*7th European Conference on Industrial Engineering and Operations Management*
*Augsburg, Germany, July 16-18, 2024*
Publisher: IEOM Society International, USA DOI: 10.46254/EU07.20240159
Published: July 16, 2024

# Methods for Product Planning and Validation for a Modularized Software-Defined Car Concept

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## Abstract

The automotive industry faces growing demands and technological shifts, necessitating new approaches. In the context of increasing sustainability requirements, the future car must remain adaptable throughout its lifecycle. Similar to smartphones, it should receive over-the-air updates to extend its functionality. Achieving this requires fundamental changes in electronics, software, hardware architecture, and development processes. The authors face part of these challenges as part of the project Software-Defined Car (SofDCar). This paper addresses different aspects in context of product planning and product development for a software-defined car. The aim and vision of a methodological overall framework was broken down to the goal of creating an initial framework. This idea includes three fields with several approaches. The first field focuses on the development of a roadmap based on future scenarios. With two approaches, a cross-generational roadmap for the implementation of product properties was developed in this research based on changing product properties, robustness and innovation potential. Further, an initial approach was developed to continuously monitor the roadmap against the future environment to be able to anticipate and implement them into the car. The second field focuses on validation of the identified product needs by assessing the products future benefits. Based on these benefits, requirements for the validation system are derived. To enable updates and upgrades, planned product properties must be designed for extensibility and exchangeability. Hence, the characterization of the design space was focused within the third field. An approach was developed to define modules by considering suitable interfaces and standardization using design-for-modularization.

## Keywords
Design for Modularization, Foresight, Product Engineering Process, Software-Defined Car and Validation.

## 1. Introduction
The constantly growing and evolving requirements of users and technological changes in the mobility industry are forcing the automotive industry to adopt new approaches. In the context of growing sustainability requirements, the car of the future must be adaptable throughout its life cycle, for example to implement new functionalities via over-the-air updates and thus extend its operating life. This should work in a similar way to a smartphone, whose functions can be changed using apps. To enable this, the electronics, software and hardware architecture in the car as well as the development methods and processes must be fundamentally changed and developed to positively shape the technological requirements of digitalization. By developing new methods and concepts, it should be possible to anticipate, plan and validate requirements and product functions of a car across all development stages. These challenges are being addressed in several sub-work packages in the Software-Defined Car (SofDCar) consortium project which is part of a government-sponsored research program and founded by the German Ministry of Business Affairs and Climate Control (BMWK). (SofDCar Website 2024; SofDCar Project Proposal 2021).

Therefore, different fields are examined in this paper and integrated into an initial methodological framework. For the planning, foresight methods are used to derive future product properties based on scenarios and implement them into a roadmap. Monitoring methods are developed for the continuous integration and comparison of these plans with foresight to be able to anticipate changes in requirements and boundary conditions at an early stage. Besides monitoring future requirements and boundary conditions, the derived needs and benefits – modelled in the product profile – must also be assessed in order to validate them. The necessary validation system is to be defined through requirements. To enable updates and upgrades, the planned product functions and properties must be designed to be extendable and exchangeable using suitable approaches, e.g. design-for-modularization, for which suitable interfaces and standardization guidelines must be defined.

## 2. Literature Review

### 2.1 Product Planning and Foresight

The product engineering process (PEP) is part of the product life cycle and consists of strategic product planning, product development and production system development (Albers and Gausemeier 2012). Development should always be future-oriented to lead to a successful product and to be successful on the market (Cooper and Kleinschmidt 1993; Lindemann 2016). A successful product on the market can retrospectively be classified as an innovation (Schumpeter 1939). It is essential to firstly focus on the needs instead of specific solutions (Patnaik and Becker 1999). Therefore, the product profile, a model of a number of benefits for suppliers, customers and users that specifies the solution space for the design of the product, is crucial and was implemented in the understanding of an innovation (Albers et al. 2018). Technical systems are not developed completely new but in generations and always based on references through the three variation types carry-over, attribute and principle variation, which is described in the model of SGE – System Generation Engineering (Albers, Kürten et al. 2022). A model to describe product engineering processes in individual sequences based on basic and core activities is the iPeM – integrated Product engineering Model (Albers, Reiß et al. 2016). To anticipate the future environment, foresight methods are used for the early identification of future developments (Micic 2007). Various instruments exist according to the addressed, ascending time horizon: prognoses (short-term, operative), trends (medium-term, tactical) and scenarios (long-term, strategic). Scenarios can be separated by using future-opened and networked thinking to describe alternative, consistent images of the future (Fink and Siebe 2016). Scenarios are systematically created using the scenario technique based on key factors by projecting their characteristics into the future and linking them consistently (Gausemeier et al. 1998). Foresight was considered as a separate process but is more and more included in the PEP (Müller 2008). Meyer-Schwickerath (2014) examined general possibilities for an integration into the PEP. Marthaler (2021) proposed a systematic approach to derive properties for several future product generations through strategic foresight. Based on scenarios, relevant future product properties are derived and roadmaps towards the future target state are created (Albers, Marthaler et al. 2022). Kuebler, Schuster et al. (2023) developed a methodological approach to determine changing product properties using foresight. They can further be classified as static and dynamic and prioritized for later upgrade planning (Kuebler, Schuster et al. 2023; Kuebler, Thümmel et al. 2023). Updates and upgrades aim to extend the life cycle of a product and its useful time (Albers et al. 2023).

Foresight tools, e.g. scenario updates and monitoring, can be used to take account of changes in future developments (Siebe 2018). Different fields of actions were identified showing the need for action towards the continuous integration of foresight in the PEP (Thümmel, Kleinschrot et al. 2023). In an analysis of the integration of monitoring approaches in the PEP, there could not be found suitable approaches yet (Thümmel, Schwarz et al. 2023).

### 2.2 Validation and Verification

Albers (2010) characterizes validation as a central and knowledge-generating activity within the product development process, distinguishing it from verification. According to VDI 2206, verification assesses whether the realization of a system or product conforms to the underlying specification, but it does not evaluate the relevance of the specification or its benefits for the designated stakeholders (Albers, Behrendt et al. 2016; Albers and Düser 2011; VDI-Richtlinie). In validation, this evaluation takes place, which is why VDI 2206 defines validation as checking whether the product is suitable for its intended use or achieves the desired value or benefit for the defined stakeholders. Thus, validation addresses the question of whether the correct product is being developed, while verification answers whether the product has been developed correctly (VDI-Richtlinie). To illustrate the relationship between validation and verification, Albers, Behrendt et al. (2016) incorporate verification as an activity within validation and expand it to include the activities of evaluation and objectification. Evaluation involves examining increments of the product or the associated development from a stakeholder perspective and is predominantly subjective, based on personal perceptions. Objectification describes the extent to which the modeled requirements, objectives, and boundary conditions align with the expectations and needs of the stakeholders (Albers, Behrendt et al. 2016; Albers et al. 2015). Validation activities should be carried out continuously during the development process (Albers et al. 2015). The iPeM - integrated Product engineering Model supports the stakeholder with the planning of these activities. The iPeM describes various layers that consider the systems to be developed in product development alongside the current and next generation that will be launched on the market in layers: Production System Layer, Strategy Layer and Validation System Layer. All increments are created in the validation system layer to enable validation. (Albers, Reiß et al. 2016) To describe the relationship between product and validation system, Mandel et al. (2020) present a process. Based on the product profile, validation needs are determined and converted into several validation objectives. These validation needs correspond to knowledge and definition gaps. Knowledge gaps refer to the missing or incomplete knowledge required for the solution. Definition gaps refer to unspecified parts of the solution, but also parts of the solution that have not yet been decided upon. (McManus and Hastings 2005) Based on these validation objectives, test cases can be derived in which the configuration and the test objective can be defined. The results can then be fed back and the gaps closed or minimized. (Mandel et al. 2020)

### 2.3 Modularization

The characteristics of modularity include commonality and combinability. Commonality refers to the ability of a module to be utilized multiple times across various or identical product variants. This is facilitated by interface standardization, which enables the repeated use of modules. (Krause and Heyden 2022) Modularization and interface standardization are also central aspects of product development that are closely linked to the concept of the design space. The design space represents the range of possibilities or parameters to consider when designing a product. It provides a framework for creative decisions and innovation (Sovani and Khondge 2013) and is closely linked to modularization, an approach that breaks down a product into independent modules. Modules are hierarchically structured product components developed according to technical and strategic aspects. (Lindemann 2016) Interface standardization, which involves the definition of standardized interfaces between the modules, facilitates the adaptation and extension of the product and enables seamless integration and interaction of the modules. (Hildebrand 2005) These concepts form a holistic approach by reducing complexity and facilitating the handling of products in all value-creation processes to design flexible, adaptable, and innovative products.

## 3. Methods

### 3.1 Research Need and Research Goal

The provisioning of extended and new product functions for customers and users, needs a systematic planning. Especially the faster development cycles of future generations compared to those today in the automotive industry and the trend towards more software focus are current challenges. This leads to the need of a systematic planning process across multiple development stages and generations considering different domains. This includes the planning of new product functions and properties as well as the times of implementation of both hardware and software. To limit the effort for development and validation, the realization and analysis of the impacts and consequences of functions to be implemented must be planned cross-generational. The implications due to the interaction of different hardware and software configurations further increase the complexity.

To deal with these challenges, the aim is to develop a methodological overall framework for cross-generational planning, analysis of impact and validation of product functions for a software-defined car. Existing methods and approaches, as shown in the literature review, need to be evaluated and – if necessary – adapted to the cross-domain usage for hardware and software development. Individual goals, that are focused in this paper, are to develop methodological approaches to create roadmaps for time of implementation based on future robustness and innovation potential as well as for actualization based on environmental and premise monitoring. The time of implementation into the product can be both within the product development and while the product is in the market by using updates and upgrades. Further, an approach for identifying requirements towards the validation system to estimate the extent of validation needed to ensure the customer and user expectations. Finally, a procedure model should be developed to characterize the design space for the implementation of future development activities with the help of design-for-modularization as well as the definition of interfaces and suggestions for standardization.

### 3.2 Research Design

Based on the research need and the research goal, the following research questions were derived to this research project. With the questions, this work can be structured and the results will also be analyzed and evaluated.

1. How can future product properties be derived from strategic foresight, implemented into a development roadmap and monitored against changes in the future development?
2. How can requirements towards the validation system be derived for validating identified future product profiles considering benefits and expectations of customers and users?
3. How can a process model be developed to characterize the design space for the implementation of identified future product properties considering the definition of interfaces and standardization?

To answer the research questions and thus to achieve the set research goals, several approaches were used like the Design Research Methodology (DRM) of Blessing and Chakrabarti (2009) or the Framework for Design Support Development of Marxen (2014). However, there was no overall systematic research design in use, as the goals were partially given by the project plan in the consortium. Besides systematic literature reviews (SLR) in all parts of the research, interviews were conducted as well as workshops within the project consortium or in other research projects.

### 3.3 Research Environment

The research is carried out in the three-year project Software-Defined Car (SofDCar), which is part of a government-sponsored research program and founded by the German Ministry of Business Affairs and Climate Control (BMWK - 19S21002). In total, thirteen partners are involved both from academia and industry with mostly background of software development and automotive industry but also product development. The project aims to develop a vehicle concept that is seen as part of a network of all vehicles and the surrounding infrastructure. The goals are, besides others, to create a concept that enables a long operating life of a car by adding functions using updates and upgrades to be resilient to technological changes and thus increase the sustainability. Therefore, the project is divided into four focus fields, called workstreams: 1 – "Data Loop", 2 – "Re-Deployment", 3 – "Digital Twin" and 4 – "Demonstrators". The topics in this paper are allocated to workstream 3 "Digital Twin" which focuses on the increasing and more differentiated consumer demands and user experience expectations as well as strong technological changes in the mobility industry by creating a virtual replication (digital twin) of the vehicle and its environment. (SofDCar Project Proposal 2021)

## 4. Results

In the following sections, the three research questions will be answered separately by their topic and role within the project. Afterwards the topics will be combined into an initial methodological framework to highlight the coherences conjunctions between them.

### 4.1 Product Planning – Future Product Properties Using Foresight to Create Roadmaps

For the planning of product properties and to create an implementation roadmap, future scenarios must be created to give an overview of different, consistent possibilities of the future. Therefore, customer-environment scenarios were built by using the scenario technique of Gausemeier (1998). This included the identification of key factors of the environment of the automotive industry and their projection into the future in two different dimensions with low or high characteristic each. For example, for the key factor infrastructures, the two dimensions were utilization of the road network and availability of real-time capable internet connections. In total, 13 key factors were used to create seven scenarios by combining their projections in a way that the resulting scenario is internally consistent with the other projections. The scenarios represent the possible future space of the environment for the automotive industry with focus on software defined cars and were already described in the paper of Kuebler and Thümmel et al. (2023) and are shown in Figure 1a. For the roadmap, the systematic approach of Albers, Marthaler et al. (2022) was used within a workshop to derive relevant product properties for the future. Therefore, current properties were identified from existing cars. Possible future properties were derived from the created customer-environment scenarios. An evaluation of the development potential of the properties towards future-robustness and invention potential was conducted for each property with every scenario. From that evaluation a prioritization in early, mid-term, long-term or no variation of the property can be derived in either a portfolio or a cross-generational roadmap, which is shown in Figure 1b. The most relevant properties are those with an early variation, e.g. customizability, connectivity and architecture, that should be focused early. Afterwards, another workshop was conducted with several members of the project to create product profiles for products with properties that were identified earlier. These were, for example, "we need a product or service that enables synchronization of user profiles across several vehicles" or "we need a product that can fulfil changing stakeholder requirements by adaption of technological realization".

For further assessment, another systematic approach of Kuebler and Schuster et al. (2023) was used. This approach focuses more on upgradeability and modularization to address the changing product properties identified. Current properties were analyzed and the customer-environment scenarios were used to project them into the future. In contrast to the first step, this time it was more focused on - but not limited to - components and properties of the drive train to limit the scope onto an example and therefore raise the level of detail, e.g. energy storage, torque generation and torque transmission. The properties with their future projections were combined to product scenarios and evaluated against the customer-environment scenarios within a delta analysis. Dependent on the number of possible options and thus the definite or vague assignment, the properties can be classified in either static (definite) or dynamic (vague). Static properties have one distinct projection and therefore a low propensity to change, whereas for dynamic properties no distinct projection can be assigned leading to a high degree of uncertainty. Hence, a flexibility in the selection and implementation of a projection is required.

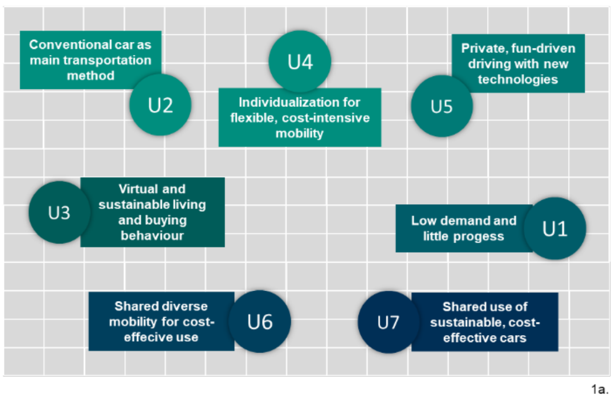



Figure 1a. Future environment scenarios (Kuebler et al. 2023b) and
Figure 1b. 4-field-portfolio for variation of product properties based on invention potential and future-robustness

The uncertainty is the reason for the consideration of monitoring of the future development of the environment. Every foresight process only can provide an overview of the possible alternatives but not the incontrovertible future. Therefore, the product planning and roadmaps should be monitored against the future development and updated if a change is detected (Thümmel, Schwarz et al. 2023). Such changes could be within general boundary conditions, legislation, market and technological developments and thus customer requirements. In a comprehensive systematic literature review of Thümmel and Kleinschrot et al. (2023), it was found that there are no existing methodological approaches that connect strategic foresight and the product engineering process continuously. Also, there was no definition of monitoring in context of the PEP, wherefore an own understanding and definition was developed for scanning and monitoring. Scanning is a preceding activity to detect indicators by screening, while monitoring is a targeted search for changes in those identified indicators (Albers et al. 2024). Besides, the two activities were classified as validation activities and support several more activities within the PEP. In a first approach, the product profiles were classified and located in the future space by evaluating against the scenarios (Thümmel et al. 2024). For more operationalization, a descriptive and a process model was developed. The process model specifies the chronological sequence for monitoring in five steps: planning, evaluation, deviation, advice and adjustment. The descriptive model specifies the boundaries of indicators and product properties in context of the future space. Depending on the time horizon, different instruments of foresight are used at different stages of the project resp. the product engineering process. As the project proceeds, the scope becomes smaller, thus changes may only be implemented in the next generation or in subsequent updates or upgrades.

All methodological approaches combined give an answer to the first research question and enable the derivation of product properties from strategic foresight, implement them into an implementation roadmap and monitor them against changes that may come up during the development or operating life of the product.

### 4.2 Validate Product Profiles - Requirements Towards the Validation System

To derive requirements for the validation system, validation needs and objectives must be derived. Validation needs are derived from the product profile and validation objectives are defined based on these needs, from which test cases and thus requirements for the validation system can be derived. The derivation of validation needs is therefore critical when defining requirements for the validation system.

Especially in the validation of product profiles in early phases of development projects, the derivation of validation needs is challenging because it is often not clear which definition and knowledge gaps need to be closed. For this situation, Schwarz et al. (2024) describe a process in which a product profile can be validated by evaluating the identified benefits (see Figure 2). The validity of a product profile shows whether a benefit generates realizable added value. This describes the existing gap that corresponds to the need for validation. In this publication, a total of three product profiles were evaluated, which were created earlier as described in the previous chapter. By using the portfolio in step 3, validation needs could be derived and validation objectives derived (see Figure 3).

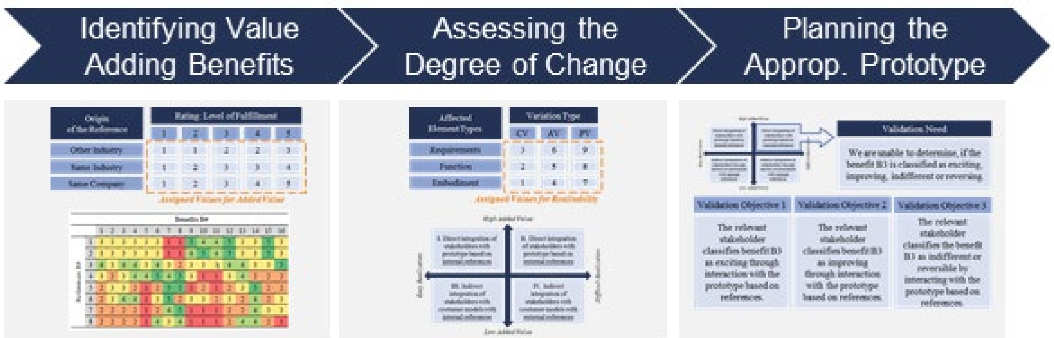


Figure 2. Overview on an Initial Process for Validating Product Profiles in Early Phases of Engineering Processes according to Schwarz et al. (2024)

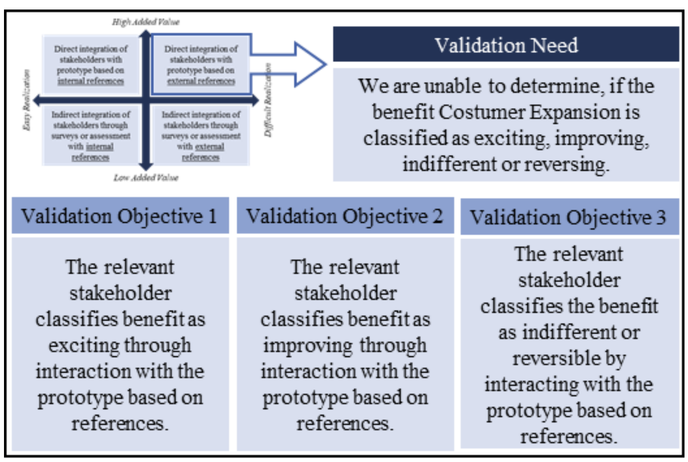


Figure 3. Example of a Validation Need and Validation Objectives for the Benefit "Expansion of the Costumer Base" as a Preparation for Deriving Requirement Regarding the Validation System, illustration according to Schwarz et al. (2024)

The derivation of requirements for the validation system for the validation of product profiles is based on the planning of the right prototype. To this end, Schwarz et al. (2024) describe aspects that must be considered when planning the right prototype and can be categorized into aspects for a needs-based or situation-based prototype. The aspects are Purpose, Target Group and Result (needs-based) as well as Resources, Competences and Boundary Conditions. A total of six requirements were derived for the validation system for the Benefit Costumer Expansion (see Table 1). Requirements were derived for each benefit from each of the three product profiles.

Table 1. Derived Requirements regarding the Validation System for the Benefit Costumer Expansion

| # Nr. | Requirement: The Validation System should… |
|---|---|
| VS-R1 | … enable the evaluation of the costumer expectations regarding the Kano model. (Purpose) |
| VS-R2 | … have the possibility to integrate current and future stakeholder into the validation process regardless of the current relationship with the provider. (Target Group) |
| VS-R3 | … measure the acceptance of the categorization of the customer expectations based on the assessment of the benefits. (Result) |
| VS-R4 | … integrate existing validation configuration from previous generations and previous generations of references. (Ressources) |
| VS-R5 | … integrate knowledge and competences regarding existing references in own and competitor. (Competences) |
| VS-R6 | … use no developed ideas regarding the product profile. (Boundary Condition) |

Requirements could be derived through the application. These requirements correspond to stakeholder requirements and not yet system requirements, which can only be derived from these requirements when designing the solution for the product profile. The approach in this chapter answers the second research question.

### 4.3 Conception and Design - Modularization Strategy and Specification of Standardized Interfaces

In these times of rapid technological development and growing demand for sustainable mobility, the automotive industry faces the challenge of developing vehicles that are not only environmentally friendly but also flexibly adaptable. Modularization enables an efficient solution through independent, optimizable units. (ARE 2022) The resulting flexibility ensures that the vehicle can be adapted to different users and usage scenarios throughout its service life. (Fehrenbacher et al. 2023) Seamless integration of new functions is achieved by defining standardized interfaces between modules. Based on the characterization of development activities and the defined modules and interfaces, a design space should represent the possible configurations and adaptations of the vehicle within the defined development activities, including hardware components, software functions, and vehicle features. (Sovani and Khondge 2013) The provision of software functions and validation of these under different product configurations are also covered in this project. Software and hardware changes to the product must be made in parallel; the trigger to start the adaptation can be made on both sides. The design space represents all possible configurations that could be considered for a product or function, in this case, one for storing and providing electrical energy.

As part of this project, a hybridized powertrain is being modularized. Here, we use the integrated product engineering model (iPeM) to make vehicles more adaptable to different customer requirements. (Albers, Reiß et al. 2016b) According to Albers, it forms a reference model for system generation development (SGE). (Albers et al. 2017; Albers, Kürten et al. 2022) The SGE model and the iPeM thus attempt to close the gap between process management and engineering design of different domains. Both models thus form a suitable basis for developing a product that serves several buyer groups with different product requirements during its utilization phase through a well-thought-out system architecture. (Fehrenbacher et al. 2023) Based on many different Products, a reference system is determined, and Product profiles are created for different user groups at the beginning of the development process. (Albers, Kürten et al. 2022) The insights acquired during this phase, coupled with the application of Blees' (Blees 2011) modularization strategies through technical-functional, geometric, and product-strategic aspects, establish the reference for the design and subsequent construction of a product's modular system architecture. (Figure 4) The result of these processes is a product generation with several variants that can exist on the market simultaneously. As these variants can be adapted to changing boundary conditions over time, versions of these variants can be created with the help of adaptations. The resulting technical system consists of several components (subsystems) connected by as few standardized interfaces as possible.

In the context of this standardization of interfaces, a methodology based on the iPeM and the V-model is provided, according to Grimske (2014). The methodology consists of two steps: the interface system design and the interface design, each divided into four phases. The interface system design aims to determine the number, position, and multifunctionality of the interfaces in the overall system. The interface design aims to work out the interfaces' concrete geometric and material design, applying cross-domain and domain-specific solution principles. (Grimske 2014).

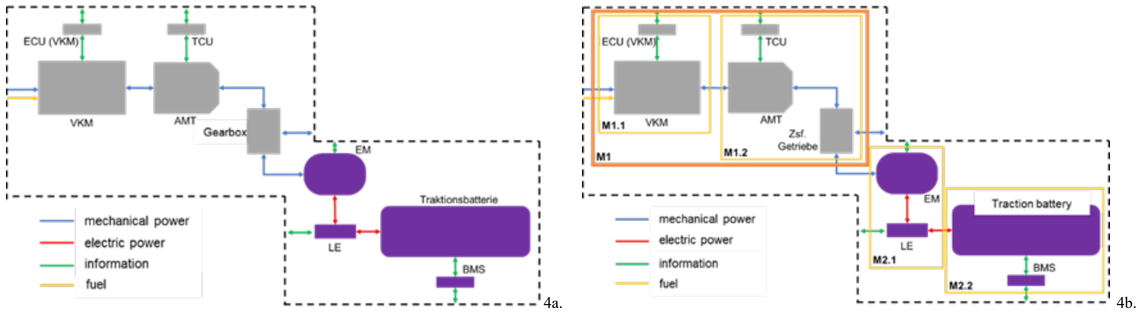


Figure 4. Example of modularization of a drive train of a hybrid vehicle in P3 arrangement
a) Before modularization b) after modularization (Fehrenbacher et al. 2023)

The borders of the modules can then open up possibilities for a specific design space specification. Each design space is derived from future engineering activities and customer requirements, as well as boundary conditions determined in advance. It contains possible configurations and adaptations of the module that are possible within the scope of defined development activities. This includes hardware components, the interaction with software functions, and the overall features of the vehicle in the context of the module under consideration. In today's world, characterized by rapidly changing system architectures, the early provision of universally applicable cables, connectors, computers, and corresponding installation space is becoming increasingly important. This is the case, for example, with components used to control autonomous vehicles.

Recycling issues or regulatory requirements are problems that affect us today and in the future. In this respect, the form and function of the electrical energy supply could provide a concrete example of a design space. Assume that one of the first development stages of the vehicle involves selecting and implementing the energy source. The design space for this stage of development could include all possible types of battery technologies or other forms of electrical energy supply and storage that could be considered, such as lithium-ion batteries, solid-state batteries, or even fuel cells. A process for validating these different solutions in the electrical energy storage design space can be seen in Figure 5. In this virtual future Scenario, different battery technologies can be easily exchanged using standardized interfaces, so the effects on consumption can be estimated, for example.

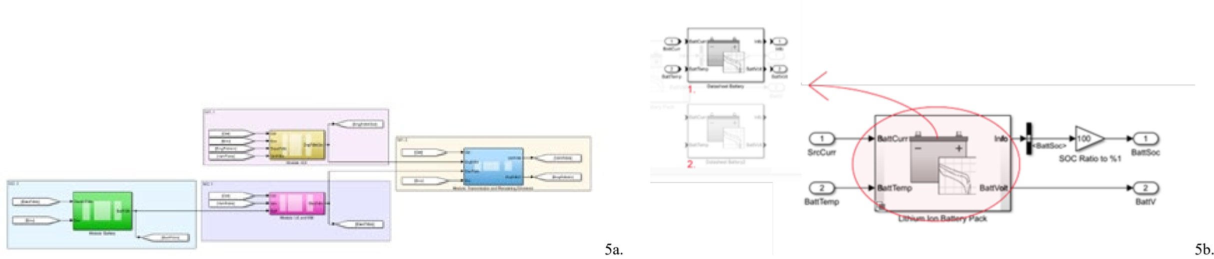


Figure 5. a) 1st level of the modular structure of a P3 hybrid in the Simulink model
b) Simple exchangeability of the traction battery made possible by standardized interfaces

### 4.4 Initial Methodological Framework

All topics and approaches described above are related to each other within the product engineering process. Therefore, they were combined into an initial methodological framework to highlight the coherences and conjunctions between them in context of the development of a software-defined car. Besides the three main fields of "Product Planning", "Validate Product Profiles" and "Conception and Design" with their approaches and activities, there are several side activities that were combined in a fourth field "Associated Activities" that are partly related to the main fields. They are shown in Figure 6.

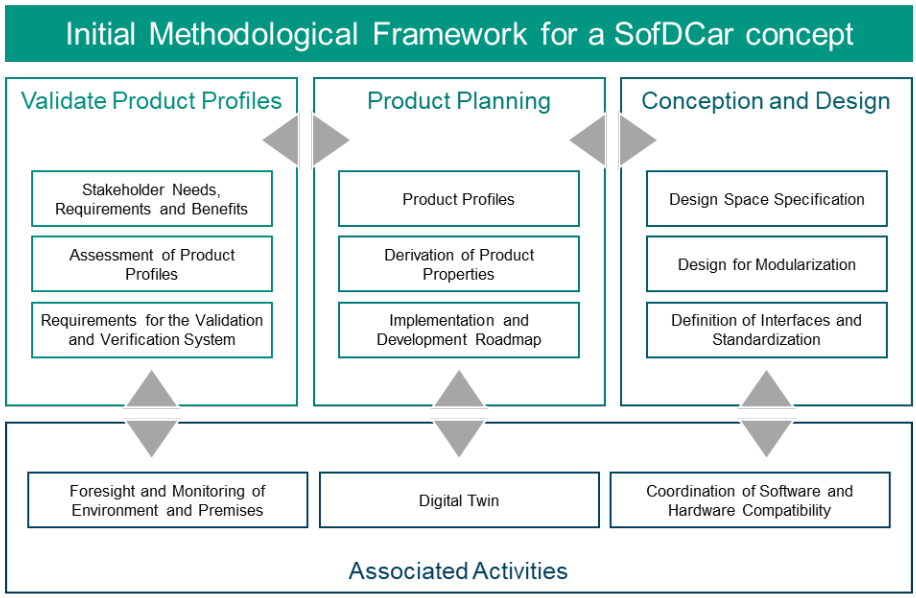


Figure 6. Initial methodological framework for a Software-Defined Car

The first step is to start with the field "Product Planning" - that connects all activities as a center - by creating scenarios using foresight. Product profiles and product properties can be derived from the scenarios and be transferred into a implementation and development stage roadmap. The planning needs to be monitored and may be updated if a change is detected in parallel to the whole engineering process of the car. This is a very first version of a vague digital twin, which can be modeled using different methods and tools. In the product profiles, several stakeholder needs, requirements and benefits are contained that need to be validated in the field "Validate Product Profiles". Therefore, the requirements for the validation system must be specified for further evaluation with focus on the stakeholders. Similarly, the verification system must be developed to clarify what needs to be tested with focus on the product and its sub-systems and components. Those components are specified within the field "Conception and Design". Here, the design space of the whole car is specified and planned in an exchangeable way by using design-for-modularization to create updateable and upgradeable components which are planned in correlation within the field "Product Planning". Essential part is to define the interfaces between different standardized modules. For a planned change of modules, the impact must be evaluated and validated that the hardware is compatible both with other hardware and software. Also, it needs to be clarified by validation that the customer expectations of the required and planned functions and properties are met in all variations and variants. The digital twin as a virtual replication of the stakeholders, their requirements, the planned properties and the components can help to handle the coherence and conjunction of the different aspects of the complex task of developing a future software-defined car.

## 5. Conclusion and Outlook

To develop an initial methodological framework for cross-generational planning, analysis of impact and validation of product properties for a software-defined car, several topics were analyzed separately and merged. For the planning of a product, several approaches were developed and used to create a roadmap for time of implementation by using strategic foresight and scenarios. A methodological approach was developed for actualization of this roadmap based on environmental and premise monitoring. To plan the validation activities and ensure, the customer expectations are met, a separate approach was introduced that assesses the needs, requirements and benefits of the stakeholders. To implement the planned properties, an approach for characterization of the design space was developed that defines exchangeable modules with standardized interfaces to enable updates and upgrades in the car. In an initial framework, the coherences and conjunctions were described to connect the approaches with each other.

The approaches need to be evaluated and tested in further research as they are in an initial state and not validated for use. Several research is ongoing to improve the level of detail as well as the usability of the developed approaches. The initial framework could also be developed further in more detail, certainly, it may be limited to specific companies as the coherences and conjunctions are specific and depend on the structure of the development process within a certain company. The interaction – and thus the impacts – between software and hardware domain needs to be investigated in more detail, which is already planned in the special research field (SFB) convide, where researchers of informatics, electronics and mechanics work together to better understand the independencies and find ways to improve the collaboration in both research and industry.

## Acknowledgements

This publication is based on the research project SofDCar (19S21002), which is funded by the German Federal Ministry for Economic Affairs and Climate Action.

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**Katharina Bause** graduated in 2011 from the Karlsruhe Institute of Technology and began her career at the Institute of Product Development (IPEK), focusing on Drive Systems and Systemic Mobility. Her research concentrated on Drive System Topologies for Battery Electric Vehicles (BEV). In 2016, she became a team leader in Drive Systems. From 2018 to 2024, she headed the research department for Drive Systems, Clutches and Tribology Systems. Since 2024, she has been the department manager for Automated & Connected Mobility, Drive Systems Engineering, Medical & Health Technologies, and System Tribology.

**Albert Albers** has been full professor for product development and head of IPEK - Institute of Product Engineering at the Karlsruhe Institute of Technology (KIT) since 1996. He received his doctorate in 1987 under Prof. Palandan of the University of Hannover. Before his appointment to Karlsruhe, Prof. Albers worked for LuK GmbH & Co. OHG, most recently as head of development and deputy member of the management board. He is a founding and former board member of the scientific society for product development WiGeP, a member of the German Academy of Science and Engineering (acatech) and a member of the Advisory Board of the Design Society. Since 2008, he has been President of the Allgemeiner Fakultätentag (AFT e. V.). In addition, Prof. Albers engages in the VDI and serves on the advisory boards of several companies. In 2016, he and the IPEK team were awarded the Honorary Award of the Schaeffler FAG Foundation for excellent achievements and competencies in science, research and teaching in the technical-scientific field.