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New Holistic Approach Towards a Technology-Driven Development-Model in Automotive

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Abstract

The use of agile methods can also be advantageous in the development of physical products, as pilot projects have shown so far. However, the transfer of agile methods to the entire organisation is difficult, due to the different, prevailing circumstances of the various development activities. We have therefore defined a new approach subdividing product development into agile technology-driven and traditional product-oriented development. This model considers the methodological characteristics and thus enables the combination of the benefits of both agile and traditional development methods..

Keywords: *design process, automotive process, agile development, hybrid development, design methodology*

1. Significance and Objective

For decades, the automotive industry has been under increasing pressure to transform. External factors such as climate change and urbanization, but also new customer expectations, are leading to increasingly complex products with simultaneous demands for reduced development times. (Schömann, 2012; Schuh et al., 2017a) These factors ultimately lead to an increase in development complexity, as new functions need to be additionally taken into account during development (Reichelt et al., 2019; Reichelt et al., 2021a). Furthermore, disruptive players such as Tesla have also roiled the industry with their technology-driven product development. New technologies, which nowadays have significantly shorter time-to-markets than traditional automotive manufacturing, are becoming crucial success factors for maintaining competitiveness in the automotive sector. But the use of new technologies complicates the prevailing stringent planning in the classical sense. Agile methods offer great advantages for the development of complex products and innovative technologies due to their flexibility and iterative character. (Albers et al., 2019a; Boehm and Turner, 2005; Lévárdy, 2006)

Therefore, agile methods have also been increasingly used in hardware development for several years. However, in the course of the envisioned agile transformation, a limited applicability of agile methods in the automotive sector with its very distinctive processes, methods and culture is increasingly emerging, despite scaling frameworks. Hybridization, i.e., the congenial use of agile and traditional methods, is seen as an alternative to scaling. (Reichelt et al., 2021b; Timinger, 2017)

However, in order to achieve the goal of an efficient application of agile and traditional methods, more is required than the belief that the "best of both worlds" can be achieved through an integration of agile methods only. A detailed examination of the methods and processes in the automotive sector shows that a hybrid solution in combination with a process- and work-specific split into technology-oriented and product-oriented development can offer the intended methodological advantages.

The aim of this paper is to present a novel, initially theoretical approach for hybrid development in the automotive industry, derived from both academic research and practical experience. Based on the characteristics of the two methodical worlds, agile and traditional we match the according requirements in the different stages of vehicle development. Therefore, the benefits of each methodical approach can be realized, without generating an overhead during the implementation.

2. State of The Art - Hybrid Development

We started with an extensive systematic literature review to determine the state of the art. Within this we focused primarily on approaches and research on hybrid project management and development. In addition, the basics of hybrid project management as a research and application area were investigated.
Moreover, the results from the literature are complemented by insights from the practical experience of implementing and scaling agile methods in a plan-driven development environment.
Regarding unpredictable changes and requirements in product development, the acronym VUCA - volatility, uncertainty, complexity, and ambiguity - is usually used to classify the various constraints to change, especially for the entire company (Bennett and Lemoine, 2014). When considering automotive-specific challenges on a technological level, the acronym eascy from PricewaterhouseCoopers can be used: electrified, autonomous, shared, connected, yearly updated (Kuhnert et al., 2017).
New technologies, especially from consumer industry, can be mentioned as an example of the constraints on change in the automotive industry. Compared to the automobile, these have significantly shorter life and development cycles. The integration of continuous innovations poses challenges to classic innovation processes, which ultimately require new methods.
For the theoretical determination of which method is suitable, a so-called Complexity Matrix - also known as Stacey Matrix - is usually used (Goll and Hommel, 2015; Project Management Institute, 2017). For example, agile methods are typically used to systematically reduce uncertainties in unclear and therefore complex development environments, with mainly occur in the technology development - also known as early stages (Boehm and Turner, 2005; Project Management Institute, 2017; Schuh et al., 2017a). This possibility is attributed to agile methods, as the core characteristic of agile methods is a strongly methodical, iterative, and incremental approach (Albers et al., 2019b; Böhmer et al., 2015; Schuh et al., 2017b).
The effectiveness of agile methods for this use case has been proven both in business (case studies, success stories) and in science (studies, surveys). However, this applies primarily to pilot projects and not to entire companies. (Reichelt et al., 2021b)
Traditional values (time-cost-quality), in particular quality, have a special importance in the (European) automotive industry. However, an improvement of these core values through agile methods cannot be observed (Atzberger et al., 2019).
Defined quality standards must be met for the release of a vehicle. Especially with regard to these standards, the use of agile methods stumbles: because either time benefits are lost due to external and generally stringent procedures, or products and functions are released that do not meet the quality level so far, so that recalls have to be carried out in the end due to malfunctions in software and hardware. These quality standards are intrinsic to maintaining customer satisfaction, so that losses in quality can ultimately lead to a loss of customers and thus purchasing power.
The quality requirements are very diverse and range from legal to company-specific guidelines and specifications. The achievement of quality standards (e.g. NCAP rating), especially for vehicles, is based on stringent and firmly defined work steps and processes. These processes generally require prototypes with a high degree of maturity. Due to longer delivery times of these physical parts scheduling agile methods do not match properly and therefore traditional methods become necessary (Baschin et al., 2021).
In the course of continuous development and the increase in certification and quality requirements, the corresponding processes have grown over the past decades and have been continuously optimized. Continuous and regular assessments, e.g. by means of maturity evaluations, are therefore essential and firmly implemented in the product development process as milestones or quality gates. These are usually optimized by traditional methods and processes such as the stage-gate process by Cooper (2007).
Therefore, the characteristics of traditional methods are the continuous, decade-long adaptation of these methods to changing, growing framework conditions (Boehm and Turner, 2005). Hence, these methods are considered optimized for stringent process steps.

Figure 1 summarizes the different circumstances as well as the characteristics of agile and traditional methods.

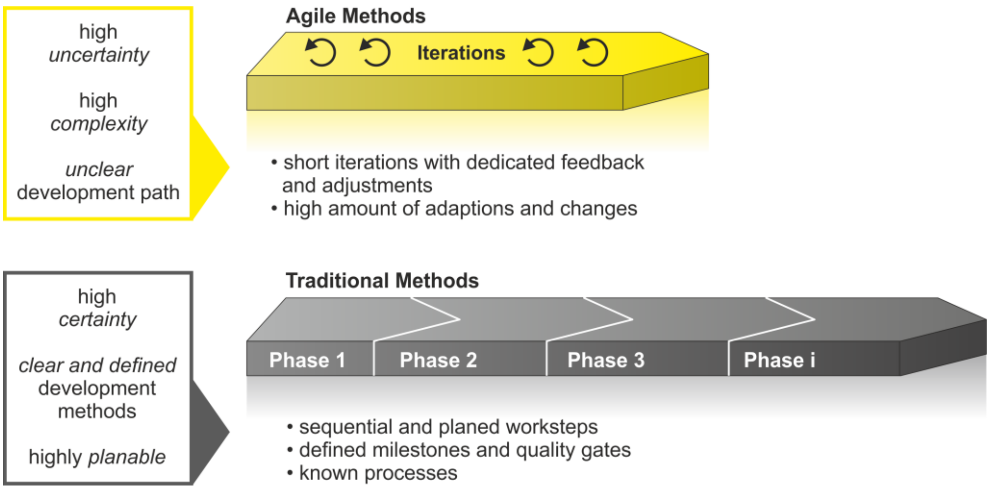

Figure 1. Overview on the different characteristics of agile and traditional methods

The 1:1 transferability of agile methods to hardware processes is only possible to a limited extent (Atzberger and Paetzold, 2019; Ebert and Paasivaara, 2017; Heerwagen, 2018). The extension of agile methods to the entire product development can be realized either by scaling agile methods or hybridization. However, scaling is increasingly reaching its limits (Atzberger and Paetzold, 2019; Conboy and Carrol, 2019; Komus et al., 2020), making hybridization a more effective approach. (Reichelt et al., 2021b)

Agile and traditional methods can be combined in various ways. Timinger and Seel (2016) as well as the Project Management Institute (2017) present different combinations for the sequential but also parallel usage of agile and traditional methods in a hybrid framework. Figure 2 shows the different possibilities of combining agile and traditional methods. The figure demonstrates that the various hybrid strategies either combine agile and traditional methods equally sequentially or simultaneously, or one method predominates and the other is then only partially applied.

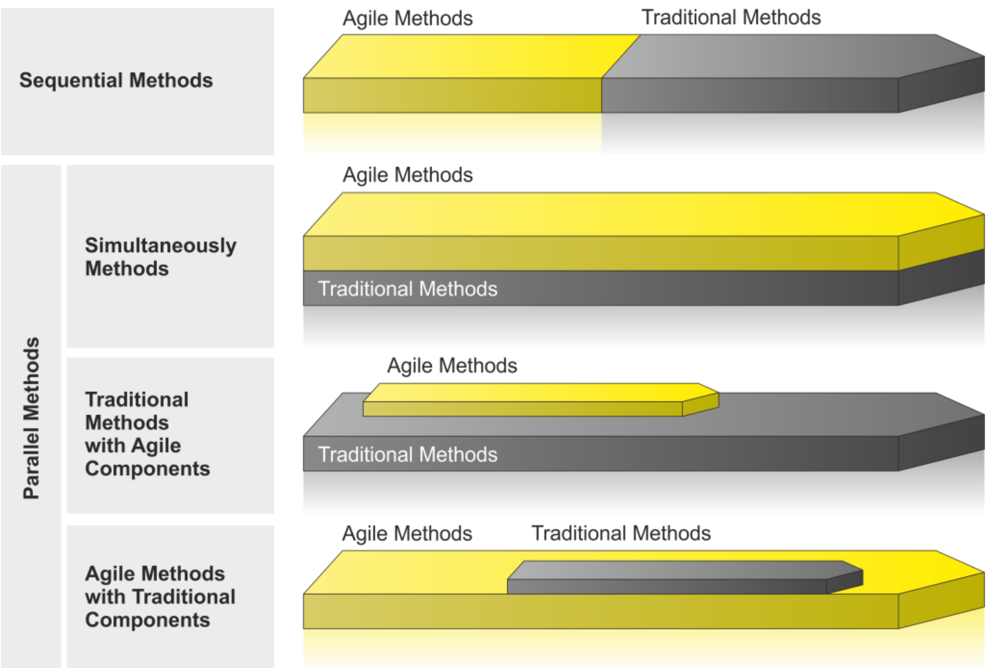

Figure 2. Overview over different kinds of hybrid combination of agile and traditional methods, based on Project Management Institute (2017) & Timinger and Seel (2016)

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Heimicke et al. (2020) have conducted an overview of existing hybrid approaches. It was determined that in most cases agile methods are integrated into a traditional environment. Additionally, hybrid approaches have been existing since the beginning of agilization in 2001. However, there is currently still some uncertainty in the use of hybrid approaches. In particular, the question of how to efficiently integrate agile and traditional methods is currently still very unclear. (Heimicke et al., 2020)

Initial approaches for the hybrid method approach in hardware development are, for example, ASD - Agile System Design by Albers et al. (2019a); the agile stage-gate according to Cooper (2014) and the Agile-Waterfall Hybrid Product Development by Schuh et al. (2017b).

Albers et al. (2019a) present a possibility to select a suitable method for traditional, agile and hybrid based on criteria. However, they do not address the logical sequences in automotive development. So that a compass exists for the selection of the project methodology. However, there is no guidance on how requirements can be determined in general, especially in the early phases, and how effective decisions can be made for agile or traditional methods.

Cooper and Sommer (2018) stated that agile methods may not work for all phases but especially for early stages they can enable innovation, whereas later stages need more precise and standardized method-sets. But the so called Agile-Stage-Gate does not provide any guidance when and when not, agile methods could be beneficial and therefore can be integrated in all phases equally.

In Schuh et al. (2017b), both agile and traditional teams can be used within the different structural and process-related work steps. The decision for or against the use of agile methods depends on the framework conditions. Eventually, agile and traditional teams can and should co-exist in this hybrid model, exchanging information with each other primarily via clear interfaces and synchronizations along the development process.

All approaches are characterized by a parallel combination of agile and traditional methods. According to Timinger (2017), this parallel combination can enable better adaptation of the methodology to company-specific conditions but poses the risk of leading to more complexity and thus to a deterioration of the process through too frequent or superficial changes between the methods. Only through the conscious and targeted application of this hybrid form can the benefits of both worlds be played out (Timinger, 2017). Furthermore, in current hybrid models, the decision for methods is only supported in a basic way; there are currently no adaptable decision support tools that take into account the characteristics of the methods and the different development stages. As a basis for decision-making, the complexity and necessary organizational consequences are not taken into account (Brandl et al., 2018; Kuster et al., 2011).

Holistic approaches that take a comprehensive view of vehicle development from the idea to production make it possible to design the entire product development process in a hybrid manner, although the focus remains on the product. As a result, technology developments continue to be subordinated to this logical product development process, which has been established over decades.

3. Technology-driven Development-Model in Automotive

As the state of the art shows the specific requirements of modern development can only be met to a limited extent through the pure integration of agile methods into existing plan-driven development. This perception is also reflected in the practice of many companies that are currently involved in the integration of agile methods. In particular, the methodological distinction between technology and product development, due to the different requirements and characteristics of each, has not yet been taken into account. However, this is an essential component to ensure the success of future developments. Therefore, we defined an approach separating the vehicle development process into technology-oriented development and product-oriented development.

3.1. Methodology

As a basis for the creation of the model, we conducted a systematic literature review. On the one hand, this shows the multi-layered experiences in the use of agile and traditional methods. Thus, a general classification of essential characteristics for the two methodological approaches and their suitability in principle for use in different circumstances could be derived. On the other hand, existing approaches could thus be identified and analysed. Our focus is always on the superordinate methodological level,

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or the basic characteristics of development, so in this publication we focus primarily on the core characteristics of product development and project management. Therefore, our literature review considers mainly the characteristics of agile vs. traditional and hybrid approaches in project management. There are other relevant fields of research - such as technology or innovation management, but to consider them in this first theoretical step would be too extensive.

In addition to the literature results, the approach was derived based on insights and experience of the authors: The knowledge and experience gained from implementing agile methods in many development and strategy projects, as well as from expert insights, expert discussions in the areas of strategy, vehicle development, technology and design concepts, and scientific research, are all incorporated into the creation of the model.

3.2. New Approach

The central component of the model is the matching of the existing process requirements with the methodical possibilities of the two worlds: agile and traditional. This is done by specifically targeting the different characteristics of agile and traditional methods identified from the literature (see Chapter 2). Based on different circumstances in the various stages of product development the methodical choice for each stage is considered based on these characteristics. In this way, a methodical evolution can be realized, such that neither a general forcing nor a complete, radical dissolution of existing structures takes place.

Therefore, the different stages of vehicle development need to be separated into technology-oriented development and product-oriented development. The different requirements and circumstances of the two core domains are being observed in the literature, but no distinction is being made so far.

Schulz et al. (2000) found similar relationships in the aeronautics industry. As a result of their research, they present an approach to separate technology and product development. The so-called "Total Technology Development" constitutes separate technology streams which develop new technologies more or less detached from the actual aircraft development. As soon as these technologies are ready for use (reach a certain level of superiority, robustness, and maturity), they are introduced into the regular product development as a push principle. This ultimately leads to a continuous development of innovations in a product that does not change significantly in terms of its nature (i.e., product definition and requirements).

In the context of the automotive industry, these observations can be transferred to a certain degree. The early phases are usually understood as fuzzy frontends (Cooper, 2014). These phases are characterized by a high degree of uncertainty and are usually determined by an iterative and incremental procedure. (Albers et al., 2017; Cooper, 2014; Cooper and Sommer, 2018; Lévárdy, 2006)

In this paper, we will use the basic principles of the "Total Technology Development" approach of Schulz et al. (2000) to present a new holistic model for the methodically optimized development of vehicles based on the current challenges in automotive development. Our focus is mainly on the consideration of the previously described characteristics in order to be able to meet the methodical, process-related, and product-based requirements within this model.

We have divided vehicle development into two domains that enable methodically optimized work within these separate domains. Complementing the considerations of Schulz et al. (2000) and Lévárdy (2006), the model is divided into technology-oriented Tech-Streams and product-driven, classic product development. These are continuous and run parallel to each other. In the following, the two defined domains of the model are described in detail and introduced with the terms Tech-Streams (TS) and shortened Product Development (sPD). Subsequently, an overview of the overall development approach, i.e. in particular the interrelationships and transfer between TS and sPD will be discussed.

Ultimately, this model is a central approach to how the best of agile and traditional can be established in a hybrid overall structure.

3.3. Tech-Streams (TS)

The Tech-Streams provide a framework for researching and developing new technologies and innovations. In order to maximize the innovation potential, these developments are independent of any product-specific requirements. This approach promotes so-called object-oriented development (Vetter,

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2011). Unlike Schulz et al. (2000), these Tech-Streams consist of multiple streams that promote different technologies and trends individually or in combination.

Activities in the Tech-Streams follow the technological strategy direction. This technology development is intended, among other things, to develop new disruptive and radical technologies to a level of maturity so that they are ready for development as part of a specific concrete, shortened product development process.

The goal of these tech streams is to research and develop new technologies. In order to achieve the highest potential for success, these streams should develop in a targeted but not plan-driven manner. It is necessary to continuously reduce the uncertainty and complexity of innovation development. For this purpose, an iterative and incremental approach is important, whereby agile methods are suitable for these circumstances of innovation development (Böhmer et al., 2015; Lévárdy, 2006). Therefore, the Tech-Streams are oriented to a basic agile framework.

Figure 3 illustrates the domain of the Tech-Streams and provides an example of a tech stream with its agile framework. The Tech-Streams follow a previously defined and continuously developed technology roadmap (Tech-Roadmap). This consists of at least a vision and a defined strategy. The work and outcomes of the various streams are aligned with this strategy. Due to the different complexity within the technology development, there are different progressions of the maturity level. This also affects the different starts and ends of the streams.

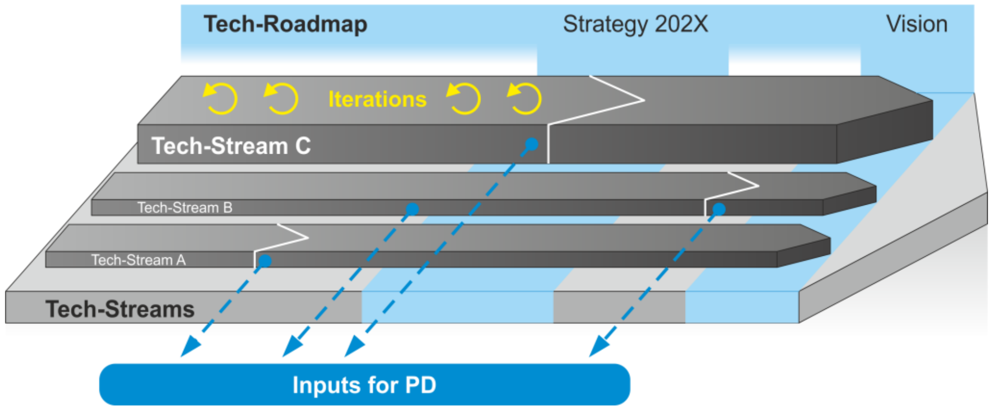

Figure 3. Correlations between the agile tech-streams and the tech roadmap and inputs to Product Development (PD)

Within the Tech-Stream, a technology is developed from the initial idea to a defined maturity level within this domain, i.e., also with the inclusion of other streams. Once a defined maturity has been proven, the results are made available for product development and handed over. This input is represented by the blue arrows.

By consistently separating technology development from product development, a better focus can be placed on the development of new technological innovations. The similar design of the various Tech-Streams with a fundamental orientation towards agile methods also creates a strong coherence that enables more intensive and targeted technology development.

3.4. Shortened Product-Development (sPD)

In contrast to the technology-oriented Tech-Streams, the shortened Product Developments focus on the development of specific vehicles. Unlike Schulz et al. (2000) or Lévárdy (2006), this product-specific development always takes place in a separate product development process, which can differ fundamentally from previous projects. Furthermore, technologies from the Tech-Streams do not have a direct impact on a currently running development project, but rather flow into the definition phase of a new product as essential inputs.

The sPD is based on well-known process models from the automotive industry, such as the stage-gate process (see, for instant Cooper, 2014; Cooper and Sommer, 2018) or the general development process according to VDI 2221. Following Gusig and Kruse (2010), the sPD is described by three core phases. Figure 4 illustrates a generic sPD. The main steps are the *definition* of the product, the *conception* of

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the vehicle concept and the *validation* of the vehicle. The different milestones are shown and serve as central points of synchronizing the different activities in sPD. During the sPD, inputs from the TS can be included in the development at various times. The way TS is incorporated into sPD borrows from a new, adapted combination of the two hybrid strategies (Chapter 2, Figure 2): both Simultaneous Method and Sequential Method (Project Management Institute, 2017; Timinger and Seel, 2016).
The product development of serial vehicles starts on the basis of a portfolio strategy. In addition to the known product characteristics and general requirements (target market, target customers, number of units, ...), this strategy is also based on a portfolio strategy at the start of the project. Within the *definition* phase the characteristics of the vehicle are determined, taking into account available new technologies from the Tech-Streams. The new technologies do not have to be ready for series production at the time of the vehicle definition; it is sufficient to make a precise estimate that these technologies will reach the necessary maturity within the context of the process.
This step represents the main opportunity to flexibly adapt the product to changing technological and market-specific requirements.
The definition phase is followed by the *conception* of the vehicle. In addition to finishing the styling, this is also where the final definition of the technologies used from the Tech-Streams is made. The necessary readiness for series production of the technologies must be confirmed by the tech streams by the concept freeze (for hardware technologies) or production freeze (for software technologies) at the latest, so that the corresponding technologies can be implemented or applied in the product. The application of the selected technologies to the actual vehicle and its derivatives starts with the concept phase and is driven forward by the vehicle developers.
Finally, the vehicle is prepared for market launch. The main steps in this process include *validation*, homologation, and the start of series production.

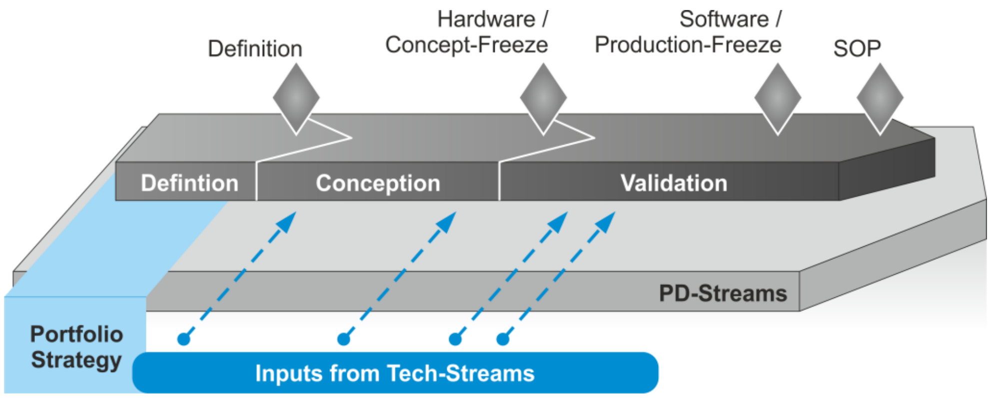

Figure 4. Shortened Product Development (sPD), including inputs from portfolio strategy and Tech-Streams (TS)

Overall, the sPD reflects the logical and stringent structure and sequence of a plan-driven product development. This product-oriented development is primarily focuses on the fulfilment of the quality standards and thus is significantly oriented on processes that have been optimized over many years. Therefore, the methodological characteristics of this domain are based on the traditional methods (see Chapter 2).

3.5. Interdependencies between TS and sPD

The essential connections between the Tech-Streams and the shortened Product Developments are, on the one hand, the connecting strategies: both the technology strategy and the portfolio strategies are directly related. For example, the portfolio strategy should consider the broad technologies which can be conceived from the tech roadmap. This roadmap guarantees a quasi-direct market introduction of new technologies through a matching product roadmap.
On the other hand, the transfer of technologies to the sPD itself is one of the most central connections or overlapping points: As soon as technologies have reached the appropriate level of maturity to be developed into a commercial and ultimately producible product, they can be integrated into a

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development project. The time of integration or application is determined at the beginning of each new sPD process in the product definition. Either the technology is already ready for use at this time or it is foreseeable that the technology will be available during the course of the sPD and can accordingly still be integrated in time. The transfer thus operates according to the pull principle; if a technology is relevant and available for a sPD, it can be integrated or applied in the product functions. However, the decision for or against the use of a technology does not only depend on its degree of maturity. Rather, the definition phase enables a flexible design and module strategy for the vehicle based on other influencing variables, such as the combined integration of several innovations at once or limitations in the in-house production or procurement of essential components for the corresponding technology.

The clear separation from technology development and the corresponding reduction in development effort results in a significantly reduced process for developing a product ready for serial production. Consequently, new products can be introduced to the market in shorter cycles. On the other hand, this creates the opportunity to flexibly address changing market requirements, as the final definition of the product is much closer to the start of production than with previous models. Another advantage is that the combined technology and portfolio strategy makes it possible to plan the integration of a new technology in several series at the same time.

Ultimately, by maintaining optimized assurance and approval processes, consistent quality can be achieved while at the same time increasing the flexibility of product design and positioning. This combination leads to an increase in flexibility of the entire product development and creates the possibility to adequately meet the current challenges, especially through the conscious methodical orientation.

To illustrate this, we describe the development of a charging cradle for smartphones as a fictional example below. Thereby, we address the respective characteristics of the domains.

The technology strategy specifies that connectivity between the vehicle and mobile devices is to be developed in the course of a tech roadmap. The integration of smartphones is specifically addressed within a separate Tech-Stream. In an iterative and incremental approach, various technological solutions are selected, evaluated and finally the system of a smartphone charging shell with connectivity technology (wireless transmission, and charging possibility) is presented. This development matches the predefined strategy and an application in future products is basically feasible. In the following, the Tech-Stream will develop this charging shell until it is ready for serial production. Other Tech-Streams are also included, such as the development of new HMI systems. Once series production readiness has been verified, the new technology is available for use in a specific vehicle model for the first time.Based on the portfolio strategy, the sPD of a new vehicle model starts. The production-ready technology of the charging shell is included in the vehicle specification as part of the product definition. The product developers of the sPD now apply the basic technology according to the vehicle and requirement-specific configurations of the vehicle. Thus, in the course of the sPD, on the one hand the integration into the vehicle package and on the other hand the exact design of the charging cradle including integration into the vehicle architecture are developed. Due to the late definition, it is possible to respond earlier to changing conditions caused by new smartphone innovations (e.g., new sizes or new connectivity technologies). This means volatile innovations, e.g. from other industries, can be integrated into new corresponding product generations more quickly.

4. Conclusion and Outlook

In this contribution, the status quo of hybrid method approaches was presented on the basis of an extensive literature research. The existing approaches only address the possibilities offered by a conscious combination of agile and traditional methods to a limited extent. Technology development with its own development characteristics continues to be integrated into the previous product-oriented development process.

In order to meet the challenges, but also the differences between agile technology development and traditional product development, we have developed a model that provides a consistent separation between tech-oriented and product-oriented development. Moreover, the presented model is based on the practical experience of the authors.

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In contrast to the basic considerations of Schulz et al. (2000), we foresee a deliberate methodological and organizational separation between technology development (Tech-Streams) and product development (shortened Product Development). The essential connection between the two domains is the technology transfer in the pull principle: new technologies are developed from the Tech-Stream domain to production maturity and can then be integrated into the development of a specific product. Crucial to the use of new technologies is the strategic matching of the tech roadmap and the portfolio strategy. In the sPD, the product characteristics are determined in the so-called definition phase, which, compared to previous product development models, can be significantly shorter before the start of production. Based on the characteristics of the domains, we propose a basic agile orientation within the Tech-Streams in order to appropriately utilize the advantages of agile methods in this innovation domain, which is mainly characterized by uncertainty. Although the circumstances are similar to the much-described early stages of a classic PD (Albers et al., 2019b; Boehm and Turner, 2005; Schuh et al., 2017a; Project Management Institute, 2017), these streams differ significantly from this phase. Although the Tech-Streams are in principle preceding the actual product development (sPD), no product-specific development takes place. Furthermore, the activities of the TS run parallel to the sPD, which means that results from the TS can also be integrated at later stages in the product-oriented development. The sPD is reduced to concept work and validation and is oriented towards the established and optimized processes. Accordingly, the basic methodological framework here is traditionally oriented.

In the end, this division can significantly contribute to increasing the flexibility of vehicle development: By shortening the sPD, a stronger market and customer focus can be realized while at the same time maintaining the usual high level of quality standards. Due to the detached technology developments, the focus can be on the development of new and radical innovations without product-based limitations restricting the solution space at an early stage. Summarizing, the approach offers the following benefits: On the one hand, new and changing challenges can be better addressed and the life cycles as well as the development cycles can compete with external constraints, e.g. from the consumer industry. Strategy (company, design, product, ...) will also be integrated much earlier than before and will fulfil its cross-sectional function even more effectively. For example, the core process of styling development can anticipate technological changes at an early stage and can be initiated in principle even before the product is defined (i.e., start of the sPD). This makes it possible to start the intensive and necessary styling iterations in a targeted manner at the start of the project.

The model presented is intentionally kept generic in the first instance. On the one hand, this enables better adaptation to company-specific requirements and provides the adaptation to other branches besides the automotive sector. On the other hand, we have deliberately focused here on a superordinate view on the methodological level: the presented approach can and should be considered in much greater detail, also with regard to other specific areas such as innovation management. Nevertheless, the detailed design options of the model are so extensive that they cannot be further detailed in this publication.

Our further research focuses on more detailed investigations regarding the adaptation of the model to a specific use case. By applying the approach to different examples and conducting case studies, empirical values are to be collected and based on this, an application guidance is to be created.

A particular research focus will be on the methodological characteristics within the two domains. In this context, the early stages of the sPD, i.e., the product definition phase and the design-technology convergence (as an essential part of conception), represent critical aspects that will be crucial for the successful application of the approach. This is due to the fact that the central findings and requirements that ultimately determine the product design and functions converge in these process sections of the sPD. Here, a support for the decision between agile and traditional method use within the sPD is developed. Development complexity is examined more closely as a key decision factor.

In order to be able to apply the model, changes in the organization and the development environments are required. Which framework conditions should be changed in order to be able to implement the distribution of accountability and responsibility in an organizational sense will be a further point of investigation.

Evaluation of this model is planned primarily in the highly complex development environment of the automotive industry, so that adaptation to other industries with similar challenges is straightforward, providing a general approach to maintaining competitiveness in a volatile environment.

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