle release plans according to the user-specific requirements. By systematizing release planning via our methodology, organizations can define a platform-spanning and model-spanning release plan similar to the one we exemplify. Consequently, organizations can facilitate their release management and benefit from overarching synergies regarding coordination, predictability, costs, and time-to-market.

5.5. D: Platform Requirements Engineering

Guidelines A to C explain how to develop an electrics/electronics platform release plan, including its organizational and strategic impact on individual vehicle projects. Our last guideline, Guideline D, connects the electrics/electronics platform release management with electrics/electronics platform requirements engineering. The electrics/electronics platform requirements engineering should be applied iteratively for each release and is crucial support for effectively developing and using the electrics/electronics platform release plan. Specifically, to determine the optimal content, timing, and deployment strategy of individual releases, a wide range of requirements for an electrics/electronics platform must be considered. To systematically manage these requirements, we build upon existing methods in requirements engineering (Balzert, 2009; Pohl, 2010; Sommerville, 2011) and adapt them to the context of temporary automotive electrics/electronics platforms.

Today, automotive manufacturers face various *internal* (e.g., increasing connectivity, data complexity) and *external challenges* (e.g., regulatory requirements, intensifying competition). Together, these challenges create significant cost and innovation pressures for the manufacturers. To tackle these pressures, automotive manufacturers must *derive and align the functional and non-functional vehicle requirements* posed by such challenges. For this purpose, a comprehensive requirements-engineering framework is needed to systematically identify, specify, and verify requirements.

Since each vehicle model is different, this process should be performed individually for each vehicle project. Subsequently, the specific *set of vehicle requirements* should be derived and documented for each vehicle. Then, the individual sets serve as input for *synthesizing the vehicle requirements*. This means to align and prioritize the individual requirements to define the *set of electrics/electronics platform*

Table 1
Overview of our expert workshop (WX) participants.

ID	Role	Experience	W1	W2	W3	W4	W5	W6
P1	Architecture Release Manager	>10 years	○	●	○	●	●	○
P2	Product & Portfolio Manager	>10 years	○	●	○	●	●	○
P3	Cyber Security Expert	>5 years	○	●	●	○	○	●
P4	Platform Manager	>10 years	○	●	○	●	○	●
P5	OTA-Release Manager	>5 years	●	○	○	●	●	○
P6	Process Manager	>15 years	●	○	●	○	○	●
P7	Portfolio Strategy Manager	>5 years	●	○	○	○	○	●
P8	Software Platform Expert (Consultant)	>5 years	○	○	●	○	○	●

requirements, which allows to achieve cross-vehicle synergies. Next, a user should *consolidate the electrics/electronics platform requirements across platforms* for additional synergies. The resulting *consolidated electrics/electronics platform requirements* serve as input for *revising the electrics/electronics platform release plan and the functional road-map*. In turn, new requirements for future releases, such as technical or functional specifications, can be identified from the revised functional road-map. Therefore, electrics/electronics platform requirements engineering should be applied iteratively to each release of the electrics/electronics platform release plan. We consider this electrics/electronics platform requirements engineering as a crucial part of electrics/electronics platform release management.

5.6. Summary

As we display in Figure 4, the electrics/electronics platform release plan that we construct via Guideline A forms the core element of our methodology that is continuously refined. In the end, the release plan connects the functional road-map with individual vehicle releases, which should be aligned and consolidated via Guideline B to achieve synergies. For this consolidation, it is particularly important to define and match the deployment strategies of changes as we define in Guideline C. This entire process is supported by electrics/electronics platform requirements engineering, which we explain in Guideline D. Essentially, Guidelines A to C define how to construct a consolidated electrics/electronics platform release plan, while Guideline D defines how to use this release plan continuously within the planning and requirements engineering of an organization. In combination, these guidelines define our methodology for centralized electrics/electronics platform release management.

6. Validation (RO_3)

In this section, we first present our validation of our methodology through expert workshops. Afterwards, we present practical insights from implementing parts of our methodology at Volkswagen AG. Lastly, we discuss threats and limitations of our methodology.

6.1. Validation

Design and Participants. To validate our methodology, we employed a series of six iterative workshops with a total of eight experts from Volkswagen Group and its subsidiary brands. We provide an overview of the experts and the workshops in which they participated in Table 1. When inviting experts, we aimed to cover a wide range of perspectives across areas like portfolio management, software release management, and platform management. For this purpose, we recruited volunteers with diverse profiles, resulting in experts with various roles (e.g., architecture release manager, process manager, OTA-release manager) and extensive experience in the automotive domain (i.e., four >5 years, three >10 years, one >15 years). By involving experts with different points of views in different workshop iterations, we aimed to obtain a broader overview of the applicability and possible refinements of our methodology across all possible stakeholders involved in its use. Please note again that we conducted the workshops iteratively to designing our methodology. Thus, their outcomes informed the design of our guidelines and methodology, with our report in Section 5 explaining their final and agreed upon state.

Conduct. In total, we conducted six workshops, with each expert participating in at least two workshops. Usually, a workshop took around 1.5 hours. However, we remark that we did not use fixed time boxing to conduct the workshops. Instead, we tried to collect all feedback we could within each workshop and stopped when we noticed that there was no more feedback. Moreover, we closed the workshop series when the experts agreed that all validation criteria were fulfilled by our methodology. So, we used saturation in terms of refinements to the validation criteria or our methodology as stop criterion rather than a certain time period.

We used the first four workshops for in-depth discussions and refinements of our validation criteria as well as our methodology. During the last two workshops, we focused on consolidating the results and validating our methodology according to the criteria we defined with the experts based on our requirements (cf. Section 4). By processing and re-examining the experts' comments on our methodology, each expert was able to contribute their own ideas and suggestions based on their practical experiences. Ultimately, this led to systematic improvements and a thorough evaluation of the practical feasibility of our methodology. We structured the individual workshops differently, depending on their primary goals, which we detail next.

Goal: Defining Validation Criteria (W1–W4). To prepare the validation of our methodology, we derived and refined a set of validation criteria for our methodology according to our requirements in Section 4. These served as starting point for planning and conducting each workshop. In the first four workshops, the first author started by introducing himself and our research project, followed by a brief inquiry about the roles and experiences of the participants. Subsequently, the first author and experts reviewed the validation criteria we defined collaboratively to ensure that these were comprehensive, relevant, and effective to evaluate our methodology. At this point, we paid particular attention on asking the experts to assess the criteria in terms of their practical relevance and actual value for successfully implementing our methodology. This process allowed us to iteratively refine our validation criteria. In the end, all experts agreed that the criteria were a suitable basis for the subsequent assessment of our methodology. We provide an overview of the final criteria we used for the validation in Table 2.

Goal: Collecting Feedback on Our Methodology (W1–W4). Also within the first four workshops, we collected feedback regarding our methodology. Generally, the first author provided a detailed explanation of our methodology and its development. Thereby, we prompted discussions among the experts and with the first author about our methodology's comprehensiveness and applicability. During these parts of the workshops, we ensured that every expert had the opportunity to express their thoughts, encouraging all of them to contribute further ideas and improvements to the methodology. This stimulated the experts to engage in in-depth discussions, leading to several ideas for refining our methodology. To conclude each workshop, we documented the results in minutes and reviewed them with all experts to verify that the details were correct and comprehensive. Please note that we cannot share these minutes for confidentiality reasons. Following each of these four workshops and in anticipation of the validation workshops, we refined our methodology based on the insights we obtained.

The experts generally shared a common understanding and aligned in their views on temporary challenges in practice. They also had possible methodologies in mind to address these challenges, which we noticed to mostly align to our understandings and ideas. This alignment is not surprising, given that we built on our previous and related work, some of which we conducted in close collaboration with practitioners (Holsten et al., 2023, 2024). Consequently, the workshops centered primarily on refining specific elements of our methodology. For example, we discussed the timing and frequencies of individual release types. Due to founding our methodology on previous work, empirical studies with exerts, and practical experiences, there was little need to redesign our overall methodology.

Goal: Validating Our Methodology (W5–W6). In the last two workshops, the first author reintroduced our refined methodology and asked all participants to evaluate it based on the specified validation criteria. During both workshops, we received positive feedback from the experts. Specifically, each one confirmed that all validation criteria are met. For this reason, we concluded the validation process as successful and consider our methodology to align with the needs and experiences of experts in the automotive industry.

6.2. Practical Use

Implementing our methodology within an organization impacts various departments, processes, and responsibilities, with changes only becoming visible after longer periods of time and metrics being hard to assign to specific changes. For these reasons, a systematic and holistic assessment of our entire methodology in practice (e.g., through action research or experiments) is not feasible. However, some parts of our methodology have been or are being implemented at Volkswagen, while others are currently being planned. Essentially, this represents parts of an action-research-like case study from which we can derive practical insights. We consider this adoption of our methodology as further indication of its practical value, while it is also a great opportunity to share insights. To this end, we present an overview of planned and already implemented parts, highlight the rationale behind them, and outline benefits that have been achieved or are anticipated by experts of Volkswagen.

Implemented: Harmonizing Electrics/Electronics Platform and Vehicle Releases. As a first step, Volkswagen has started to harmonize electrics/electronics platform and vehicle releases, addressing and partially implementing Guidelines A and B of our methodology. Specifically, a comprehensive release schedule has been introduced to integrate the different release types and account for new vehicle as well as lifecycle releases based on the electrics/electronics platform release plan. In turn, the focus of the strategic planning has moved more on the timing and content of electrics/electronics platform releases—reflecting the increasing importance of software-driven functionalities that are shared across vehicle models. Although we can assess the actual impact of this change only in the medium to long term, synergies in testing and validating electrics/electronics platform releases are anticipated. Likewise, improvements regarding overall release costs are expected, due to the harmonization impacting both the frequency and volume of releases.

In Progress: Revising Requirements Engineering. Currently, requirements-engineering processes are being revised at Volkswagen. The goal is to focus more on electrics/electronics platform releases, ensuring that cross-vehicle changes on the electrics/electronics platform are systematically assessed and incorporated into decision-making. This includes establishing a dedicated requirements consolidation phase at electrics/electronics platform level. During this phase, requirements of individual vehicle projects are collected, harmonized, and prioritized if necessary (Guideline D). The phase is designed to be integrated as an iterative process into vehicle-project planning to enable regular re-evaluations based on updated insights and external factors. These changes are anticipated to significantly enhance

Table 2
Overview of our validation criteria.

Category	ID	Criterion
Automotive Practice	**C1**	*The methodology considers established automotive product-structuring concepts.*
	C2	*The methodology considers established automotive timings, such as model-year changes.*
	C3	*The methodology considers automotive-specific requirements of product releases.*
Practical Value	**C4**	*The methodology integrates perspectives from the domains of mechanical engineering, software engineering, and electrics/electronics engineering.*
	C5	*The methodology considers the increasing relevance of software in modern vehicles.*
	C6	*The methodology supports lifecycle-oriented complexity management.*
Centralized Management	**C7**	*The methodology establishes the electrics/electronics platform as part of product management and consolidates responsibilities.*
	C8	*The methodology considers the entire electrics/electronics platform lifecycle including OTA software updates.*
	C9	*The methodology enables a targeted electrics/electronics platform variant management.*

decision-making consistency by reducing isolated solutions and prioritizing comprehensive impact assessments. Additionally, the connection between brands and vehicle projects shall be improved, fostering cross-vehicle synergies and accelerating time-to-market. Finally, incorporating the electrics/electronics platform release management into central decision-making processes is intended to increase transparency and awareness regarding the development and management of software-intensive products. In particular, factors like backwards compatibility, OTA capabilities, and software complexity are emphasized as critical for decisions.

In Progress: Centralizing Electrics/Electronics Platform Release Management. As we have highlighted in our previous work (Holsten et al., 2024), implementing centralized electrics/electronics platform release management requires not only refinements of processes and methods, but also adjustments to the organizational structure. This is particularly true for the product and portfolio management. To establish a stronger focus on the electrics/electronics platform and its strategic release planning, Volkswagen has started organizational changes to centralize the management of electrics/electronics platform releases. Specifically, a centralized electrics/electronics platform functional-planning process has been established to enable strategic release planning (Guideline A). This process prioritizes the technological and functional advancement of the electrics/electronics platform and ensures its efficient integration into individual vehicle releases. Moreover, a central decision-making authority for electrics/electronics platforms has been partly introduced and harmonized with responsibilities in technical development (Guideline B). So, new vehicle projects and lifecycle updates shall become more aligned, fostering synergistic and platform-oriented release planning.

Anticipated: Improving Decision-Making Consistency. The previous changes are expected to result in improved decision-making consistency, leading to smoother vehicle launches, higher software quality, and increased process efficiency. In particular, the functional-planning process is intended to enhance the alignment of vehicle requirements at the electrics/electronics platform level. It shall further support the strategic evolution of the electrics/electronics platform and its vehicle models. Here, it is important to ensure cross-generational software compatibility early on in the planning to ensure long-term OTA-capabilities for vehicles at the customer (Guideline C). Centralizing decision-making authorities at the electrics/electronics platform level is considered a key enabler for achieving these objectives at Volkswagen. Synergistic planning and advancing of vehicle models via a shared electrics/electronics platform require coordinated goals and decision processes to achieve the anticipated benefits.

6.3. Threats and Limitations

We recognize that our methodology faces limitations and threats to validity. First, *internal validity* measures the extent to which a study reliably determines causal relationships between the variables examined. For our interviews and expert workshops, the primary concern is the potential influence of interviewee biases and subjective interpretations of the authors during the data analysis. To minimize such personal biases, we adhered to established methodologies. These included reviewing related work on the topic and following established guidelines for conducting interviews, workshops, open coding, and card sorting to define key requirements. For our validation, we used expert workshops to promote discussions among participants to integrate diverse perspectives and achieve an overall understanding. By iteratively refining and validating our methodology with the experts, we aimed to mitigate subjectivity biases or too narrow perspectives on its development.

Second, *external validity* refers to the generalizability of our findings. In fact, the representativeness of our methodology and its validation process pose inherent limitations, since we worked with only one organization from a specific domain. To enhance generalizability, we incorporated insights from both literature and practice when defining the requirements of our methodology. Furthermore, we involved experts from diverse brands, departments, and roles within Volkswagen to involve different points of view and

experiences. Still, the external validity of our work and methodology are limited. This is somewhat inherent to developing a methodology of practical value, since it must be customized to its specific context. In contrast, we argue that our work is transferable, meaning that it can inform and guide practitioners and researchers in other domains, even if it is not directly generalizable. We argue that particularly other domains in which complex electrics/electronics architectures exist (e.g., robotics, cyber-physical production systems) can benefit from it and can adapt our contributions.

Lastly, *construct validity* is concerned with the alignment between the researchers' intended and actual measurements. Here, it may have happened that the goal of our workshops and methodology were not clear to our experts or that communication barriers resulted in misunderstandings in the data we elicited. To mitigate such threats, we explained our work at the beginning of each workshop, asked whether any clarifications were needed, engaged in post-workshop discussions, and validated the protocols with each participant. Moreover, we conducted two conclusive workshops in which the experts validated the resulting methodology and checked that all relevant insights were incorporated.

Similarly, the selection of our validation criteria poses a potential threat. To verify that our methodology provides the intended benefits, the validation criteria must accurately reflect these outcomes. To ensure their feasibility for evaluating our methodology's practical value, we conducted an initial validation of the criteria during the workshops. This method helped us confirm that the validation criteria accurately reflected the intended value of our methodology and were relevant for practitioners, thereby mitigating this risk. In addition, we have shown that parts of our methodology have been implemented within Volkswagen, meaning that it was so far comprehensive and useful for the target audience of practitioners in the automotive domain.

7. Conclusion

In this article, we have proposed a methodology for centralized electrics/electronics platform release management. We highlighted our methodology's benefits in addressing the increasing relevance of software in modern vehicles and its applicability in the automotive industry. At its core, our methodology revolves around implementing a centralized electrics/electronics platform release plan. This plan strategically guides the portfolio management and integrates requirements engineering, lifecycle management, OTA software-updates, adapted decision-making processes, and functional road-maps. To validate our methodology, we conducted a series of eight expert workshops and derived practical insights from the initial implementation of selected parts of our methodology in practice. Our contributions provide valuable support for practitioners in implementing electrics/electronics platforms, while also highlighting potential directions for future research. For instance, we plan to practically implement more and more parts of our methodology to further evaluate its effectiveness in overcoming the challenges we identified. To this end, refinements, adjustments, and improvements will be needed, ideally also incorporating insights form other domains to improve the generalizability of our methodology.

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CRediT authorship contribution statement

Lennart Holsten: Conceptualization, Methodology, Validation, Investigation, Writing - Original Draft, Writing - Review & Editing, Visualization. **Jacob Krüger:** Methodology, Validation, Writing - Review & Editing, Supervision. **Thomas Leich:** Conceptualization, Supervision.

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