Customizing the Product Life Cycle and its Management for the Optimal Handling of Digital-Physical Products within the Railway Industry

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Abstract

Competitive products are considered as an essential source of corporate success, which is why their continuous development plays a decisive role. Thereby, diverse product innovation results from the integration of digital solutions in physical products. Such so-called "digital-physical" products are hybrid products, meaning neither purely physical nor purely digital, in which information technology is an integral component and plays a significant role in determining the functionality of the product. Digital-physical products enable companies to use new sales strategies, services and business models along the product life cycle to ultimately increase the product's sales. This creates various opportunities outside of product development, especially for sectors such as the railway industry, whose products are required to have a long service life. At the same time, this affects the management of the product along the life cycle and leads to a change in company-specific processes, concepts and models. Particular attention is paid to product management, which is responsible for controlling and planning the activities of a product. Despite the obvious changes caused by digital-physical products, many companies still use their previous concepts and models like the life cycle model in product management and only adapt them inadequately to the new circumstances. This can result in ineffective and inefficient management of products. Researchers have recognized this importance and are therefore focusing on adapting life cycle concepts for the purely digital world. However, little is known about the discussions around adapting life cycle concepts for the transition between physical and digital worlds, especially outside of product development. Therefore, the aim of this study was to explore the influence of digital-physical products on the market phase of the classic product life cycle model and the product management as well as product managers. Specifically, the product life cycle model within Siemens Mobility GmbH (Business Unit Rail Infrastructure) and its product management were to be adapted to digital-physical products. In this study, the inductive-qualitative research approach was used, and the case study served as the research strategy. The case study was well-suited for this study as it was necessary to delve deep into the subject matter to gain an understanding of the benefits of digital-physical products and to identify and analyze the impact on the traditional product life cycle and product management. Expert interviews and focus groups were used as data collection methods to benefit from the personal experiences of the experts, most of whom work with digital-physical products, and thus generate knowledge together. With the help of these methods, the perspectives and experiences of the experts in this field could be revealed and understood in order to achieve the objectives of the study.

As a result, the research has shown that digital-physical products have a significant influence on the classic product life cycle and that a change in the way these products have been handled so far is necessary. In this context, considering the boundary conditions of the railway industry and the aforementioned company, the product life cycle model was expanded to include an integrated digital cycle within the product life cycle and a new role, the digital product manager, was introduced. Furthermore, as a result, the previous product management was organizationally supplemented by a digital portfolio in order to be able to optimally manage digital-physical products. The study thus provides a scientific contribution on the correlation between digital-physical products and the theory of the product life cycle model. The previously missing understanding of how digital-physical products interact within the framework of the product life cycle model as well as its impact on product management was addressed in this thesis. In this way, a contribution was made to the product life cycle theory by mirroring and integrating the nature and characteristics of digital-physical products. The findings and changes resulted in a product life cycle model and product management adapted for digital-physical products. In practice, the study helps to better structure the often-reactive behaviour of a product manager in relation to these products. The orientation towards a second cycle that focuses on the digital part of a product helps with strategic decision-making and roadmap planning in practice.

Declaration

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Worcester and is original except were indicated by specific reference in the text. No part of the thesis has been submitted as part of any other academic award.

The thesis has not been presented to any other education institution in the United Kingdom or overseas. Any views expressed in the thesis are those of the author and in no way represent those of the university.

Signed:

Vikrant Rampal

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Abbreviations

AI	Artificial Intelligence
APM	Asset Performance Management
AR	Augmented Reality
B2B	Business to Business
B2C	Business to Consumer
CENELEC	European Committee for Electrotechnical Standardization
CEO	Chief Executive Officer
CPO	Chief Product Officer
HRM	Human Resource Management
IIoT	Industrial Internet of Things
IoT	Internet Of Things
IPM	International Product Manager
IT	Information Technology
LCC	Life Cycle Costs
MTBF	Mean Time Between Failure
NPM	National Product Manager
PLM	Product Life Cycle Manager
PLM-D	Product Life Cycle Manager Digital
PLM-S	Product Life Cycle Manager Sales
PLM-T	Product Life Cycle Manager Technology
PM	Product Management
RI	Rail Infrastructure
R&D	Research and Development
TA	Thematical Analysis
USP	Unique Selling Proposition
UX	User Experience

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1 Introduction

This chapter provides an overview of the present study including the research context and research gap. Furthermore, the research aim and the research questions to be investigated and the structure of the study are presented. The overall objective of the study is to close the current knowledge gaps in the literature on the relation between digital-physical products and the product life cycle model. In the context of the railway industry, firstly the characteristics and influence of digital-physical products along the product life cycle are investigated. Secondly, the characteristics of digital-physical products in the context of the traditional product life cycle model are investigated. Finally, the effects on product management are examined, and optimization potentials for dealing with digital-physical products are derived from a product management perspective.

The chapter is divided into six sections. The research context is presented first (section 1.1) followed by a description of the research problem (section 1.2). In addition to the research problem, this section also describes the research gaps in the literature. Then, the research aim and questions are presented (section 1.3). Next, the rationale for this research is explained (section 1.4) and an overview of the research methodology used here is given (section 1.5). The chapter concludes with the outline of the overall structure of the thesis (section 1.6).

1.1 Research context

1.1.1 Introduction to product management

Offering competitive products is the basic prerequisite for the economic success of companies. However, this can only be ensured in the long term if customer-oriented products are developed, successfully launched on the market, and their product lifecycle is optimally designed subsequently (Hecker, 2012). This service is usually provided in the form of products. Accordingly, products are seen as a major source of corporate success and great importance can be attached to them and their management, the so-called product management (Sendler, 2013). In a narrower sense, a product refers to a tangible good, but today the term product is often used for both tangible and intangible goods (services). Thus, actually any tangible or intangible good that serves to satisfy the consumer's needs is covered by today's concept of product (Bruhn & Hadwich, 2017). Everything that is offered on a market and, that the customer can acquire, use, experience, consume or interact with, is a product.

The concept of product thus includes services, people, places and even ideas in addition to material goods (Bruhn & Hadwich, 2017). The main department responsible for managing products is the aforementioned product management, whose approaches and management concepts are widely used in many organizations. (Aumayr, 2019). Among other things, product management provides information and facts from the market, analyses competitive products and derives strategies for the product with the help of business analyses. Furthermore, it acts as a coordination point between other departments such as marketing, sales, manufacturing and development. Product management includes the planning and control of the products and services to be marketed and thus bears the responsibility for the respective products and product success (Matys, 2018).

To ensure efficient and effective management of products, various concepts and approaches exist within product management, such as the management of business models, decision-making processes and life cycles (Bruhn & Hadwich, 2017). These concepts map the entire design process from different perspectives and represent procedures for successfully leading the product management organization in practice. For example, product management operates in a dynamic environment and has to adapt to changing framework conditions again and again. The life cycle concepts take a time perspective and help to become active as a strategic analysis and forecasting instrument for key events. Within the life cycle concepts, the product life cycle represents the classic form of application in business administration. This so-called product life cycle ranges from the idea for a new product to product specification, development, market launch, distribution and the so-called phase-out, the withdrawal of a product from the market (Gaubinger, 2015). The concept of the product life cycle can be seen as an important tool of strategic management, providing information about market development, customers, and position in relation to the product (Biermann & Erne, 2020). In the literature, the classic form of the product life cycle is understood as a division into five phases (introduction, growth, maturity, saturation and degeneration phase), each of which includes different and heterogeneous tasks (Matys, 2018). However, due to external requirements such as society and politics as well as internal requirements such as pricing policy and service level, the product life cycle can vary greatly in content and develop different variants. These and many other factors determine the character of a product life cycle in the respective industry, and even in the respective company (Raubold, 2011). Similarly, Guiltinan et al. (1995) already stated that due to the high heterogeneity of the product life cycle, it is advisable to focus on a specific industry or feature.

1.1.2 New opportunities through digital-physical products

In addition to the aspects mentioned above, the diversification of a company and that of the product life cycle model is extended by the increasing number of digital components in a product (Hendler & Boer, 2019). A so-called digital-physical product, also known as smart product (Yoo et al., 2012) or hybrid product (Porter & Heppelmann, 2014; Novales et al., 2016), refers to a tangible object or device that combines physical components or features with digital capabilities or attributes (Roecker & Mocker, 2018). In doing so, the product integrates both physical and digital aspects to provide enhanced functionality, interactivity, or connectivity. According to Novales et al. (2016) and Roecker & Mocker (2018), the digital aspect of these products includes software, algorithms, data processing and connectivity that enable them to perform various tasks and to communicate with other devices or systems and their environment. The products can use technological approaches taken from the Internet of Things (IoT), artificial intelligence (AI) and cloud computing to enhance their functionality and adaptability. One of the criteria for defining a digital-physical product is understood to be the integration of the physical and digital components: "*There must also be integration between the physical and digital components. Purely digital versions of physical products (e.g., a digital PDF version of a magazine) thus do not constitute digital-physical products*" (Roecker & Mocker, 2018, p. 10). Examples of such digital-physical products are networked household appliances or sports shoes that track training through a chip and send the information to a smartphone. Accordingly, Porter and Heppelmann (2015) argue that IT is transforming products and increasingly integrating into the product itself. This change opens up new potentials for companies (Novales et al., 2016).

Digitally refining existing products leads to changes in market structures and offers enormous opportunities for companies. It affects the development and marketing of products as well as the design of new business models (Hendler, 2019). New technological possibilities, such as the networking of intelligent products even during their use by customers, are expanding the topic area from product development and manufacturing to the aftersales and service area (Gentner & Oßwald, 2017). According to surveys by bitkom in 2020, the business model is changing in more than every second company as a result of digitalization (Horvath & Michel, 2016). The clever combination of big data and one's own core competence is already opening up new business models tailored to the target groups in most companies. Within the company, the use of digital technologies also creates great opportunities to increase the efficiency and productivity of employees, for example with the help of collaboration tools for customer or employee communication (Porter & Heppelmann, 2015).

Meanwhile, product management experts such as Aumayr (2019) and Bahrenburg et al. (2019) agree that the responsibility of dealing with the new opportunities can be assigned to product management. Product management makes a decisive contribution here, above all by recording new customer requirements for basic technologies, but also by consistently pursuing internal, innovative ideas (Pichler, 2021). In addition, the product manager is suited to leveraging potentials delivered by IoT through his or her autonomous actions within the company (Aumayr, 2019).

Although the integration of digitalization in a company increases complexity, it also seems to be the remedy of the future (Hoffmann, 2020). This is also the case in the area of rail-based mobility. Because it is precisely in this area that digital-physical products should bring about a positive change (Harms, 2017). Hardly any other industry is currently as much in the spotlight as the rail industry. The debate about climate-friendly mobility is leading to a real push in the industry, and digital-physical products play an essential role in this.

1.1.3 The influence of digital-physical products in the field of the railway industry

On the one hand, it is now common knowledge that rail transport is much more environmentally friendly than air or car transport, but on the other hand, its reputation is repeatedly called into question by delays or even complete train cancellations. Over the next few years, the industry wants to double the number of passengers and also bring more freight traffic onto the environmentally friendly railways (Neumann & Krippendorf, 2016). In order to be able to achieve this overarching goal, the global markets of the rail industry have changed fundamentally in recent years and have been growing steadily for years (Neumann & Krippendorf, 2016). The main drivers can be traced back to the higher investments in infrastructure by countries resulting from climate change and the opportunities opening up through digitalization (Pfäfflin et al., 2020). A feasibility study, initiated by the Federal Ministry of Transport (2020), has shown that rapid implementation of digitization measures will also bring immediate improvements in some areas. All the necessary technology building blocks are already in place, what is still missing is the adaptation to their specific purpose. Thus, digital-physical products are moving more and more into the focus of manufacturers. Reliability, energy efficiency and operating costs are to be positively influenced (Liu & Yan, 2018). For example, there are switch sensors for remote diagnosis as well as fibre optic cables in the track bed for locating animals and cable theft. Furthermore, there are sensors for train detection which, in addition to their actual task, provide further data to the operator and manufacturer.

In addition, digital-physical products make it possible to collect data about the product itself, the environment and the customer, from which further benefits can be derived for the manufacturer and railway operator. This corresponds to an essential aspect, as data is the raw material of the future and forms the basis for tomorrow's developments (Brauckmann, 2019). Consequently, companies in the rail industry continue to expand their business from product to service, as innovative trends in mobility are emerging due to the new possibilities. The digital enrichment of new functions and capabilities in physical products results in a change of market structures and business models (Liu & Yan, 2018). At the same time, the new opportunities brought about by digital-physical products present companies with challenges that have been insufficiently illuminated to date and have a direct impact on the management of products along the product life cycle (Gentner & Oßwald, 2017; Bahrenburg, 2019).

1.1.4 Challenges posed by digital-physical products in the railway industry

Despite the immense advantages and opportunities offered by digital-physical products, there are also challenges in dealing with these products. In the context of advancing digitalization, companies will consider digital business models in their medium- and long-term strategies, but these must be adapted to the existing boundary conditions and processes as well as models, which needs to be tailored to digital-physical products. In this context, two main challenges will be described.

The handling of digital-physical products

One of the challenges is the prevailing uncertainty in dealing with digital-physical products, because competitors or new players from outside the industry can come onto the market at any time with a smart object and make your own product look old (Bruhn & Hadwich, 2017). Both the pressure and the lack of experience with new business models in different phases of the product life cycle or the unclear responsibilities within a company regarding the digital aspect of a product lead in practice to an intuitive and unstructured approach (Aumayr, 2019). This statement is supported by Bahrenburg (2019, p. 12), who argues that "*Today's business processes are still very much shaped by mechanical design and do not take sufficient account of the trend towards smart products [...]. Here, on the one hand, adapted PLM [Product Life Cycle Management] concepts will be necessary [...]*". A study conducted by BearingPoint, Karlsruhe University of Applied Sciences, Prof. Dr. Jörg W. Fischer and the Steinbeis Transfer Centre for Computer Applications in Mechanical Engineering, showed that around 71% of companies are only insufficiently prepared for the increasing product and production complexity.

In addition, the classic stand-alone product management solutions would reach their limits in the course of the immensely increased product complexity. According to Bahrenburg (2019), in order to be able to exploit the potential offered by digital-physical products, the company does not need to develop a digitization strategy, but rather "*it is a matter of aligning the corporate strategy and processes in such a way that their company can exist and be successful in an increasingly digitized world in the first place*" (Bahrenburg, 2019, p. 1).

Considering the market phase

In addition to the high safety requirements, it is also the market entry barriers as well as long life cycle durations that pose a major challenge. In some industries, such as the railway industry, life cycles of several years and decades are common, while for other products they last only a few days or months (Raubold, 2011). The main reason for this is the high investment required for the development and production of these products. Manufacturers need product life cycles of several years to ensure sufficient profitability and to recoup the high investments through product sales (Biermann & Erne, 2020; Chandra, 2019). For example, transport infrastructure products (equipment for securing and directing traffic) have an average life cycle of around 25 years. Due to the long product life cycles, digital enrichment of products must also be possible outside of development. This is because, on the one hand, shortening the long product life cycles is not wanted by the operator and, on the other hand, new developments at too short intervals would not be economical for the manufacturers (Chandra, 2019; Lui & Yan, 2018). In the literature, most approaches regarding digital-physical products and the product life cycle focus on the optimization of new development (Sawalsky, 2013; Hoffman, 2020), but the investigations of optimization potentials hardly refer to existing products, i.e., current products in the market phase. This phase usually covers the period from market launch to the product's withdrawal from the market at the time of the sales stop. This ignores the fact that newly developed products in this industry must be in the market phase for many years. It is these products that generate the most revenue for suppliers, compete fiercely and define the company (Brockhoff, 1999; Bruhn & Hadwich, 2017). In the case of complex technical systems that are supposed to offer a "*long service life, high availability, safety and reliability, such as railway traffic control systems, the ownership costs many times exceed the costs of its acquisition*" (Ciszewski & Nowakowski, 2018, p. 30). Therefore, a long market phase is prescribed for product manufacturers in this area (Ciszewski & Nowakowski, 2018). Nevertheless, society and politics are demanding innovative solutions as quickly as possible, so that digital-physical products with their advantages and resulting changes in the market and business take center stage (Liu & Yan, 2018).

The present research is to start precisely in the environment of the challenges mentioned. On the one hand, the research should take place in the context of the product market phase, since it is precisely in this phase of the product life cycle that changes can be better identified. On the other hand, the changes in product management and its product life cycle concept are to be derived in the context of digital-physical products. With the help of digital-physical products, it is possible to achieve results in every phase of the product life cycle. It is necessary to understand which added value digital-physical products deliver in the individual phases of the product life cycle and how the management of these products must be adapted in order to be able to exploit the entire potential. This aforementioned consideration is to take place in the researcher's direct environment, namely at the global manufacturer for railway infrastructure products, Siemens Mobility GmbH Rail Infrastructure.

1.1.5 The opportunities for Siemens Mobility in the railway industry

Siemens Mobility GmbH is a business unit of the Siemens Group and one of the leading players in the rail industry. The business units within Siemens Mobility, such as Rolling Stock and Rail Infrastructure, offer a holistic product range for all vehicle and infrastructure requirements. The aim of Siemens Mobility GmbH is to continue to play a leading role in the market and to further shape the mobility of the future (Siemens Mobility, 2022). The rail industry is undergoing a fundamental change, in which the company wants to play a major role in shaping and promoting it. The Rail Infrastructure business unit in particular harbours enormous potential through additional services provided by digital-physical products. For example, this unit is active in predictive maintenance and repair and claims to be the first company in the rail industry with a data analysis center. The study was carried out in the environment of the globally active manufacturer of railway infrastructure products Siemens Mobility GmbH (Business Unit Rail Infrastructure), a leading company in the railway industry, at its headquarters in Germany. The business unit includes the entire value creation of the products from research and development to product management to sales and recycling of the products. The company is considered one of the most successful companies in the rail industry in general and in rail infrastructure especially, alongside competitors such as Alstom and Thales (European Commission, 2019). According to a 2019 study by the European Commission on the competitiveness of the rail supply industry, "*European companies Siemens (EUR 8 billion) and Alstom (EUR 7 billion) are the worldwide leaders in terms of rail industry turnover, only after Chinese CRRC (EUR 30 billion), whose turnover is largely based on its huge domestic market*" (European Commission, 2019, p. 10).

The current figures have continued to increase compared to 2017, as can be seen in Figure 1 in comparison with competitor Alstom.

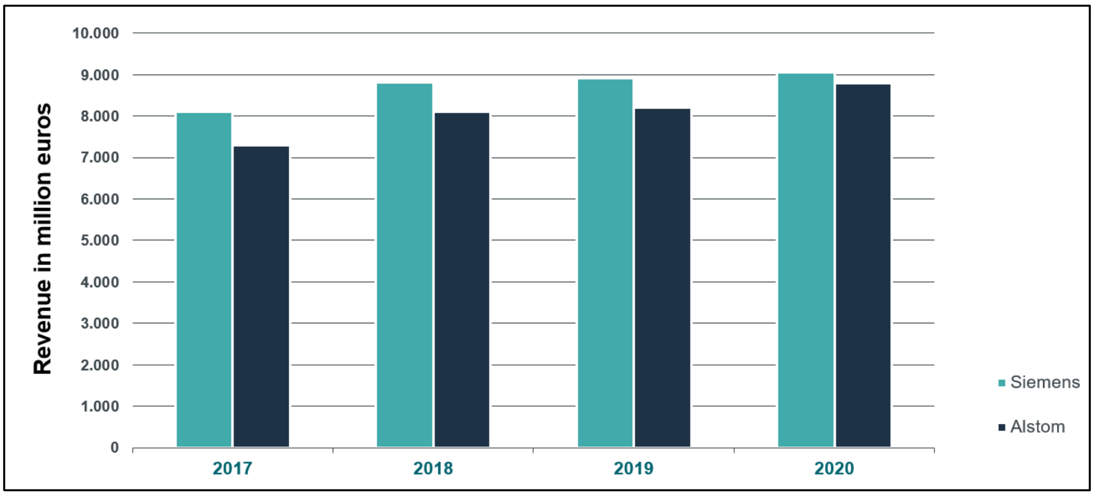

Figure 1: Overview of annual revenues of Siemens Mobility GmbH and Alstom from 2017 to 2020 (Source: European Commission, 2019)

In terms of rail infrastructure, European industry is the world leader here. Siemens is the world market leader with a market share of 40 % (European Commission, 2019). Together with Thales (20%), these two companies alone hold around 60% of the global market share in this segment of rail technology, as shown in Figure 2:

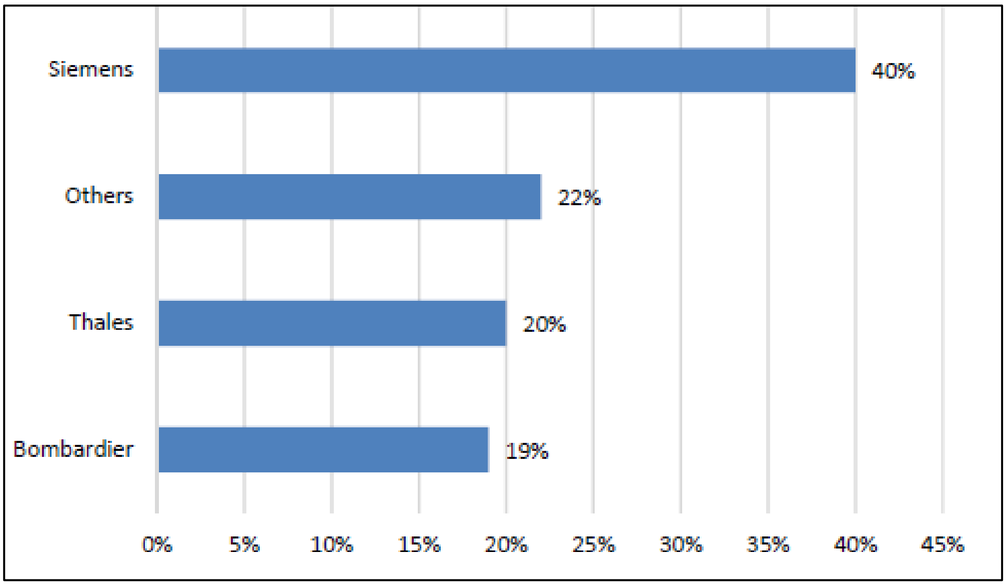

Figure 2: Overview of the market share distribution in the rail infrastructure sector from the year 2019 (Source: European Commission, 2019)

The product portfolio of the Rail Infrastructure Business Unit of Siemens Mobility GmbH contains over 600 products and has a very heterogeneous structure, which leads to a not inconsiderable complexity (Siemens Mobility, 2022).

In addition to the classic wayside products such as track vacancy detection or signals, the product portfolio has been expanded in recent years both in these classic areas with additional products and with new areas, mainly from the software sector. By crossing the classic products with aspects from the software area, additional segments can be covered, and thus new customer groups can be developed. The corporate strategy is geared towards this target, with the product strategy as one of the decisive pillars contributing to the overarching corporate goal. Within the framework of the product strategy, the introduction of digital-physical products serves the existing segments and opens up new ones, so that a specific clientele can be addressed with which high profitability and margins can be achieved (Siemens Mobility, 2022).

Through direct research in the company, the researcher has access to experts. Therefore, many of the insights that contribute to optimizing product management for digital-physical products were gained from the company of Siemens Mobility GmbH. Many of the solution approaches are reflected to this company after enrichment with further insights from the literature, the industry itself as well as on the comparison of related industries. Many studies have already shown the representative use of a company for the industry, such as those by Wagner & Gassmann (2019), who used Siemens AG as an example to examine the role of companies in sustainability development, or Mertens & Benlian (2016), who discussed the digital transformation in the automotive industry using the example of BMW. These examples from the literature, as well as the market position of the company presented here, underpin the approach of referring to the company presented here as an example for the industry.

1.2 Research problem

The introduction of digital-physical products will lead to increased competition in the rail industry (German Federal Network Agency, 2017). Innovative solutions from the competition can erode market share and ultimately reduce a company's revenues. Companies from outside the industry and start-ups are increasingly entering the sector with digital add-ons, resulting in new competitors along the value chain. In one way these trends threaten the profitability of established companies in the industry and in another way, these trends also offer new growth potential for additional business for these same companies. In this context, the optimal management of digital-physical products takes on a special role, because products are becoming increasingly similar in saturated markets (Bruhn & Hadwich, 2017). Adding digital assets to physical products enables the individualization of service programs and provides them with a unique selling proposition.

Not only does that open up growth opportunities, it also enables stronger customer loyalty (Hermann & Huber, 2013). The successful implementation of customized solutions therefore requires a problem-oriented product management concept tailored to this in order to be able to compete successfully in global cost, quality and time competition (Hermann & Huber, 2013; Aumayr, 2019).

However, studies such as those by Namatherdhala et al. (2022), Hofmann (2020) or Romero et al. (2021) prove that product management needs to change, and it is already changing. It is noticeable that these studies outline the product manager for the digital world and that product management is also designed for the purely digital world. The other extreme in the literature deals with the optimization of classic product management, which is mainly oriented towards physical products (Biermann & Erne, 2020). What remains unconsidered, however, is the study of the adaptation of the product management and its life cycle concepts for digital-physical products. This type of product is described by some researchers such as Hendler (2019) as an intermediate step, which correspond to an essential part of the digital transformation and can determine the future existence of companies (Hendler, 2019; Bahrenburg, 2019; Hofmann, 2020). This makes the efficient management of digital-physical products indispensable for business success, and it is important to understand how these products behave along the product lifecycle in order to ultimately derive actions and make better decisions (Romero et al., 2021). According to Bahrenburg (2019) and Romero et al. (2021), today's processes are not yet designed for digital-physical products, in some cases not even prepared for them. This results in the research problem itself, namely the gap between the strategic vision and the current operational processes (Stark, 2022). On the one hand, there is the strategic vision of a company that is increasingly becoming a manufacturing service provider that links its products with a range of services in order to offer its customers added value through unique problem solutions. On the other hand, however, there are still the previous operational processes and models in the company that still follow an old pattern and are not mapped according to the company's strategic vision (Bahrenburg, 2019). Proven concepts of product management therefore need to be rethought in order to implement the company's strategic vision and take advantage of the growth opportunities through digital-physical products (Aumayr, 2019). This missing link can be observed in the literature as well as in practice.

1.2.1 Research gap

In general, the current literature covers the changes of digitalization from mainly two views. The first involves the discussion of digitization strategies for the entire company (Appelfeller & Feldmann, 2018; Multerer, 2019) and the second involves the changes along the value creation processes of a company (Kirchner et al., 2018). An analysis of the effects and changes of company divisions that are only indirectly involved in value creation has been insufficiently investigated so far (Gentner & Oßwald, 2017). For example, product management and its concepts, which have the planning and control of products along their life cycle as their core task. In the literature, an increasing number of discussions focus on the digitalization and optimization of product management and its life cycle concepts with a wide variety of thematic focuses, such as software product management (Fricker, 2012) or the influence of artificial intelligence (Wang et al., 2021). However, the majority of studies focuses primarily on optimizing and changing product development (Gmelin & Seuring, 2014; Egbert et al., 2020; Hendler, 2019), or focus on product management for purely digital products (Hoffmann, 2020). In this context, Gentner & Oßwald (2017) or Hoffmann (2020), for example, discuss the product manager for the digital world. However, this does not take into account the examination of the adaptation of product management and its concepts and people in the transition phase from physical to purely digital products, i.e., the focus on digital-physical products (Bahrenburg, 2019). Although there are already initial approaches in which digital-physical products are placed in relation to companies (Porter & Heppelmann, 2015) or Industry 4.0 is placed in relation to product management (Gentner & Oßwald, 2017), this is not done in relation to the concepts of product management, such as the product life cycle. Using this, companies can, for example, gain insights into the product life cycle and accordingly introduce appropriate adaptation measures or take suitable marketing measures throughout the product life cycle (Matys, 2018). The product life cycle theory therefore supports companies in maximizing profits through the efficient management of products (Stark, 2022). In order to gain the maximum benefit from digital-physical products, it is necessary to explore how digital-physical products behave within the product life cycle model. The research on how these products interact within the framework of the product life cycle model can then be used to derive organizational changes in product management, and all the way up to the company. This aspect is supported by Schicker & Strassl (2019) and also Bahrenburg (2019), who call for a more in-depth analysis of PLM concepts in the context of digitalization. After all, the result of the so far insufficient scientific research on digital-physical products in the context of product life cycles is often the application of intuitive procedures for concretely upcoming issues in practice (Schicker & Strassl, 2019).

Product managers act intuitively in the market phase domain and are subject to "reacting" instead of "acting" (Matys, 2018) and act according to familiar patterns designed for physical products (Bahrenburg, 2019). As a result, the full potential of digital-physical products is not realized. The consequence of inadequate management of digital-physical products can be the loss of market share and revenue losses, despite technical innovation (Aumayr, 2019). The management of products is mainly responsible for the successful profitability of a company (Stark, 2022). Therefore, it is necessary to rethink the product life cycle model as well as product management and, if necessary, adapt it to digital-physical products (Stark, 2022). This is because the highest possible profit can be achieved in every phase of the product life cycle through optimal management of digital-physical products.

From the perspective of digital-physical products, previous studies have mostly focused on the impact of IT on business processes, while "*the transformative impact of digital technologies on [...] products has remained surprisingly unnoticed in the [...] literature*" (Yoo et al., 2010, pp. 724). In line with the early stage of research on digital-physical products, the focus has so far been on defining, categorizing and classifying digital-physical products (Herterich & Mikusz 2016; Püschel et al., 2016). Furthermore, in this context, the literature almost exclusively discusses the development process of digital-physical products as well as the increasing complexity of the product portfolio. "*Because digital products (so-called smart products, smart services) are now being added to the core products and services that characterized a product portfolio together with hybrid service bundles in times before digitalization. [...]. These factors increase the complexity of the portfolio and thus also the risk of misallocations and misinvestments*" (Schicker & Strassl, 2019, pp. 3). To further break down this complexity, it is significant to explore the influences of digital-physical products on other areas. The need for further research is supported by Novales et al. (2016, p. 9), who argues that "*Empirical research analyzing digitized product manufacturers can help further classify and categorize the challenges and to formulate propositions relating [...] management challenges*". Authors such as Baumers et al. (2020), Zheng et al. (2019) and Porter & Heppelmann (2015) also agree with this aspect and call for further research and investigations regarding digital-physical products. As a result, a more in-depth examination of these products in relation to other corporate areas such as product management is appropriate to be able to understand the complexity of these products holistically. This is because the approaches that have not yet been sufficiently researched also leave questions unanswered in practice. "*Only a deeper understanding of the opportunities and challenges of digitized PSS [Product Service Systems], grounded in theoretical and empirical research, will provide the deeper insights needed to guide companies through this transition*" (Lerch & Gotsch, 2015, p.56).

A gap thus arises from the lack of knowledge about digital-physical products themselves, their understanding of how these products behave within the product lifecycle, and their implications for product management and product managers. In this context, Aumayr (2019, p. 133) argues that "*not losing sight of the essentials is therefore a major challenge for many professionals and companies are not sufficiently aligning the product lifecycle with the digital future*". Figure 3 illustrates the relationship between the aspects of digital-physical products, product management and product life cycle in the context of this study:

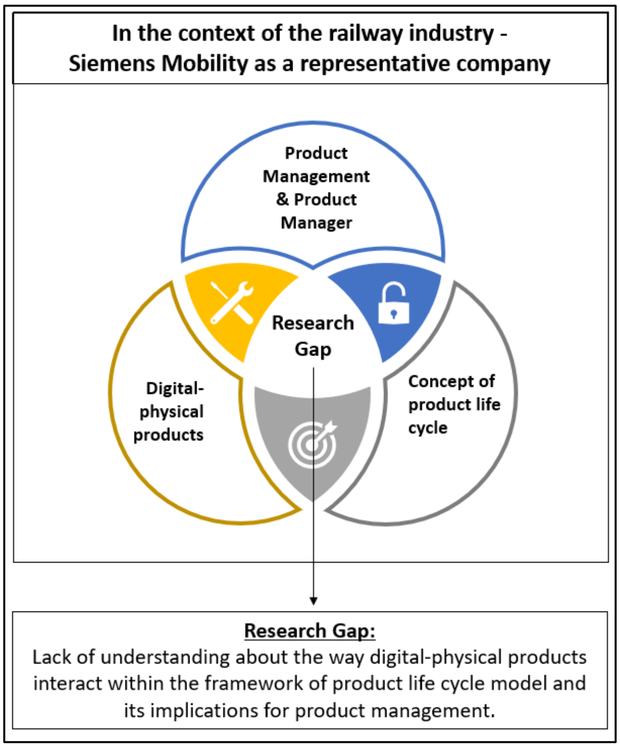

Figure 3: Classification of the thesis with a summary of the research gap (Source: Authors own illustration)

In summary, there are gaps in both theory and practice in dealing with digital-physical products and their product management. This study therefore aims to contribute to the discussion of the impact of digital-physical products on the product life cycle model and the associated digital product management.

From a practical point of view, the internal product life cycle model and the organizational product management of Siemens Mobility GmbH are theoretically extended to include digital-physical products. Furthermore, the project is mirrored on products of the transport infrastructure, more specifically on products of the railway infrastructure, as this offers a very good opportunity to show optimization potentials for existing products and processes due to its mature development and the high complexity of the long-lasting products.

1.3 Research aim, questions and objectives

The aim of the thesis is to investigate the relation between digital-physical products and the product life cycle model as well as product management. Specifically, the product life cycle model within the railway industry needs to be further developed in such a way that the characteristics of digital-physical products are mapped. In this way, recommendations for the management of digital-physical products in the individual phases of the product life cycle can be derived. In addition, the influence of digital-physical products and the change of the product life cycle model on the existing product management will be investigated. The study will thus make an important contribution to the currently discussed digital product management and improve the current scientific discussion in this research area.

Research questions

Based on the identified research gap and the research aim the following research questions and objectives can be derived:

- What influence do the characteristics of digital-physical products have on the product life cycle model in the railway industry?

  The research question identifies and analyses the added value of digital-physical products for companies in the railway industry. By answering the research question, a contribution is made to the phenomenon of digital-physical products in general, as their characteristics and influences outside of product development are investigated. Specifically, a contribution is made to the influence of the products on the individual phases of the product life cycle, which ultimately lead to a reduction in complexity in dealing with these products.

- How do digital-physical products interact within the framework of the product life cycle model in the context of the railway industry?

  Answering the research question will provide an understanding of the way digital-physical products interact within the product life cycle model. An understanding of this is an important factor for market success in order to be able to meet the future requirements of customers. Answering the research question provides scientific knowledge about the connection between the digital-physical products and the theory of the product life cycle model.

- How do the identified changes within the product life cycle model affect the product management?

  In answering this research question, the researcher reflects the changes in the product life cycle model caused by digital-physical products on product management. In doing so, the researcher contributes to the young field of digital product management and presents a product management adapted for digital-physical products. In contrast to previous research, the change in product management is derived from its concepts, and not from corporate strategy as before.

Research objectives:

- To investigate the influence and characteristics of digital-physical products on the product life cycle by expert interviews in the company.

- To further explore the interaction of digital-physical products within the framework of the product life cycle model through focus groups within the company.

- To examine the impact of the modified product life cycle model on the product management through focus groups within the company.

1.4 Research rationale

The motivation for the research can be categorized into three interrelated ways of looking at it. The first motivation for investigating the topic relates to the research context. The digital transformation of products is causing an important shift of paradigm in many industries, including the rail industry (German Federal Network Agency, 2017). The railway industry is facing major challenges due to the current discussion on climate change and the ongoing digitalization that is changing the environment. The development of digital-physical products is one of the levers for competitive capabilities, but another one is the optimal management of digital-physical products along the entire product life cycle. This is because management has a direct influence on the success of a product since it has an overall view of the market, the state of development, production, and the subsequent marketing strategy (Hermann & Huber, 2013). In addition to dealing with the new products, it is also the digitalization of the company processes themselves that makes the product manager’s task increasingly interdisciplinary and thus also more complex across all phases of the product life cycle.

The product manager, as an entrepreneur in the company, should control this increasing complexity and also open up new business potential. The entire environment of product management is changing, and this research is intended to simplify precisely this change and complexity of the whole. From the researcher's point of view, the adaptation of the previous product life cycle model to the new world is therefore indispensable in order to be able to continue to operate successfully in the future.

A second important motivation for this study is to investigate digital-physical in the use phase, rather than in the context of product development. The reason is that the literature almost exclusively discusses the optimization of the design and development process of digital-physical products. The general solution is usually to shorten product life cycles so that new features can be integrated with each new development. However, as described in section 1.1.4, this is not always possible in areas of rail infrastructure. There are hardly any studies that focus exclusively on the use phase, examine the transition between physical and digital products and consider their effects, and provide recommendations for action for companies and product managers.

The final reason for the selection of this research topic relates to the fact that the author is working as a global product portfolio manager and experiences the challenges described as well as the lack of adaptation of the model every day at work. As a global portfolio manager, the author, together with his team of product managers, is responsible for the management of physical and, in the future, also digital-physical products over the entire product life cycle and the creation of product strategies and roadmaps of about four different production lines.

The existing management guide for products is not adapted to the new requirements and possibilities of digital-physical products, so that the identification of new potentials is not or hardly taken into account, and a non-standardized process leads to increased additional work. The full potential of digital-physical products is not exploited because structures and processes are not adapted. Nevertheless, top management is under increasing pressure to develop new markets and derive new business models. Thus, uncovering and structuring optimization potentials in the market phase of a digital-physical product can lead to sales increases, securing market shares and quality improvements. By conducting the study, the author could gather important insights in his field of work and implement them if necessary.

1.5 Research methodology and approach

The paradigm of constructivism used for this research assumes that the researcher seeks to understand and interpret the place in which the person lives and works (Creswell, 2013). It also assumes that reality is constructed only through the relationship between our mind and the outside world (Hopf, 2016). Constructivists therefore "*believe that our understanding of the world depends on our interpretation which is coined by our language and social environment*" (Reber, 2016, p. 112). This assumption of the philosophical paradigm is essential as it informs the entire research design and findings of the research process (Easterby-Smith et al., 2002).

In this research, a constructivist approach was adopted which aims to co-construct knowledge about digital-physical products and its influences on the product life cycle model and product management. In addition to literature research, the data collection methods of expert interviews and focus groups were used to benefit from the personal experiences of the experts, most of whom work with digital-physical products, and thus jointly generate knowledge. Through the aforementioned methods, the perspectives and experiences of experts in the field could be revealed and consequently the researcher could hear and understand their views to achieve the objectives of the study. Furthermore, the experiences of the research participants were also based on individual subjectivity, thus emphasizing the importance of personal interpretations (Meyer, 2009). This study used the inductive-qualitative research approach. The case study served as a strategy as it helps to look at a case from multiple perspectives in order to understand and explain it in its particularity. A case study allows both context and process to be analyzed and helps to translate the particular into the general. The case study research design fits well with this research because the researcher needed to delve deep to gain an understanding of the benefits of digital-physical products as well as understand and analyze the behaviour within the product life cycle and product management.

A single case study is justified by addressing a critical or typical case and can make a significant contribution to testing, disproving, or extending existing theoretical frameworks (Elam et al., 2013). In addition, the single case study is applied to typical or representative situations for a large number of cases to be investigated. The results found there allow conclusions to be drawn for other situations, or as in this case, for other product management organizations and concepts. This research strategy is in line with the philosophy of constructivism and the qualitative-inductive approach that underlies this research.

1.6 Structure of the thesis

This thesis is divided into a total of six chapters. **Chapter 2** provides an overview of the relevant background literature related to product management, the associated product life cycle and digital-physical products. The chapter addresses basic definitions of the complex field of product life cycle and digital-physical products, highlights some important research, points out the research gap and identifies the facilitating and inhibiting factors of product life cycle. The research methodology is part of **Chapter 3.** The chapter begins with the philosophical assumptions and ontological as well as epistemological approaches for this research. It then discusses the qualitative research method using the case study approach. This chapter also explains and justifies the data collection methods used in this research, namely semi-structured expert interviews and focus groups. This is followed by a description of the data analysis with thematic analysis as the analytical approach. The chapter also discusses the main ethical considerations associated with the study and thus concludes this chapter. **In Chapter 4**, the data analysis results of the qualitative data analysis and findings are summarized for the reader. The qualitative data obtained from the data collection is presented through illustrative quotes to show the range of participants who contributed to the study. **Chapter 5** discusses the findings of this research and presents the condensed answers to the research questions. Finally, the thesis offers a general conclusion in **Chapter 6**. The conclusion summarizes the main findings from the case and highlights the unique contribution of this research. This chapter reflects on the theoretical and practical implications of this study by summarizing the research questions, outlining what the research has achieved and highlighting the findings of the empirical work. Towards the end of the chapter, some recommendations are made, and the chapter concludes with a discussion on the limitations of the research.

2 Literature Review

Chapter 1 gave an introduction to the topic and described the objective of the thesis. However, to make the entire topic more understandable and the classification more comprehensible, chapter 2 has the task of presenting the theoretical basis for the study. The chapter contains the most important definitions and the presentation of previous research work, taking into account the questions to be investigated. In this chapter, the literature on product management, the product life cycle and digital-physical products is summarized, examined, and discussed, and used as a basis for new approaches. However, before product management or the product life cycle are treated in depth, the term product will first be explained in more detail in section 2.1, as there are various interpretations to this term. After the general presentation of the term product, it will be expanded to include digital-physical products. The various definitions regarding this type of product as well as theories and models will be presented and discussed. Section 2.2 then describes product management and product manager in more detail. This is because product management today can be presented as classical product management, but also in different variations of it. After presenting the different variations, the current literature around product management is discussed. The concepts of product management as well as an overview of the different life cycles are addressed in section 2.3. The focus is on the most prominent life cycle concept, namely the product life cycle. The theory behind it is presented and then the current literature on the topic is discussed. The preceding fundamental considerations are mirrored to the railway industry in section 2.4. In this chapter, the concepts and models of product management used in the industry are presented and critically analyzed. Afterwards, chapter 2.5 presents the essential aspects of the previous chapters and discusses the limitation of the literature regarding the topic. At the same time, this section shows the starting point of the research presented here. The final summary of the chapter is then given in section 2.6.

The sections 2.1, 2.2 and 2.3 have been structured in a similar way. At first, a basic understanding of the term and the topic area is suggested. This is placed in the overall context and distinctions are drawn from related terminology. This reinforces the general understanding of the nature of the term. Then the related concepts, models and characteristics are presented. All the subfields mentioned here encompass diverse concepts and models and can be interpreted differently depending on the context. The concepts relevant to this study will be highlighted and explained. This will be followed by the current discussion with regard to the respective sub-area.

Through this discussion, the current literature and gaps and limitations in the field are highlighted. The findings from the literature on digital-physical products, product management and product life cycle are mirrored to the railway industry and compared with other industries. Highlighting the aspects in the context of the railway industry is essential for this study, as this is the framework of the study. Finally, the gaps and limitations of previous research are summarized, and the starting point of this study is defined. The following Figure 4 illustrates the described structure of the chapter once again in simplified form:

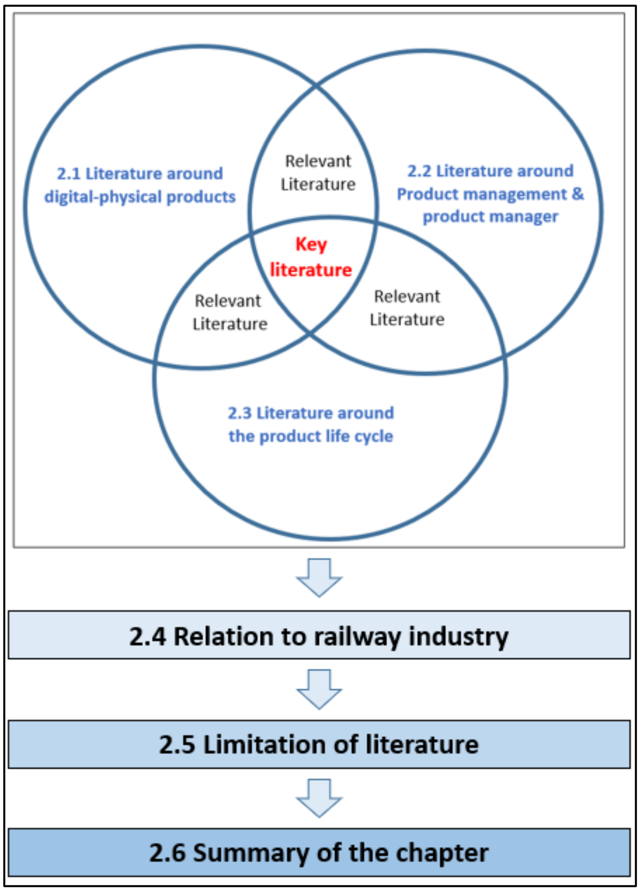

Figure 4: Schematic representation of the structure within chapter 2 - Literature review (Source: Authors own illustration)

The discussion around the individual topics of digital-physical products, product management and product managers as well as the product life cycle are very broad topics and need to be narrowed down systematically. A systematic approach to searching the literature is suitable here, which is based on systematic literature review. This is to identify and summarize the existing literature in a broad area of investigation and to identify key concepts, sources, and gaps in the literature (Jesson et al., 2011). When conducting a literature review to identify research gaps, it is important to systematically review the existing literature to determine what has already been studied and published on a particular topic (Jesson et al., 2011). This approach focuses primarily on the discussion of individual topics.

The definitions and descriptions and/or characterization of concepts, which needs to precede for a general understanding, focus on a descriptive presentation. In this case, the systematic literature review corresponds to the aim of providing a comprehensive overview of the existing literature, identifying gaps or areas for further research and informing the reader about the current state of knowledge on a particular topic (Grant & Booth, 2009). In this so-called descriptive systematic literature review, the focus is thus not on answering a specific research question (Jesson et al., 2011; Grant & Booth, 2009). The process of conducting a descriptive systematic literature review still corresponds to the systematic search, selection and critical appraisal of relevant studies, followed by synthesis and analysis of the results (Levac et al., 2010). Figure 5 below shows an overview of the structured search for the discussion part of digital-physical products, the product life cycle and product management:

	Product Management	Digital-Physical Products	Product Life cycle
Key words	Product Management	Digital-Physical Products	Product Life cycle
plus another term	definition, digital*, railway, influence, life cycle, products, future, concepts, industries	definition, railway, life cycle, characteristics	digital*, railway, influence, products*, future, software
Data bases	EBSCO - Business Source Premier EconBiz wiso - Wirtschaftswissenschaften		
Main journals pee-reviewed	Leading Information System Journals (i.e IEEE transactions on information theory) Leading Management Journals (i.e Journal of international business studies) Leading Innovation Journals (i.e. Academy of management journal)		
Others	Google Scholar Practice-oriented management reviews (i.e. Harvard management review) Library research		
Time Frame	Last 10 years: 2012 - 2022		
Language	English & German		
Number before reviewing the titles & abstracts of the identified studies	118	51	187
Number of studies included	19	20	17

Figure 5: Overview of the conducted systematic literature review (Source: Authors own illustration)

The literature search was initiated by searching for published research papers in various electronic databases using appropriate search terms. This approach identified a large number of journal articles related to the research question at hand. In addition, other search strategies were used that proved effective in discovering further literature that could not be found in the databases. In selecting keywords for search engines and electronic databases, the main terms were derived from the research question, as the selection of specific keywords is crucial to identify the available and relevant literature. These terms were combined with the Boolean operators AND, OR in order to search the literature efficiently and purposefully and to achieve an optimal search result. Electronic searches were conducted in the academic databases Business Source Complete (EBSCO), EconBiz and WISO as well as Google Scholar using the above keywords.

The focus was on leading journals in the field of information systems, management, transportation, and innovation. In addition, the scientific peer-reviewed journals in English and German published between 2012 and 2022 were taken into account. Other sources were collected through library searches for academic books and internet searches for reports from the field and were also included in the study. In addition, in order to also integrate a practice-oriented view into the research, higher rated practice-oriented management journals were included, such as the Harvard Business Review. In addition, a manual search was conducted by checking the references of the studies found and including those studies that seemed relevant in the review. As an example, the search resulted in a number of 118 documents in the field of product management. In order to separate the relevant from the irrelevant literature, firstly, the titles of the articles were checked to see if they were suitable for the purpose of the literature review. Secondly, the summaries and keywords in the articles were reviewed to determine if the articles were appropriate for the study. The articles that appeared suitable were downloaded and the full articles were reviewed. After further review of the content, 19 articles were found to be relevant. The remaining papers were excluded from the review because they either focused on a very specific area (for example, artificial intelligence in product management) or only touched on product management as an example. Although an extensive and comprehensive literature search was conducted, it was not possible to claim to cover all existing publications. Those selected for this study are shown in Appendix A. In the following, the individual but related topics will now be discussed in more detail.

2.1 The different approaches of the product concept

In the following sub-chapters, the concept of product will be examined in more detail and delineated. At first, the different forms of the product concept will be shown and expanded to include the extended product concept. Furthermore, the characteristics of digital-physical products are described and the current literature on this type of product is presented. This subchapter pursues the essential goal of delimiting the inflationary terms used and defining them for this thesis.

2.1.1 Delimitation of the concept of product

To describe the tasks and responsibilities of product management, it is first important to clarify what exactly is meant by a product. Originally, a product was understood to be "*the result of a production process in which the factors of production (human labour, operating resources, materials) are transformed in various combinations into higher-value physical goods that can be measured in terms of value added*" (Gutenberg, 1951, p. 33). This results in a supplier-related and technical concept of product, which understands a product as a physical good with certain properties that consists of clearly definable components and materials (Hermann & Huber, 2013; Geracie & Eppinger, 2013; Kotler et al. 2019). A different perspective is taken by Kleinaltenkamp & Jakob (2013, p. 7), who for the first time defined the product from the point of view of utility: "*Products represent bundles of services whose function is to solve the customer's problems. It is because of them that he seeks an exchange with the provider in the first place, regardless of whether it is consumer, industrial goods or services*". Meanwhile, authors such as Kotler et al. (2019, pp. 217) define the term product in the modern era as "*anything that can be offered to a market to satisfy a want or need*". The differentiated understanding of the product as a material good or as a service is also reflected in the distinction often cited in the literature between the substantial, the extended and the generic product. Bruhn & Hadwich (2017) defines these as follows:

1) The substantial product concept understands the product as a delimited and physical object that satisfies the basic needs of the customer. By limiting the term to physical characteristics, services are therefore not products.
2) The extended product concept understands a service package consisting of a physical product and/or an immaterial service. Here the functional benefit is in the foreground less than the physical tangible object. The extended product is thus created by adding a service to the core product.
3) The generic product concept describes all tangible and intangible facets from which customer benefits arise. Compared to the other terms, the generic product term addresses further benefit categories such as emotional or social benefits.

A further distinction of the product concept can be classified according to the supplier and the customer view, the purchase decision process, and the product organization (Piller, 2000). In the classification according to the purchase decision process, products can be divided into consumer goods, capital goods and customer-specific goods according to the course of the purchase process (Bruhn & Hadwich, 2017).

Closely related to this is the differentiation of products between business-to-consumer (B2C) as a classification for consumer goods and business-to-business (B2B) as a classification for capital goods, as the number of people involved differs significantly in both forms (Bruhn & Hadwich, 2017).

It is striking that the term product can be used and defined differently depending on the perspective from which it is viewed. Depending on the definition, this also results in a different classification of the product in companies. Due to the many different perspectives of the term, it is often used inflationary, which leads to a confusion with other terms such as feature and service (Reichart & Reichart, 2002). The approximation of the concept of product can therefore be done through the common characteristics of the different definitions. According to Heyde et al. (1991), the product concept has the following characteristics:

- A product serves to solve a problem of customers or society.
- It is characterized by a specific combination of functions and properties.
- It is the result of a company's activity to generate profits.
- It is part of the value creation process and is characterized by economic efficiency in production and use.
- It is characterized both by objective, quantitatively measurable variables and by subjective perceptions and evaluations.

The achievement of these characteristics can take place in a wide variety of ways, which is why the concept of product is in a constant state of change. According to Reichart & Reichart (2002), it is therefore not possible to give a uniform, all-encompassing definition of the concept of product as such, as this is always linked to the context. This can be a purely material good, a service or a combination of both (Bruhn & Hadwich, 2017). What is striking in the current discussion, however, is the aforementioned extended concept of product, which plays an important role in this thesis and will be described in more detail below.

2.1.2 The extended product concept

More and more traditional product providers are offering services and the reasons for this are manifold. The reasons for this are manifold. Industrial products are usually characterized by their high (technical) complexity. This opens up additional potential for the manufacturer to offer industrial services along the entire life cycle of the products (Mueller, 2013). In times of intensified competition and saturated markets with increasingly homogeneous products, services are used to differentiate a company from its competitors (Mueller, 2013).

Services are expected to lead to higher customer satisfaction and loyalty, induce switching costs, pave the way for long-term business relationships and ultimately increase company profits by compensating for low margins in the product business (Mueller & Mueller, 2020). Based on an extended understanding of the product, they are to be understood as a bundle of material and services (Mueller, 2013). If products are seen as part of a service, the effect of which leads to a solution to the customer's problem, the task of industrial services becomes clear. The bundling of material goods with services achieves a higher benefit for the customer than the material goods alone and thus lead to an expansion of the marketable service portfolio for the provider (Mueller & Mueller, 2020). Depending on whether the tangible good and the service are offered independently or as a combination of product and service, the so-called service bundle, a distinction is made between the term's "product", "service bundle" and "service" (Bruhn & Hadwich, 2017). Figure 6 summarizes the different service terms.

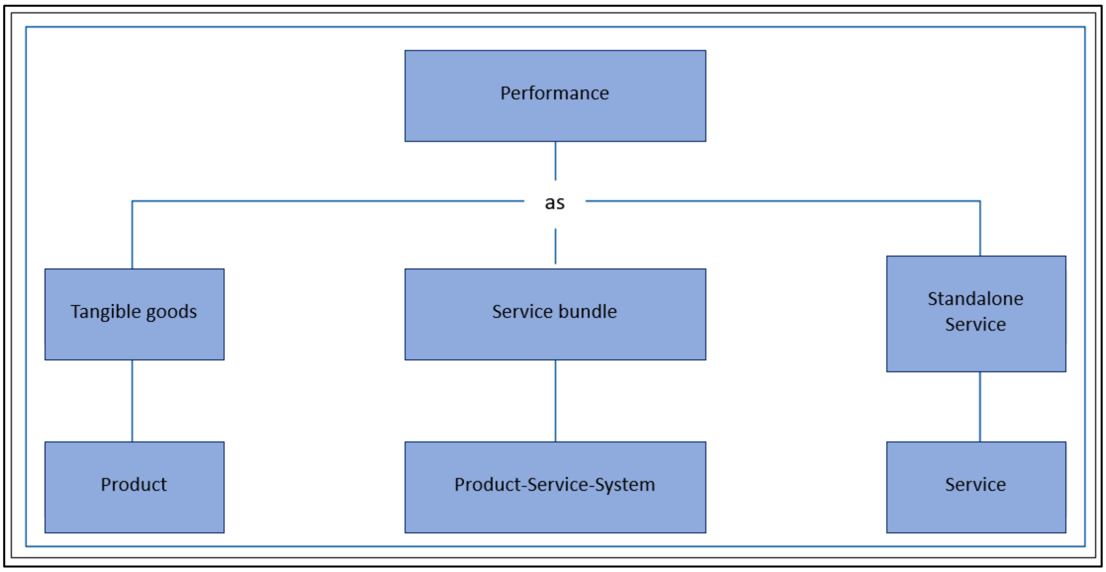

Figure 6: The distinction of terms for service (Source: Bruhn & Hadwich, 2017)

Products represent purely tangible goods and services are stand-alone, i.e., services independent of the product (e.g., repairs, training offers). Service bundles, on the other hand, are combined product-service offerings (product-service systems) that represent combinations of specifically assembled (tangible) products and (intangible) services (Tukker, 2004). In order to optimise turnover on the one hand and achieve a high level of customer satisfaction and loyalty on the other, companies are increasingly offering bundled services on the market (Huber & Kopsch, 2007). According to Huenerberg et al. (2009), a basic distinction can be made between three types of services, as shown in Figure 7.

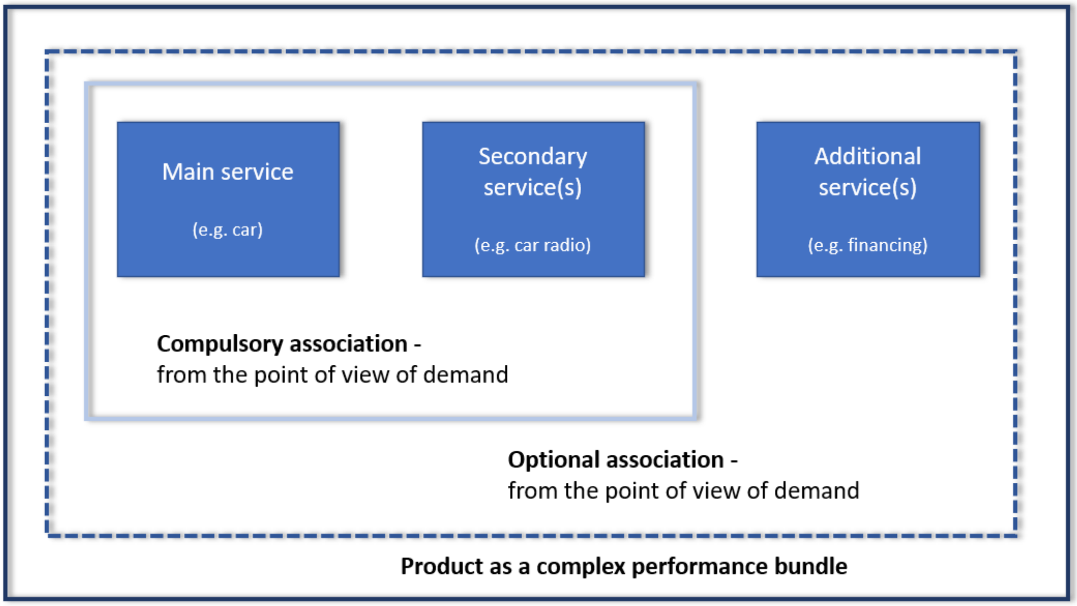

Figure 7: Types of services (Source: Huenerberg et al., 2009)

The core of the product is the main service, which at the same time serves as the starting point for further services. "*A first combination possibility arises when the main service is offered together with a secondary service in a demand-side compulsory combination. This means that the main service cannot be demanded without the ancillary service*" (Huenerberg et al., 2009, p. 208). This approach increases the customer benefit as well as the total revenue of the product. This can be extended if other ancillary services are also purchased that are aligned with the main service. As a result, according to Huenerberg et al. (2009, p. 208), "*the character of products, especially in technically oriented industries, is thus increasingly changing away from the individual material or service towards a combination of these service types, which were previously often considered separately from each other*". In the following, a modern understanding of the product is therefore advocated, which does not distinguish between (pure) material and service products.

In this thesis, a distinction between products and services will only be made in the following chapters if this is necessary for a differentiation of statements for product and service management. In the following, the basic considerations on "product" will be expanded to include digital-physical products and its characteristics as well as differences to digital and physical products will be discussed. This is because the concept of product has been given a further component by the advancing information technology. The overarching goals and characteristics of a product are still valid but are given a completely new impetus by the integration of digital assets.

2.1.3 Definition and discussion of digital-physical products

Digital technologies are increasingly finding their way into physical products. Smart cars and connected light bulbs are examples of formerly purely physical products that have become digitized products (Novales et at., 2019). These so-called digital-physical products "*are products that contain both digital and physical components*" (Novales et al., 2016, p. 2). Here, hardware components such as sensors represent the physical part and the software embedded in the product represents the digital part (Yoo et al., 2012). A major cornerstone in the literature related to digital-physical products is the ambiguous terminology. Due to the diverse definitions, the literature discusses the often-typical elements that lead to a clear definition. Many authors therefore deal with the delimitation of digital-physical products and its definitions. Digital-physical products are used, for example, as smart connected products (Porter & Heppelmann, 2014), intelligent objects (Wunderlich et al., 2015), or as cyber-physical systems (Borgia, 2014).

Even though superficially they seem to mean the same thing, there are differences in the underlying concepts. Novales et al. (2016, p. 3) gives the following example: *"[...] Rijsdijk and Hultink (2009) consider autonomous (but not necessarily networked) products such as a washing machine or an autonomous hoover that reacts to its environment via sensors to be smart products, whereas Porter and Heppelmann (2014) also consider more sophisticated products such as Sonos' smartphone-controllable speaker system that allows the product to connect to an ecosystem of third-party digital services (e.g. Spotify, Pandora, Apple Music)*". This finding by Novales et al. (2016) is also supported by other authors. Frick et al. (2020), for example, found in their study that the definition and understanding depend on the smartness dimension and the product. A different approach was taken by Huh et al. (2018) who exclude digital-physical products by defining digital-physical products as what is not possible with traditional purely physical or digital products. In summary, however, a digital-physical product is a tangible object that combines physical components with digital capabilities and enables enhanced functionality, connectivity and interactivity through the combination of hardware, software and data processing (Yoon & Jeong, 2017).

In addition to the terminology, the discussion about the advantages and features of digital-physical products also takes up a lot of space. Digital innovations help to create diverse possibilities in products. As an example, networked light bulbs can be controlled remotely (switching on and off) or operated via a smartphone (Porter & Heppelmann, 2014).

The spread of the internet as a communication environment, the increasing availability and durability of the latest sensors and an expansion of the internet to include standardized data formats and exchange protocols, enable the design of digitized products in a smart environment. In the future, great importance will be attached to these in the industry, as they achieve high economic efficiency along the entire product life cycle on the one hand and enable new services that provide customers with significant added value on the other (Sabou et al. 2009). According to Genter & Oßwald (2017) the features and benefits of Industry 4.0 solutions operate along the entire product life cycle and consequently affect not only the workpiece, which intelligently navigates through production, but above all the finished product during its use by the customer. The collection and evaluation of data can also be continued after delivery to the customer, so that new business models can arise during the use of the product. The user behavior of individual customers can be deduced from the data obtained and compared with the requirements of other customers. In this way, conclusions can be drawn for a possible optimization of product use by the customer, but also for the development of new products (Hendler, 2019).

This is precisely what further discussions in the literature refer to, namely the product developments of digital-physical products and its change on traditional product development. One example is Hendler's (2019, p. 1) investigation of coordination practices during the development of digital-physical products and their consequences for companies. "*Effective coordination of digital-physical product development involves, first, standardization of processes, outcomes and capabilities [...]. Secondly, it involves agile coordination events such as Scrum ceremonies and PI planning [...]*". In the discussion, the demanded agility of product development stands out above all. Here, established development approaches are to be expanded to include agile methods, no longer exclusively in pure software development, but also for (digitally) physical products. This is also the case according to Vries et al. (2021), who call for the development of digital-physical products to follow an agile and lean approach in order to overcome the challenges of integrating physical and digital elements. The main point of discussion in the literature is the transformation of agile approaches into traditional product development, as it is difficult to adapt to the specificities of traditional development. "*Popular agile methods such as Scrum or Design Thinking were not originally designed for the development environment of physical products. Dependence on a network of suppliers or waiting times due to the development of costly prototypes make it difficult to implement short-cycle agile product development in practice*" (Fraunhofer IPT, 2022, p.1). This also applies to Gericke et al. (2020), who speak of a multidisciplinary approach between traditional engineering disciplines and digital technologies as well as software development.

Despite the immense benefits and applications of digital-physical products, most companies are still in the early stages of using and developing digital-physical products. According to a MIT report from 2016 "*more than half of the firms interviewed believe in the value these products can generate, very few are actively using IoT (only 13%) […]*" (Novales at al., 2019, p. 3). In another study by Novales et al. (2016), it was found that identifying the use cases that are relevant to companies is a major challenge. The development, the added value and the handling of digital-physical products still represent knowledge and action gaps for companies. The qualitative study by Novales et al. (2019, p. 3) analyzed 16 companies and identified three types of use cases for a company's value creation:

1) "*First, the digitization of products affords producers the potential to improve the product itself (e.g., by adding, complementing, extending, changing or integrating product features).*
2) *Second, digitized products enable producers to servitize the product or product features, adding external-facing service offerings.*
3) *Third, digitized products allow producers to improve (e.g., inform, enrich and adjust) their internal operational processes (customer/after-sales service, maintenance, sales, and product development processes) with data related to product use and performance".*

Regarding the benefits of digital-physical products, Hendler (2019) mentions the degree of digitalization. According to Hendler (2019), the degree of digitalization and the accompanying service are in proportion to each other. This wide range of variance offers opportunities and at the same time makes it difficult for manufacturers to design and develop suitable products Digitalization opens up the possibility of networking products with each other by assigning them an IP address. This connectivity allows products to work and communicate with each other without human intervention. This results in completely new service offerings (Bauer & Horvath, 2015).

These new service offerings can promote the growth of a company and replace previous ways of doing business. At the same time, companies risk not being able to keep up with the more responsive competition, so that the existence of the company can be threatened (Novales et al., 2019). In addition, manufacturers are finding it much harder to design and develop appropriate products. Despite these advantages, much of the literature is concerned with the complexity created by digital-physical products. There are two main views: first, that digital-physical products change and complicate business processes and secondly, the complexity imposed on the customer. Emerging business models initiated by digital-physical products establish new dependencies and risks, but also return opportunities (Iansiti & Lakhani, 2014).

Lehtonen et al. (2018) also argue that effective and structured coordination and management of complexity throughout use are needed to manage the complex interactions between physical components, digital technologies, software systems and human actors. This trade-off between the benefits and the accompanying complexity creates a number of challenges for strategic management (Lehtonen et al., 2018). Value creation processes will connect and merge the industrial and digital economies, "*but they will also greatly increase the number of actors participating in the value creation process, the complexity of the products, and the resources and competencies required to create and support them*" (Lerch & Gotsch, 2015, p. 50). Moreover, they will bring challenges throughout the product lifecycle in terms of user acceptance, privacy, security, and ethical considerations (El-Gayar et al., 2020).

To overcome these challenges, effective management of digital-physical products is required. According to Zeng et al. (2020) and Thoben et al. (2017), a holistic framework for the management of digital-physical products is therefore necessary, which includes the revision of processes and customer service as well as the establishment of new business models. Rizvi et al. (2018) also join this aspect and plead for the revision of the previous management of products, caused by the integration of data analysis into product development or post-sales activities.

Product management is awarded great value in the whole discussion, as it is responsible for the planning and control of products as well as services throughout the entire product life cycle from market maturity to product elimination from the market (Bahrenburg, 2019). The new types of offerings, but also the increasing complexity and challenges, can lead to far-reaching transformations along the entire product life cycle and product management itself. For those responsible for products, this also means adapting to new structures, patterns and ways of thinking and an increase in complexity compared to long-established physical products (Kagermann, 2014). Therefore, companies need to broaden their understanding of product management and its structure so that the new service offerings can be effectively and efficiently mapped and managed through digital-physical products. (Lerch & Gotsch, 2015; Zeng et al., 2020). This shift is a first step in the direction of digital transformation and brings product management into focus. Therefore, section 2.2 will now describe product management and its facets in more detail. In addition, the role of the product manager will be examined from different perspectives.

2.2 Characteristics and concepts of the product management

In section 2.2.1, the various approaches and forms of product management will be examined. It will be shown that there is no complete definition of product management, as it depends on various internal and external factors. These factors will be described and analyzed. Furthermore, product management will be also analysed from a theoretical perspective in order to strengthen the understanding of product management on the one hand and to contribute to the discussion about the definition of product management from this perspective on the other hand. In addition, the role of the product manager is explained and discussed in this section. Finally, the current literature on product management is highlighted. The aim of this subchapter is to gain an understanding of the different forms of product management and its complexity.

2.2.1 The different perspectives of product management

The basic principle of product management is to assign individual products or product groups to one person has the responsibility of managing all product-related issues across functions (Matys, 2018). This means that good and proper management of products can significantly increase the probability of market success. Rather than being a given, managing products are an entrepreneurial task, as on average four out of ten products on the market fail to achieve their sales and/or profitability targets (Biermann & Erne, 2020). Although on the surface this seems to clarify everything, there are many different interpretations and understandings in the literature, and also in practice. Even though the goal of product management seems to be clear, the activities of a product manager differ from company to company: "*Ask 10 product managers about their tasks and you will get 10 different answers. Each company defines them differently*" (Meserve, 1989, pp.143-145). The main cornerstones that influence product management are explained in more detail below.

2.2.1.1 Influence of the changes in the market economy

One of the reasons for a different definition of product management is the continuous changes in the market economy over time. Depending on these, the area activities of product management have changed again and again. For example, a few years ago the focus was on product competition and differentiation through product innovation. Today, however, increasing commoditization is leading to a structural shift from pure product providers to service providers (Bruhn & Hadwich, 2017; Aumayr, 2019).

Figure 8 illustrates the development phases of product management and gives an initial indication of the increasing diversity of descriptions of product management. The aspects mentioned in the figure are briefly described below.

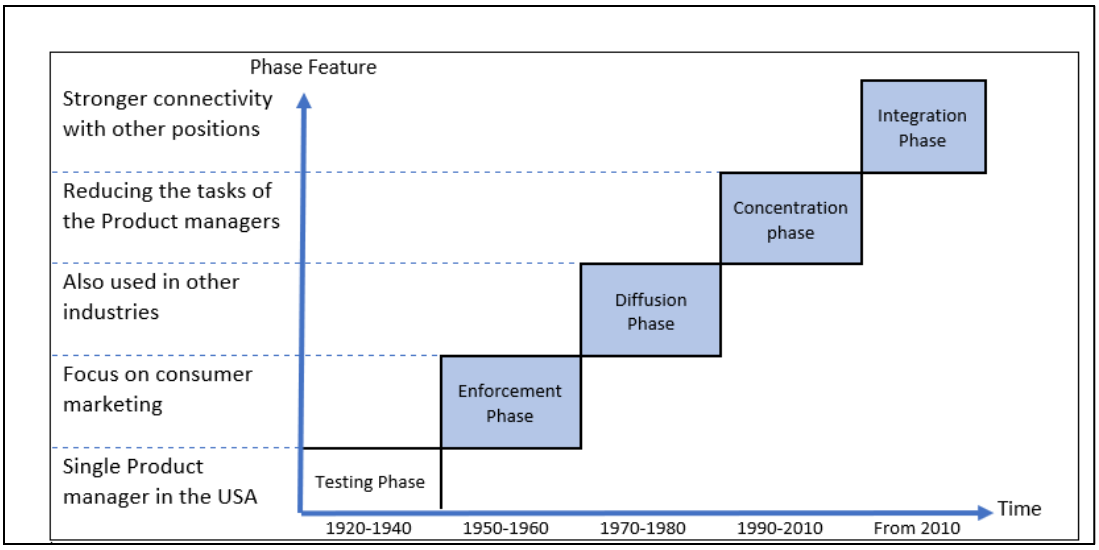

Figure 8: The chronological development of product management (Source: In accordance with Bruhn & Hadwich, 2017)

The fact that structured product management is necessary to increase product awareness and sales was first recognized by the American company Procter & Gamble in 1927. Since sales and market share were missed when a new product was introduced, a person was defined who was responsible for sourcing and coordinating market requirements as well as all other activities related to the product (Fricker, 2012). This product manager should coordinate all product-related activities and concerns, whether operational or strategic. After a short time, success was achieved and the set goals for this product were reached (Großklaus, 2009). Due to the success, this role of product-responsible coordination was introduced company-wide for all products (Großklaus, 2009). Thus, product management became established in the following years (1950-1960s) throughout the consumer goods industry. In the so-called diffusion phase, the concept was then extended to the industrial and service sectors. Especially in the service sector, the advantages of product management were discovered and thus became more and more established (Bruhn & Hadwich, 2017). The concentration phase was mainly concerned with tailoring the product management concept because at that time 60% of the industrial goods manufacturers in Germany had already introduced product management and wanted to adapt it more and more to their purposes (Bruhn & Hadwich, 2017).

Thus, certain product management tasks were assigned to new target-oriented positions such as the key account manager (Großklaus, 2009; Aumayr, 2019). As a result of the increasing globalization in this period, product management also became more and more internationally oriented, which led to many individual orientations. According to Bruhn & Hadwich (2017), product management today is in the integration phase, as shown in Figure 9. Product management is characterized by increasing networking with other departments and cooperates with almost all departments of a company "*to ensure that products are not developed bypassing the customer, but according to their wishes and needs*" (Bruhn & Hadwich, 2017, p.3).

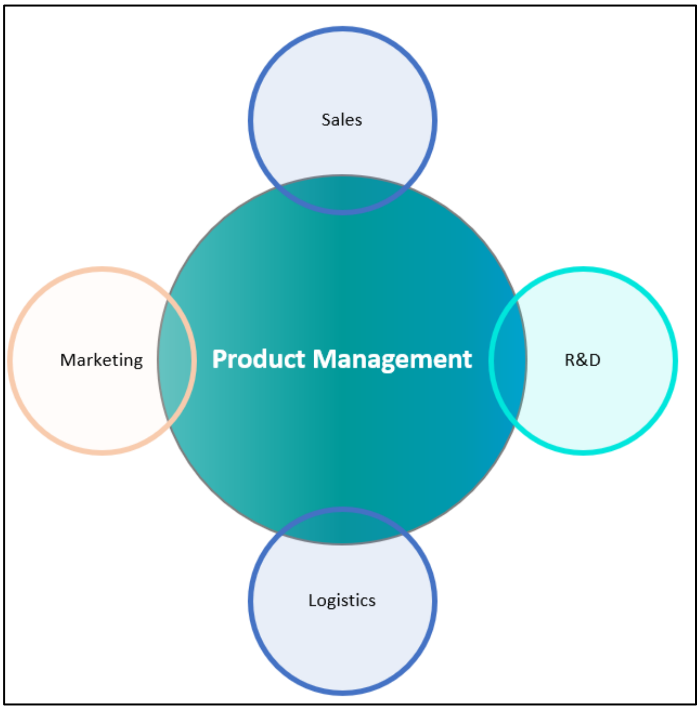

Figure 9: Interfaces of product management (Source: In accordance with Kotler, 1992)

Product management therefore acts more than ever as an interface to other departments and as a result, high demands are placed on product management from all areas. This is because the product manager must have a certain basic knowledge in almost all areas of the company to be able to coordinate the departments relevant to the product. It is therefore not without reason that the product manager is often referred to as the chief executive officer (CEO) of his or her product (Horowitz & Weiden, 2010).

2.2.1.2 Company-specific focus of product management

Another aspect for the non-uniform definition of product management is the focus of product management in the company. Depending on the industry and company, the exact positioning and focus of product management can vary (Gaubinger, 2015).

If product management is located particularly close to marketing, its core task is often to consider the marketing of the product and market analyzes (Hermann & Huber, 2013). With regard to sales, product management sometimes takes over reporting, develops product brochures or trains service. In the capital goods industry, product management is expected above all to initiate new developments, which is why the product manager in this industry often comes from research and development (Gaubinger, 2015). The non-uniformly defined areas of responsibility can be traced back to the different basic understanding of product management. Depending on the perspective from which it is viewed more strongly, a different definition of product management emerges (Bruhn & Hadwich, 2017).

According to Bruhn & Hadwich (2017), the three different perspectives that are intertwined are the functional, the organizational and the personnel perspective (Figure 10). In a functional perspective, product management is seen as an operational function that needs to be fulfilled. The focus is on developing and maintaining products to ensure long-term economic success (Gaubinger, 2015). The organizational perspective of product management, on the other hand, deals with the organizational implementation. Structural questions, such as the organizational anchoring in the company, the design of product management departments and teams, and questions of process organization, such as the coordination between product management and the R&D, market research and communications departments, are dealt with (Koppelmann, 2013). The personnel perspective looks at the bearers of product policy decisions in the company. These persons are primarily responsible for the development and improvement of products as well as the management of products on the market (Koppelmann, 2013).

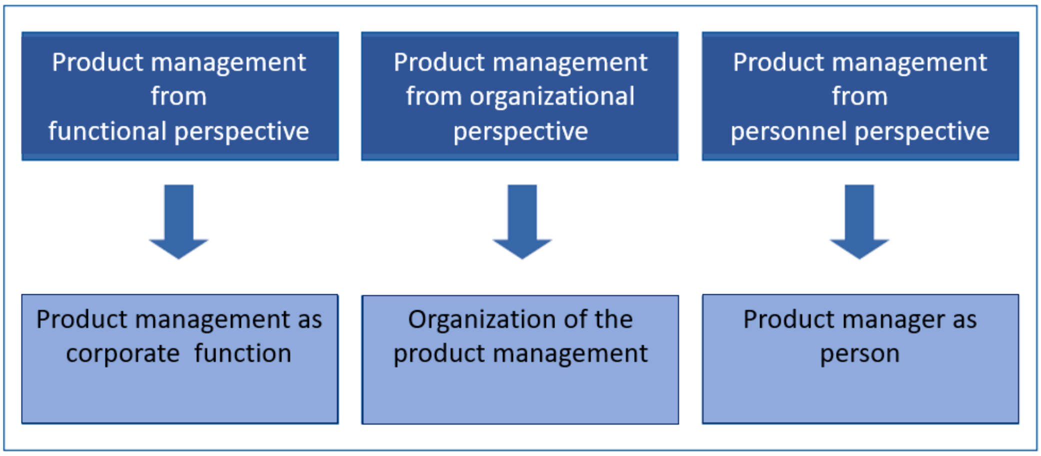

Figure 10: Product management perspectives (Source: Bruhn & Hadwich, 2017)

Looking at product management from different perspectives gives another indication as to why there is no uniform integration.

Depending on how the company combines and evaluates the perspectives or classifies them differently, different fields of activity arise for the product manager (Bruhn & Hadwich, 2017). In addition, further distinctions can be made within the respective perspectives. For example, from an organizational perspective, product management can be designed as staff-oriented, line-oriented or matrix-oriented product management (Aumayr, 2019). The advantage of matrix-oriented product management is that the product manager has to make his decisions in agreement with line managers. This means that the interests of the company are always taken into account in total. The disadvantage, however, is the enormous coordination effort and the danger of being an extension of other departments (Hermann & Huber, 2013; Aumayr, 2019). Figure 11 shows an example of a matrix-oriented product management organization in relation to marketing:

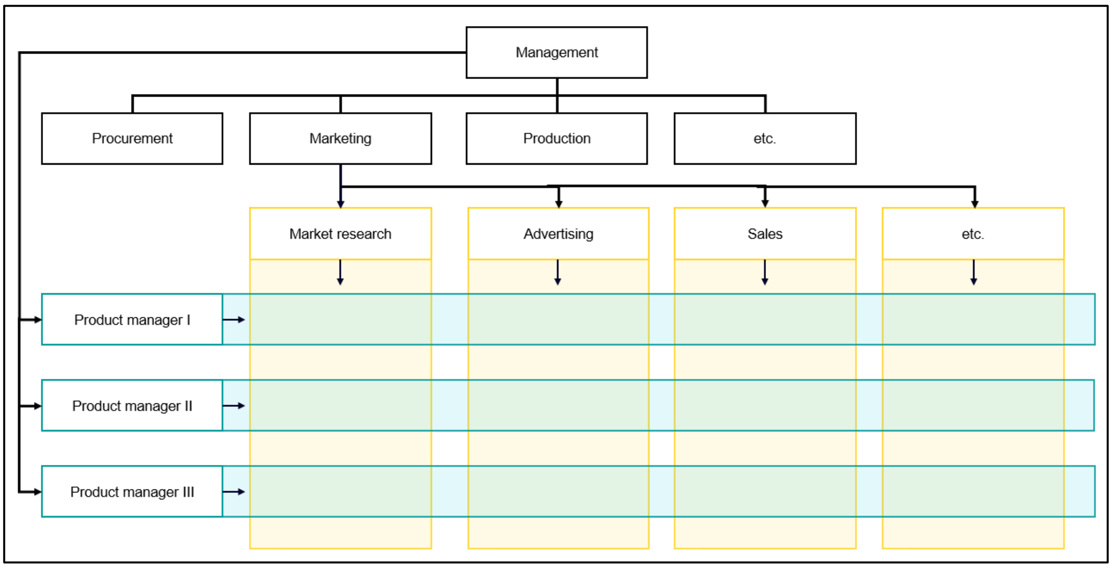

Figure 11: Matrix-oriented product management (Source: In accordance with Koppelmann, 2013)

In product management as a line operation, product management is subordinated to the company management. This means that decisions can be made more quickly and flexibly. A disadvantage is the loss of synergies, as such integration promotes product specialization but not task specialization (Köhler, 2000; Aumayr, 2019). Figure 12 shows product management exemplarily as a line unit:

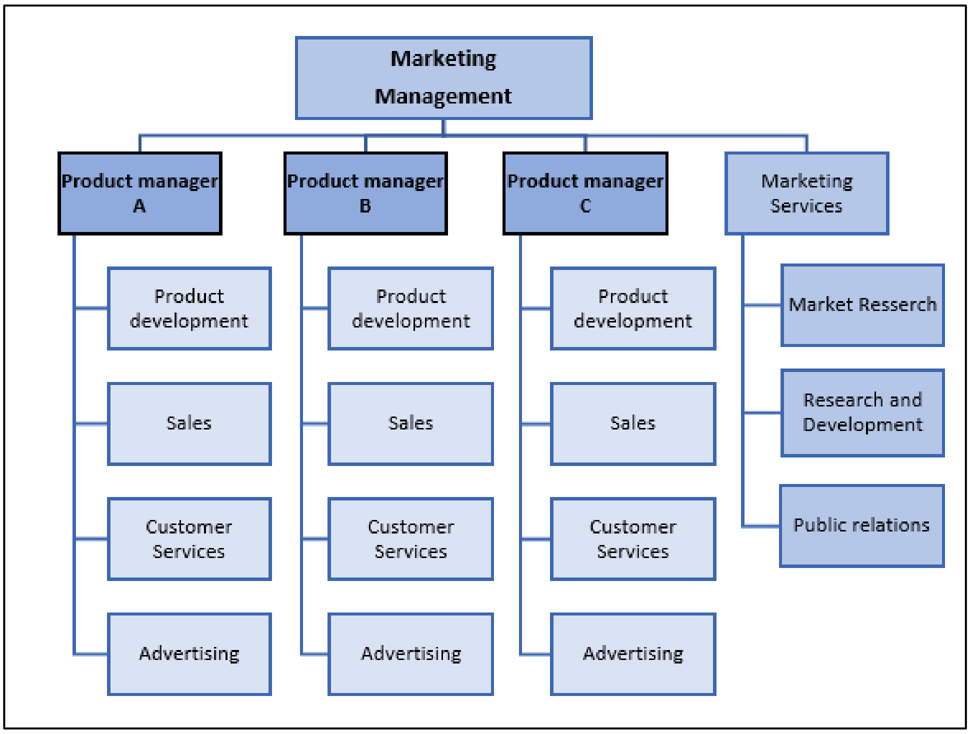

Figure 12: Line-oriented product management (Source: In accordance with Koppelmann, 2013)

2.2.1.3 External challenges to product management

Noticeable in the discussion about the classification of product management are also the challenges acting on product management. The challenges relevant to this research include the development of the environment, the own company as well as customer behavior (Bruhn & Hadwich, 2017). Figure 13 illustrates this:

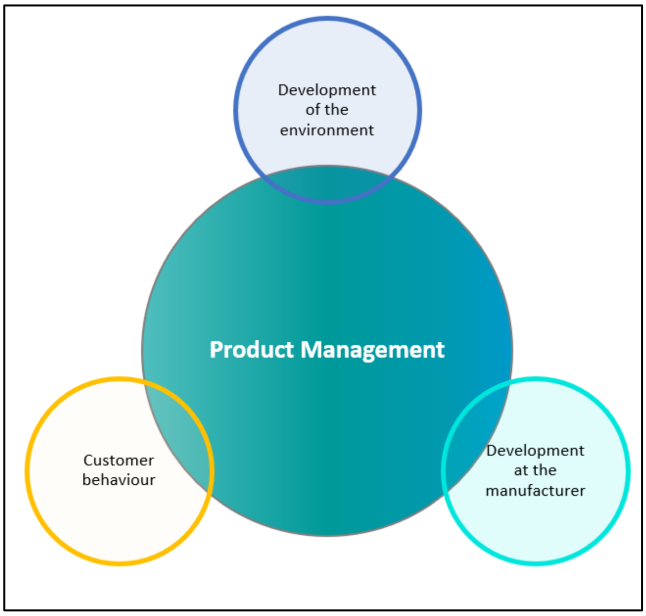

Figure 13: External forces on product management (Source: In accordance with Bruhn & Hadwich, 2017)

One of the aspects, for example, is the development of the environment. The importance of digitalization and the associated use of new technologies influences the future business processes of companies and competitive conditions. According to a study by the Chamber of Industry and Commerce, over 90% of the companies surveyed in the construction and trade sectors, as well as service providers, see a major impact of digitalization coming their way (Bruhn & Hadwich, 2017). The way in which product management is emphasized in the discussion can once again lead to a new area of activity. Climate change is another example. Customer solutions should be developed as "green" as possible and be recyclable. Such a shift of values in society also challenges companies to offer new customer solutions (Hermann & Huber, 2013; Geracie & Eppinger, 2013). In addition to the developments in the environment, the development at the manufacturer itself also has an influence on the characteristics of product management. Companies can no longer afford inefficient processes, product launch failures, faulty sales strategies or simply reacting too late to changes in the market economy. This is because, driven by IT, product life cycles are becoming shorter and shorter, competition is increasing and the urge to vary is growing (Pichler, 2022). Furthermore, more and more companies are pushing to expand their product range with services. This internal trend towards services, while at the same time being innovative and keeping costs down, presents product management with the challenge of determining which services should be performed internally or externally and at what time. This in turn has an impact on the specialization of core competences and general orientation (Pichler, 2022).

The last aspect to be mentioned with regard to external demands on product management is customer behaviour. In the industrial goods sector, product managers usually look after several product variants and their activities are strongly characterized by dealing with individual customer solutions. The products as problem solutions are usually tailored to the needs of the respective customer (Matys, 2018). Consequently, intensive cooperation with the customer is necessary. According to a survey by KPMG in 2015, around 125 CEOs emphasize that 88% consider a strong willingness to change on the part of customers to be very likely, as a declining loyalty has been evident for several years (Bruhn & Hadwich, 2017). The reason for this is the increasingly strong internationalization and the resulting product diversity on the market, as well as the service opportunities brought about by digitalization. While manufacturing companies offer services only as an add-on to their products, service providers focus on customized services. This makes it difficult for customers to remain loyal as they have more choice (Willers, 2015).

The standard product as a problem solution for everyone is moving further and further into the background, so that the targeted selection of customers and markets is increasing and the adaptation of product innovation to customer wishes is taking on an unprecedented strategic focus. The classification of product management within the various external developments leads to a different arrangement and orientation of product management (Olsen, 2015; Cagan, 2017). In this context, "*manufacturer- or supplier- and trade-specific changes as well as market- or competition-, customer- and other environment-related developments offer companies numerous opportunities to distinguish themselves in the market, but also confront them with new risks and problems*" (Bruhn & Hadwich, 2017, p. 4).

2.2.1.4 International Product Management

The last point to be added for the individual classification of product management is internationalization. This is because complexity increases when the company operates internationally. Aumayr (2019) introduces the international product manager (IPM) and national product manager (NPM), as shown in Figure 14. The head office can set up an international product management in order to be able to act more easily and quickly in the respective regions. According to Aumayr (2019), a NPM could be the local contact person and focus more on the operational part in the respective country, and the IPM could act as a strategic pacemaker for the same product worldwide. National product management is necessary for country-specific activities and assumes operational implementation responsibility. Due to this arrangement, the product management in the head office can be hung differently and take on different tasks than the national product management (Aumayr, 2019; Berndt et al., 2020).

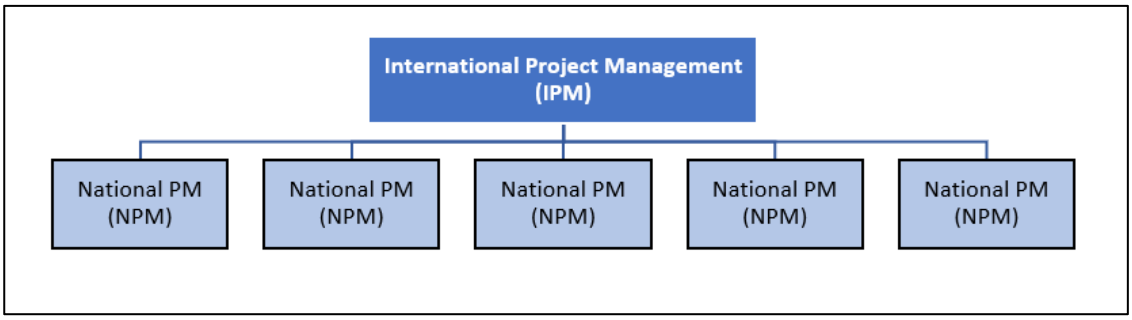

Figure 14: International product management (Source: Aumayr, 2019)

The decisive factor for the classification of product management is therefore the philosophy of the company and the overarching corporate strategy. Basically, the organizational integration and the functional benefit of product management is derived from this (Cagan, 2017; Aumayr, 2019; Gaubinger, 2015). The corporate strategy regarding digitalization also plays an important role for product management (Cagan, 2017).

Depending on how digital-physical products are classified by the company, this has an influence on product management. The investigation of this aspect corresponds to part of the present research. This subchapter discussed why a uniform arrangement of product management is difficult. The continuous changes in the market economy, internationalization, the challenges affecting product management and the subjective focus result in different interpretations of product management. In summary, it can be stated that a uniform design of product management is difficult, which is why the approach via the theory of product management is touched on below.

2.2.1.5 Theoretical background of product management

According to Bruhn & Hadwich (2017), the approach from theory is also challenging, since "*independent theory of product and service policy, which [...] could be used as an explanatory approach for product and service policy issues, does not exist*". Rather, product management is to be viewed from an interdisciplinary perspective in which various fields of science are to be used in a networked manner. These fields of science are primarily the natural, economic, and behavioural sciences (Bruhn & Hadwich, 2017).

The scientific theories are the basis for technologies and thus form an important starting point and a solid foundation for the development and modification of products. From the economic sciences, the so-called structure-behavior-performance paradigm is particularly attractive. This paradigm states that the success of companies can be explained by the structure of the industry and the behavior of the companies involved (Treusch, 2021). In other words, the influence of corporate success guides subsequent corporate structure and behavior (Figure 15).

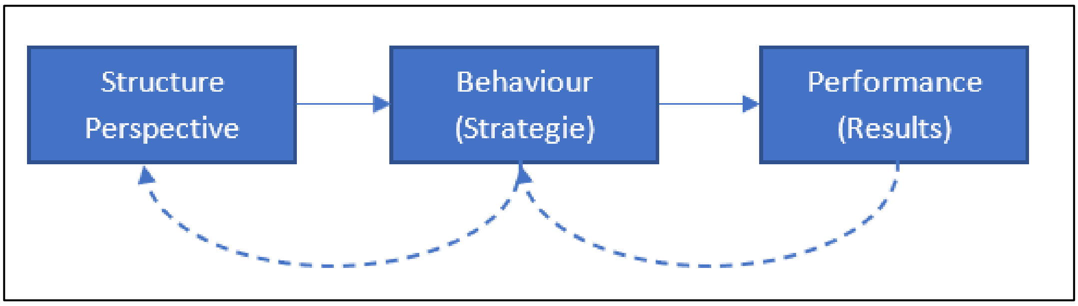

Figure 15: Structure-Conduct-Performance-Paradigma (Source: In accordance with Meffert, 1999; Bruhn & Hadwich, 2017)

In terms of product management, this means that the success of the product is determined by the structure of the product markets as well as the strategic behaviour of the product management (Treusch, 2021). "*Appropriate positioning in attractive product-market segments thus enables a long-term and defensible competitive advantage position*" (Matys, 2018, p. 118).

However, this aspect is criticized by Barney (1991), who believes that the achievement of lasting competitive advantages is only possible through an adequate strategic behaviour of a company in terms of resources. Independent of the discussion about the structure-conduct-performance paradigm, this represents another stream of influence of scientific theories on product management (Bruhn & Hadwich, 2017). As a final theoretical approach to better characterize product management, concepts from behavioral science should be mentioned here. With their help, insights into consumer behavior are used to be able to apply product policy measures in a targeted manner (Bruhn & Hadwich, 2017). The approaches from this field deal with the explanation and prediction of human decisions and try to show patterns in the perception of product behavior in order to use them for future decisions. For product management, understanding consumer perception of brands and products is of central importance, as it enables conclusions to be drawn about product design (Matys, 2018).

Like in practice, the approach of a holistic definition from theory is also difficult. The aim of this section was to highlight the complexity of a holistic definition and design of product management from the perspective of practice as well as theory and to show its complexity. Due to this, no official definition can be given here, which is why reference is made here to a general and composite definition of product management, which is often referred to in this field: Product management is the discipline that strategically manages the development, introduction and ongoing management of a product or service throughout its life cycle. This includes understanding market needs, defining product vision and strategy, capturing and prioritizing requirements, collaborating with cross-functional teams, and ensuring successful product delivery and market acceptance (Stark, 2022; Cagan, 2017).

However, before entering into the current discussions of product management, the different forms of product managers are first discussed in section 2.2.2. Similar to product management, there are also different definitions and orientations of the product manager. On the one hand, the understanding of product management will be further deepened by showing the different aspects of the product manager, and on the other hand, its possible change due to digital-physical products will be examined in this thesis.

2.2.2 The role of the product manager

Just as flexible as product management, the product manager is used in companies for a wide variety of activities and is anchored in various departments of the company organization. The tasks and functions of a product manager listed in the literature are so diverse that they can hardly be named exhaustively. One of the reasons for this is that the product manager is used as an interface coordinator, so that this person takes over tasks from a wide variety of departments (Stark, 2022). In theory, however, there are four core tasks that are assigned to the product manager. The first of these is the information task. This means that all information concerning the product and its market must be passed on to the right people within the company. The product manager should keep an eye out for product improvements and the introduction of new features. Next, planning tasks are mentioned here, which include the establishment of a customer-oriented product strategy, the operational implementation steps as well as success planning and budgeting. The control tasks refer to the process- and result-oriented success of the product. This corresponds to the monitoring of product-related activities and the measurement of key sales figures. Lastly, the coordination tasks are mentioned here. This includes the cross-functional activities that require coordination with other departments in terms of content, personnel and time (Hermann & Huber, 2013; Matys, 2018; Aumayr, 2019). Figure 16 shows a summary of the tasks:

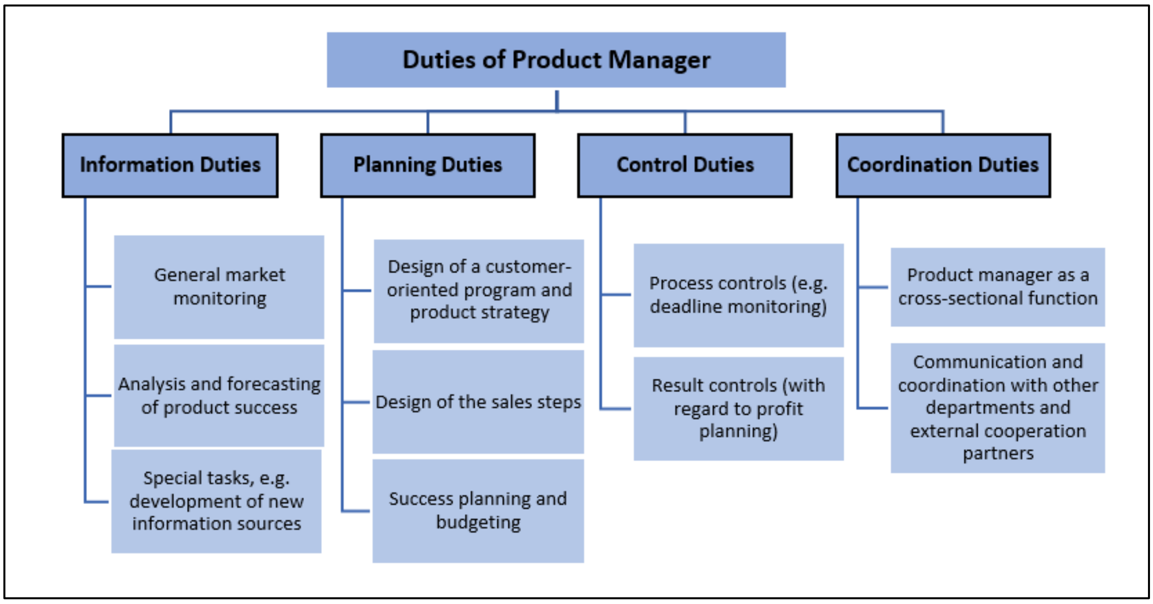

Figure 16: Core tasks of the product manager (Source: In accordance with Hermann & Huber, 2013)

As already described, these tasks only represent the core tasks of the product manager and are not fully described. Variations of the tasks result from the problem of product management because these "*lie today primarily in the work overload of the position, [...] in the lack of assertiveness and the limits of the ability to coordinate*" (Bruhn & Hadwich, 2017, p. 303).

To counteract this problem, various divisions of the product manager have emerged from practice. For example, there are product managers in their own departments with full decision-making authority. These strategically oriented product managers determine all necessary resources and ultimately decide themselves on product design, sales documents and the sales concept (Wagner, 2017). In some companies, product management is therefore seen as having a great amount of strategic responsibility (Stark, 2022). In other companies, however, the product manager is seen as a very operationally oriented function that primarily coordinates and monitors. These product managers are not responsible for strategic appraoches related to their product and therefore cannot be held accountable for the outcome. However, there are many focal points in the operational orientation of these product managers. Some are active in technical areas, others have a focus on marketing or sales (Aumayr, 2019). Depending on the focus in the respective company and individual philosophy about product management, the organizational integration of product management into a company also results. For example, in some companies product management is designated as part of (operational) marketing: "*The product manager is responsible for product marketing"* (Matys, 2018, p.5).

In addition to the division into a strategic and an operational product manager, another division can be observed that has recently become more and more important. As stated before product management is not only changing in connection with corporate development but is also strongly influenced by external market and competitive conditions. Furthermore, there are impulses to specialize in product management thematically and in terms of content. In particular, the division into a market and competition orientation and a technology orientation is favoured in practice and also consistently implemented (Hermann & Huber, 2013). This leads to the fact that product management, similar to positioning, is not only subdivided according to strategic and operational orientation, but also according to competitive and technology orientation (Aumayr, 2019). The already existing positioning matrix with the two dimensions (strategic vs. operational) can now be expanded by the two technical-content dimensions (market/competition vs. technology/technology), as shown in Figure 17.

		Technical and Content-related Orientation	
		Technology	Market/Competition
PM Positioning	Strategic	Product Manager Sales	
	Operative	Product Manager Technology	Product Manager Marketing

Figure 17:The classification of the product manager with focus on strategy, marketing and technology (Source: In accordance with Aumayr, 2019)

The two technical-content issues are still manageable and feasible for the strategic product manager (also called product manager sales) as an individual. The operational activities have to be subdivided because of too different competence profiles and these product managers are assigned to the corresponding departments. It should be noted that a strict separation of the dimensions and thus the quadrants is neither feasible nor sensible in practice. Just as a strategic product manager must fulfil a certain proportion of operational tasks, the technical and content separation will also not be 100 per cent feasible (Aumayr, 2019). Moreover, in many companies it is common for a product manager to cover both strategic and operational tasks (Matys, 2018).

Another aspect that leads to variation to the product manager is that the market no longer requires just products, it demands complex system solutions that have integrated individual products. The classic product business is thus being expanded to include system business - with consequences for product managers. The former product manager becomes now a system product manager (Aumayr, 2019). A system product manager is a role responsible for managing the development and strategic direction of a system-level product. System products are complex offerings that consist of multiple interconnected components, such as hardware, software, and services, designed to work together to deliver a unified solution. The components can be a company’s own products and/or bought-in products. Such systems are found, for example, in traffic control and flight systems, in logistics and in telecommunications. The components are integrated based on integration concepts that are specifically defined by the system product manager. These differences to the product business can therefore lead to a separation of the two areas, so that in some companies there is both product management for the product business and product management for the system business (Willers, 2015). This correlation is shown graphically in Figure 18.

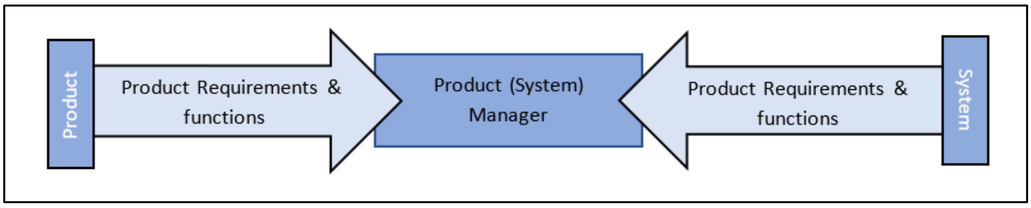

Figure 18:The division of the product manager into product and system management (Source: In accordance with Aumayr, 2019)

Whether the product manager is strategically, sales or operationally oriented depends on the integration of product management, which in turn depends on the company's philosophy (Stark, 2022). Nonetheless, product teams are always needed, i.e., players for the product manager. A distinction is made between the structure types of vertical product team, triangular team and horizontal product team, as shown in Figure 19 (Bruhn & Hadwich, 2017). The vertical product team can be set up as desired, but usually consists of a product manager, a deputy product manager (sometimes also technical experts), and product assistants. The triangular team is a cross-functional team consisting of two functional specialists and the product manager. In the horizontal team, the team is composed under the leadership of the product manager (Bruhn & Hadwich, 2017).

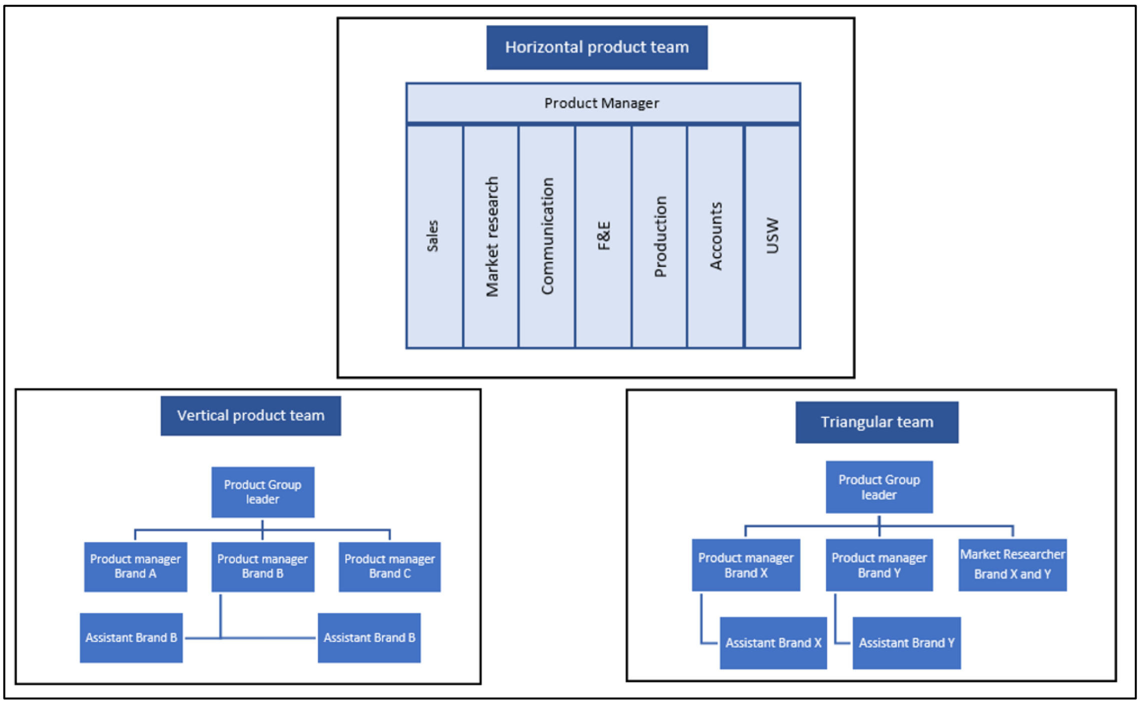

Figure 19:The different structures in setting up the product manager (Source: Bruhn & Hadwich, 2017)

Due to the different classifications of product management and the product manager, there is still no uniform definition as well as profile, as companies are confronted with different internal and external requirements depending on the industry, market, customers, products, and technologies, for instance (Olsen, 2015).

Likewise, the activities of the product manager strongly depend on the type of product, the culture, history, and organization of the company as well as the target and remuneration system. Furthermore, the continuous changes in the market economy lead to a corresponding adaptation of the use of product management (Olsen, 2015). Based on the various possible interpretations, product management and the product manager must therefore be further delineated. After the following discussion on the current literature on product management, this is further concretized in section 2.3.

2.2.3 Current discussions in the field of product management

It has been shown that a uniform definition is hardly possible from both a practical and a theoretical point of view. This aspect leads to diverse scientific research in this area with different focuses. For example, there are discussions about product management in relation to individual technologies, such as AI (Namatherdhala et al., 2022), or product management in relation to countries such as India (Majumdar, 2008) or individual industries like the tourism industry (Moreno-Mendoza et al., 2019). Due to the diverse factors that affect product management, there are hardly any uniform statements on a topic. Due to this, product management needs to be further refined be able to narrow down the current literature and mirror it to the topic. However, before going into the individual concepts and models of product management, two essential discussions from the literature should be highlighted first.

Digital product management

Digital product management is currently a much-discussed issue (Fricker, 2012; Ebert, 2014). The focus is often on the question of how software can be made more productive and brought into line with corporate strategy. Software is increasingly seen as a product and management is established accordingly. Fricker (2012, p.1) maintains that "*with a product focus in addition to the project focus, planning accuracy can be improved, time to market can be shortened, product quality can be improved, and economic success can be maintained*". In the literature on digital product management, researchers and practitioners have explored various aspects, including methods, frameworks, challenges, and best practices. For example, agile methods such as Scrum and Kanban have gained popularity in digital product management. The reason for this is that agile methods lead to fundamental differences between the classic, project-based and agile development of digital products and inevitably also lead to an adaptation of product management (Pichler, 2014; Hoffmann, 2020).

Therefore, the literature discusses the benefits and challenges of implementing agile practices, as scaling agile practices to larger teams and organizations is an important topic in the literature given the increasing complexity of software products. Frameworks that address the challenges of scaling agile practices are discussed (Hofmann, 2020; Cano et al., 2021; Tkalich et al. 2022). This is also the case in the study by Tkalich et al. (2022), which refers to the understanding of the role of the product manager in agile projects. In many technology companies, there are both product owners and product managers in large agile projects, some of whom compete with each other. Questions about the distinction from the product owner and the ideal positioning of both persons in projects are the starting point for ideas and measures here (Tkalich et al., 2022; Hoffmann, 2020). Furthermore, the literature emphasizes the importance of data-driven decision-making in digital product management. Key performance indicators and analytical tools to measure the success of a software product are examined (Fricke, 2012; Hofmann, 2020). Another aspect is the connection between AI and product management. In addition to its integration into other areas of life, product management is a new area that is merging with AI. Besides exploring the interface between the two, Namatherdhala et al. (2022) even introduce the term AI product manager, as they believe AI products require specially trained product managers. Even though this aspect has not been commented on further and needs more in-depth research, it is another contribution in the field of digital product management. Furthermore, the literature also frequently emphasizes the importance of user-centered design in digital product management. Discussions mainly revolve around the buzzword user experience (UX) design and usability testing as essential elements for the development of successful digital products. It is also noticeable that concepts such as minimum viable product and rapid prototyping are discussed in the context of digital product management and digital product development (Olsen, 2015).

These are some of the essential topics and discussions that arise in the literature on digital product management. Although the discussion about optimization in product management is not new, the main difference compared to the past is the dynamics compared to hardware products. Development times of only a few months lead to a different understanding and management of these products and thus represent one of the main differences. The exponential growth of software products leads to a constant demand for improvements in the handling of these products (Wagenblatt, 2019). It is striking that the old, physical world is hardly considered in the discussion about digital product management. The discussion about the transition phase from physical to digital products, or according to Hoffmann (2020) from old to new products, receives surprisingly little attention.

This is mainly because various studies have shown that many companies are not yet ready or have various dependencies on the old world (Bahrenburg, 2019). This is also the case in the study by Roecker & Moecker (2018, p. 3), who found that "*digital-physical products are currently not very widespread in the creative industries and only a few companies are already involved in their creation*". Although the focus of the study is on the creative industries, it shows that many companies are not yet ready to deal with digital-physical products from a product management perspective, and that dealing with digital-physical products in general is hardly considered (Roecker & Moecker, 2018). Many authors such as Jacobs (2019) or Aumayr (2019) see product management as an essential link between the old and new worlds and criticize that too little attention has been paid to this area. The increasing proliferation of digital products and services, which can bring both opportunities and challenges (Gentner & Oßwald, 2017), encourage to question product management for digital-physical products. The digital ecosystem is now more mature, and more digital offerings are anticipated to enter the market in the coming years, so companies face the challenge of consistently creating scalable value for customers with these digital solutions to the physical product (Plass, 2020; Bahrenburg, 2019). Digital offerings are subject to iterative development, so companies need adapted product management to respond to the needs of their customers (Keite, 2022).

Organizational classification of product management

Another aspect of the discussion on product management is its organizational set-up itself. The most common forms, namely staff-, line- and matrix-oriented, have already been mentioned and are constantly discussed in the literature and mirrored on the basis of specific companies or industries. In the days when the main problem of companies was to produce a certain product cheaply, the traditional functional form of organization, divided into the individual departments such as research, production, administration, etc., was certainly the most sensible, but the market has changed, and today the focus is on the question of which products can serve certain potential customers (Olsen, 2015; Stark, 2022). Increasing demands and ever-shorter product life cycles exacerbate the problem. In this dilemma, it is important to react flexibly and quickly to changes in the market. In this context, the flow of information, e.g., from the marketing department to research and development, often takes too long or is usually uncoordinated, which means that the competition is sometimes faster and can thus serve potential customers first (Aumayr, 2019). The establishment of an organization that deals exclusively with one product or product group seems to make sense in this context. At the same time, this aspect offers diverse possibilities for the interpretation of product management and consequently leads to different classifications of product management (Aumayr, 2019).

Nevertheless, the optimal organizational form of product management is currently being discussed. For example, Osterwalder et al. (2014) introduce the concept of the value proposition canvas and explain how product management can be focused on understanding customer needs, developing value propositions, and aligning the organization to deliver customer-centric products. Or Gopinath & Kishore (2017), who discuss different organizational models for product management in their journal article. These include centralized, decentralized and hybrid structures. In doing so, they examine the impact of organizational design on the effectiveness of product management. A focus on product innovation and how companies should organize their product management to foster innovation is discussed in the article by Ghasemzadeh & Archer (2019).

Initial discussions can also be found in the literature with regard to digital product management. For example, different organizational structures for digital product management and the role of leadership in fostering a product-oriented culture are explored. Discussions often emphasize the need for cross-functional teams, product-centric decision-making processes, and empowered product managers. This is also the case of Cagan (2017), whose studies examine issues such as team structure, roles and responsibilities, effective and digital product management organization. Cloutier & Paré (2013) go one step further and introduce the role of the Chief Product Officer (CPO). The role explores the responsibilities, competencies, and challenges CPOs face in leading the product management function and driving product success. These references provide insights and practical guidance for organizing and structuring product management in companies. So far, the constellations already listed (line-, bar- and matrix-oriented) have emerged as the most common product management constellations in practice (Aumayr, 2019; Matys, 2018). Nevertheless, current literature increasingly questions these and discusses various aspects such as team composition, collaboration, and stakeholder management in relation to digitalization in order to help companies adopt effective product management practices and achieve successful product outcomes (Cagan, 2017; Olsen, 2015; Ghasemzadeh & Archer, 2019).

It is clear that the complete study of product management with all its facets, concepts and models in relation to both worlds can hardly be grasped holistically so that a further subdivision must be made. As already mentioned, this means that product management must be further subdivided, which is why the next chapter describes the essential concepts and models and presents the product life cycle model, which is essential for this thesis, in detail.

2.3 Concepts and models in product management

In this section, the different models and concepts of product management are highlighted. Above all, however, the product life cycle as the most prominent concept in the context of product management is described and discussed in detail.

In most cases, a company not only produces a single product, but also offers a range of services. The economic success of a company therefore requires not only a decision on a single product or service, but also the design of a product program. This is usually developed by the corporate strategy (Raubold, 2011). The strategic decisions are made at the highest management levels and the product strategy represents the objective of future company-wide action with regard to the products. The product program is planned on the basis of the product strategy (Raubold, 2011). The design of the product program has an impact on the medium to long-term horizon of a company and includes, among other things, the planning of the length and characteristics of the life cycles. Figure 20 shows this relationship graphically:

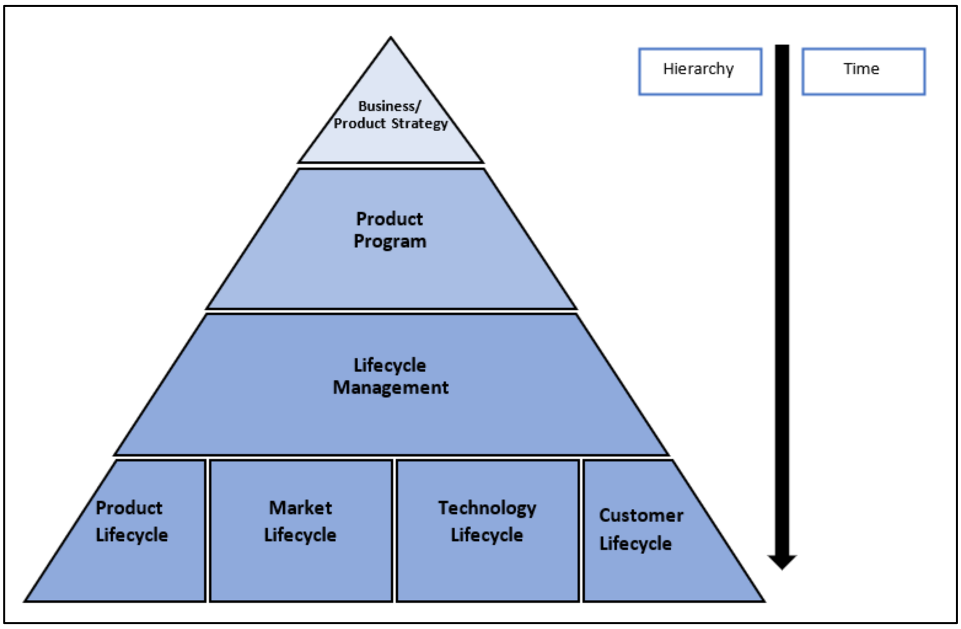

Figure 20: Sub-areas of product management (Source: In accordance with Raubold, 2011)

Specific strategy types can be chosen for corporate and product strategy, such as a focus on core competencies, diversification of the product program, the role of a mass producer or a niche strategy (Raubold, 2011; Thommen et al., 2020). The selected strategy type directly influences tactical planning as well as implementation and provides a guideline for product program design. The task of corporate program and product policy is to decide which products are developed and offered on the market. Here, the programme breadth and depth play an essential role (Raubold, 2011; Thommen et al., 2020). Product program breadth describes the number of product families or end products offered by the company on the market.

The program depth, on the other hand, is understood in marketing-oriented literature as the variety of the product program and is described by the number of varieties or variants of a product family (Thommen et al., 2020). Figure 21 shows an example from the rail infrastructure sector in terms of program depth and width.

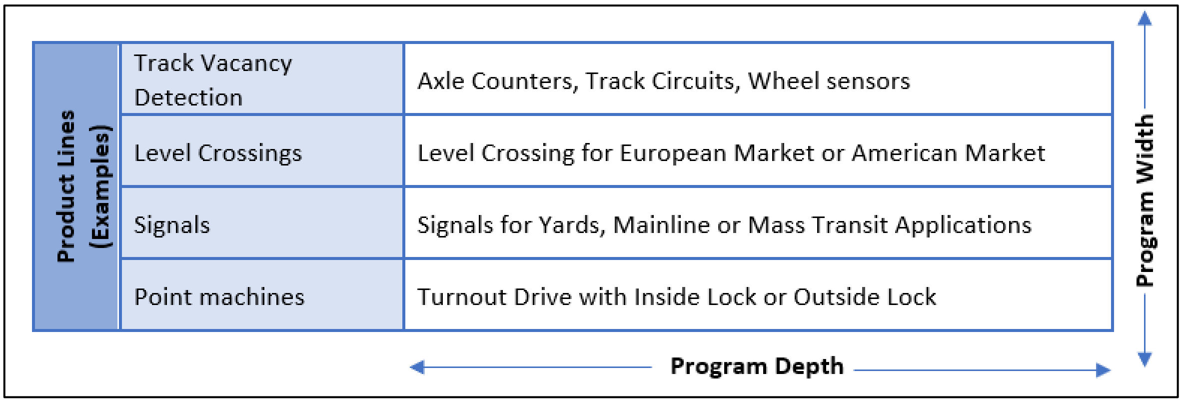

Figure 21: Product program width and depth (Source: In accordance with Thommen et al., 2020)

As described, product policy encompasses all decisions that relate to the design of a company's sales performance in the form of goods and/or services. Derived from this are various concepts for product management for the successful management of products. These are, for example, the management of the success chain, the decision-making processes and business models as well as concepts for the life cycle of products (Bruhn & Hadwich, 2017). The management of the success chain aims at increasing the effectiveness of product management. Measures are derived and presented with the help of which the success factors in product management can be identified. The permanent revision of one's own business models can lead to an increase in profit, which is why the management of business models is an important cornerstone from the profit perspective. From the process perspective, there is the management of decision-making processes. Simple and logical structures in a dynamic context are necessary to manage the success chain (Bruhn & Hadwich, 2017). Finally, the management of life cycles should be mentioned here, which will be focused on in the following. These concepts take a temporal perspective and specify the success variables over the course of a life cycle (Bruhn & Hadwich, 2017; Stark, 2022). In a dynamic environment and constantly changing framework conditions, product management must continuously adapt.

2.3.1 Definition and characteristics of the product life cycle concept

A large number of scientific works exist on the concept and management of life cycles, which deal with different thematic focal points and mostly refer to various theoretical considerations as a basis. This is because life cycle models cannot be derived from a closed theory but are the result of a multitude of empirical observations and, above all, plausibility considerations (Raubold, 2011). However, both a sufficient theoretical foundation and sufficient empirical confirmation are still lacking today (Bruhn & Hadwich, 2017). The fact that the ideal-typical representation of these models is presented without empirical validation led to criticism as early as the 1970s (Bruhn & Hadwich, 2017).

At that time, the applicability of the life cycle concept was fundamentally questioned due to its theoretical deficits (Dhalla & Yuspeh 1980; Cao & Folan 2012; Kotler et al., 2019). The overarching goal of the models is to "*identify regularities for the development of the underlying object of study as a dependent variable over time, to characterize the development over time and the phases that characterize it as well as their influencing variables, and to derive conclusions for one's own product and service strategy*" (Bruhn & Hadwich, 2017, p. 52). The achievement of this aim depends on the object of investigation (providers, products, etc.) as well as the purpose of the application and therefore results in different representations of the life cycle. These have developed in the context of business research and practice (Bruhn & Hadwich, 2017). The most common models are listed below, whereby the product life cycle model is explained in more detail and the others are only touched upon:

- Product life cycle
- Market life cycle
- Technology Life Cycle
- Customer life cycle

<u>Product life cycle</u>

The product life cycle is based on several life cycle phases that are passed through one after the other. No product in this world lasts forever and the constantly changing environmental conditions and, above all, the resulting changes in needs and customer wishes contribute significantly to the fact that products are generally subject to a limited life cycle (Gentner & Oßwald, 2017). The product life cycle is sometimes given a central position in the formulation of corporate and business strategies. Chandy et al. (2001) claim that the concept is one of the most important models for many marketing students in the US.

The many publications in recent years show the interest of academics in the concept. The concept is also accepted among practitioners and is used as a decision-making tool in almost all areas of business (Fischer, 2001), because the cycle contrasts the relationship between the development of sales or profits of a service over time. The origins of the product life cycle can be traced back to generalized observations in practice about the ideal-typical sales process of products. The idea of the product life cycle concept goes back to Dean in 1950, who described the change in environmental conditions and the resulting demands on management over the life of a product, but without referring to a product life cycle (Cao & Folan, 2012). The first closed presentation of the concept was by Patton & Deshler in 1959, who defined the life cycle as a time-related, systematic development of products along the lines of the development of natural organisms (Fischer, 2001): "*The life cycle of a product has many similarities with the human life cycle; the product is born, grows vigorously, reaches dynamic maturity, and then passes into years*" (Patton & Deshler, 1959, p.9). Patton & Deshler (1959) also designed the following illustration 22 of the product life cycle, which with its sinusoidal shape is still considered standard today:

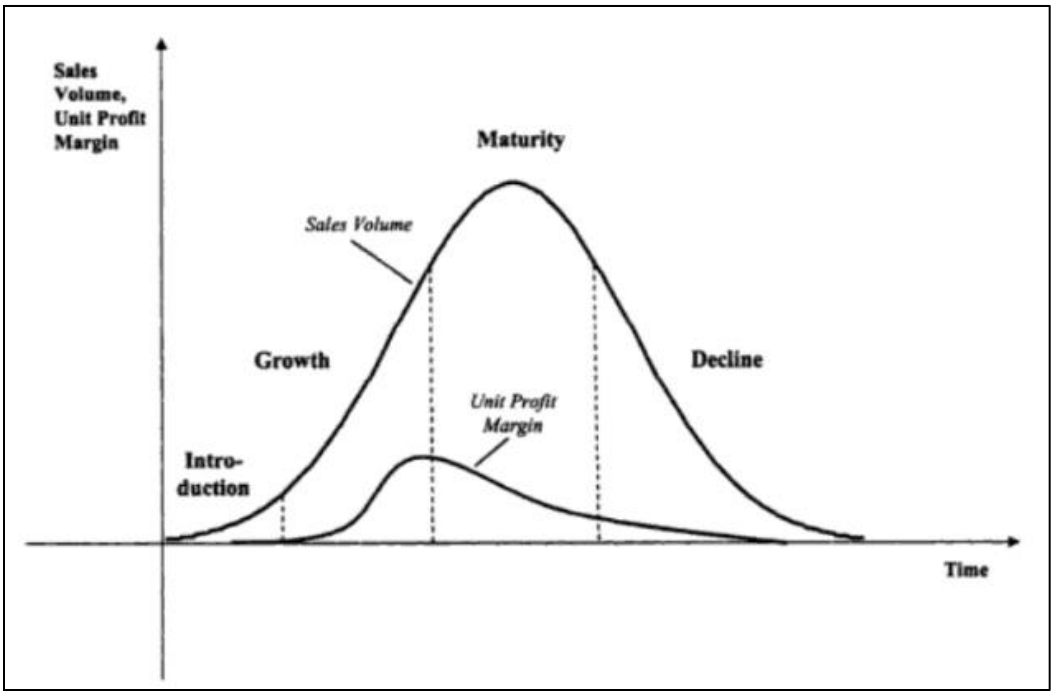

Figure 22: The classic product life cycle model (Source: In accordance with Patton & Deshler, 1959)

Product life cycle management serves as a tool for deriving strategic measures and is intended to actively manage the performance introduced on the market (Kotler et al., 2019). The company’s own products and also those of the main competitors are often assigned to a certain phase in the cycle (Kotler et al., 2019).

For example, suitable product strategies in terms of product improvement or differentiation can counteract the signs of saturation in the maturity phase, or suitable sales strategies can increase turnover in the growth phase. The management of this cycle has the task of taking measures to ultimately increase profits (Matys, 2018). In the past, it was usually only reacted to when performance had passed its sales peak and was showing the first signs of deterioration. In today's performance competition, this behaviour would force many products and companies out of the market. Today, early intervention in the life cycle is imperative for successful marketing of the product life cycle (Matys, 2018). In principle, the product life cycle covers the period from the first idea of a product until its withdrawal from the market. However, the product life cycle is mainly understood as the phase from market entry to the withdrawal of the product from the market (Schawel & Billing, 2018). Several phases are passed through and as already mentioned, no two life cycles are alike (Matys, 2018). They are as different as the products and their markets themselves. While some products' sales curves remain close to the idealized sinusoidal shape, others have undulating, almost horizontal courses or show a sudden break (Matys, 2018). Figure 23 presents the different examples graphically:

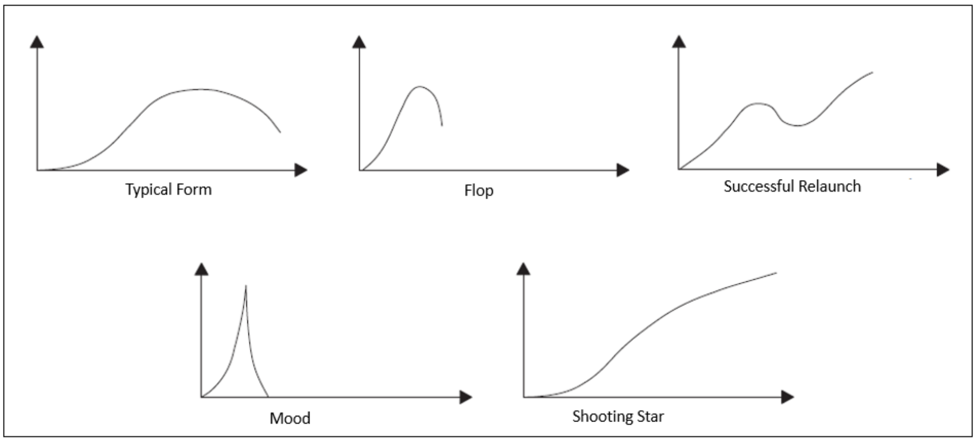

Figure 23: Exemplary representation of different product life cycles (Source: Matys, 2018)

The criticism of the concept of the product life cycle corresponds on the one hand to the one mentioned above, namely that the underlying hypothesis does not emerge from a closed theory but generalizes empirical observations. On the other hand, the course of the curve is subject to very many factors that can influence the curve in different ways. Such factors include influences from politics, society, the economy and the environment. These factors have an external effect on the system and can cause a change in the product life cycle (Matys, 2018). Although there are repeated attempts to map these factors, the possible combinations of factors affecting the cycle are too extensive. As a result, the theory takes a back seat to practical applications, because not every product life cycle corresponds to the aforementioned form and does not have to go through every phase (Kotler et al., 2019).

Another point of criticism is derived decision quality of the concept. The derived strategies in all phases can only be applied if it can be said with certainty in which phase exactly the product is. The decisions thus depend on the assumed regularities and are only of limited use as a basis for strategic decisions (Kotler et al., 2019). Nevertheless, the model basically encourages to reflect the current status of the product and to mirror this against potentially strategic measures. Due to the different characteristics of the product life cycle, the individual phases are described with varying degrees of precision in the literature. Different descriptions exist with three to seven phases, but mainly the five phases of introduction, growth, maturity, saturation, and decline are classified, which will be explained in more detail below (Raubold, 2011; Kotler et al., 2019).

Introduction phase

After the development phase, the finished product is introduced to the market and handed over to the customer. In the development and subsequent launch phase, high investments are made as upfront expenditures without any return on the revenue side. In addition to the costs for the development of the product, expenses are incurred for the preparation of production and for making the product known to the public. Advertising, public relations, sales promotion and aggressive pricing tactics are the most important elements in making the product known and positioning it in the market. The product launch determines the success or failure of the product (Fischer, 2001; Raubold, 2011). In principle, the course of the curve is explained by the success of the launch activities of the product management and the curiosity of the customer. Depending on the industry and market, this phase can last from a few months to decades (Raubold, 2011).

Growth phase

The introduction phase is followed by the growth phase, in which high investments in advertising and communication continue to be made. However, turnover and earnings increase due to high customer demand and reduce the sum of the previously made expenditures (Aumyar, 2019). Often, the profit zone is reached here for the first time. Pricing and terms policies become increasingly important as competitors try to launch similar or identical products to benefit cost-effectively from the launch activities of the first mover. If the product succeeds in exceeding a critical sales volume, exponential sales growth occurs in the ideal-typical case. The maximum profitability is in the growth phase, while the highest liquidity is achieved in the following maturity phase (Stark, 2022). Furthermore, this phase is also characterized by optimization of the technical-functional performance or elimination of some technical errors (Bruhn & Hadwich, 2017; Biermann & Erne, 2020).

Maturity phase

In practice, the maturity phase lasts longer than the previous two phases and is usually the longest market phase (Raubold, 2011). The maturity phase is when the product is so prevalent in the market that growth stagnates (Matys, 2018). It is no longer a "novelty" or a "trend", but perhaps a "must-have" (Raubold, 2011). Many well-known products that have been on the market for many years are in this phase. This phase is the most profitable, as sales are highest here. However, profits gradually decline as competition is very strong. Yet the companies still have a high market share. They can maintain and increase this through appropriate maintenance marketing and product variation and diversification (Stark, 2022; Biermann & Erne, 2020).

Saturation phase

There is a high probability that the saturation phase will occur at some point. The product no longer shows market growth. The peak has been reached and the phase of decline slowly sets in. The accruing turnover comes mainly from replacement purchases. The market potential is largely exhausted, and the intensity of competition is high. Profits therefore show a downward trend (Gaubinger, 2015). Through various modifications, one can now still try to win more customers. As a recommendation for action, achievable profits should be realized in the short term; in the medium term, a repositioning of the product or a market exit makes sense (Gaubinger, 2015).

Degeneration phase

The last phase is the degeneration phase. The market is shrinking and the decline in sales cannot be cushioned even by targeted marketing measures. The product is technically and/or fashionably outdated (Fischer, 2001). New innovative product offerings enter the market and become the focus of customer interest. The product loses market share and shows negative growth, profits fall, and the portfolio should be adjusted, unless there are interdependencies with other products (Fischer, 2001). If this is not done quickly and properly, the product can no longer generate sales, but inventories for spare parts, support, etc. tie up capital. The product should be kept on the market as long as its contribution margins are positive and a volume above the break-even point is sold, at least in the medium term (Matys, 2018; Biermann & Erne, 2020).

In principle, the product life cycle can be interpreted even further by integrating the creation and disposal phases. The disposal phase in particular is experiencing an enormous boost driven by climate change and the literature is increasingly focusing exclusively on this phase.

According to Deneux et al. (2004), the ideal-typical course of a product's life can and should be extended by adding certain time dimensions. These time dimensions should not only be taken into account in product life cycle management but should also be actively managed (Deneux et al., 2004). The analysis of the individual phases and their time dimensions can lead to certain derived measures that can, for example, reduce the time-to-market dimension. The time factor plays a key role in the success of a product, essentially caused by the digitalization of products (Deneux et al., 2004).

Although this presentation of the time dimensions corresponds to a similar criticism, namely that the course is not realistic in practice and that there is no sharp distinction between the phases, its diagnostic value should not be underestimated (Bruhn & Hadwich, 2017; Stark, 2022). Before going into the current discussion about the product life cycle, the other concepts of product management as a function of time are presented and briefly described below.

Market life cycle

The market cycle shows the temporal course of an entire market and helps product management to make a statement about the market. Through the market life cycle analysis, market potentials can be determined, and the corresponding measures can be derived, such as a new development of a product line or the removal of a product line Kotler & Keller (2016). Market cycle management determines one's own position in the market and derives further different conclusions for product management with regard to product, instrumental, sales and competitive strategy. According to Kotler & Keller (2016), the life cycle of a market corresponds to an overlapping of the individual product life cycles, which is why it resembles the product life cycle. The argumentation of the critics of this concept is very similar to that of the product life cycle, namely that the development of the market follows the ideal-typical course as well as the sharp delimitation of the individual phases (Porter, 2013; Kotler et al., 2019). Nevertheless, the consideration of the concept is important for strategic measures of product management, as it explains the temporal development of markets in a descriptive way. However, "*general recommendations for action cannot be derived solely on the basis of a current position in the market life cycle [...]*" (Bruhn, 2009, p. 72). In addition to the product and the market, the technology itself can also be represented in a cycle, which is now described in more detail.

Technology life cycle

Various approaches have been discussed in the literature for a detailed description of the technology life cycle. The most prominent technology life cycle is that of Arthur D. Little (1986), which is based on the assumption that every technology also goes through a cycle. This cycle is determined by the demand for products and services based on the technology. Based on this cycle, statements can be made about the technology potential over time, whereby an ideal-typical course over time is assumed, similar to the product life cycle. The phases correspond to the emergence, growth, maturity and age phase, whereby not every technology has to go through all phases, for example through substitution by other technologies or early elimination of technologies (Greitemann et al., 2017; Bunduchi & Candi, 2021). Figure 24 shows the course of the ideal-typical technology life cycle:

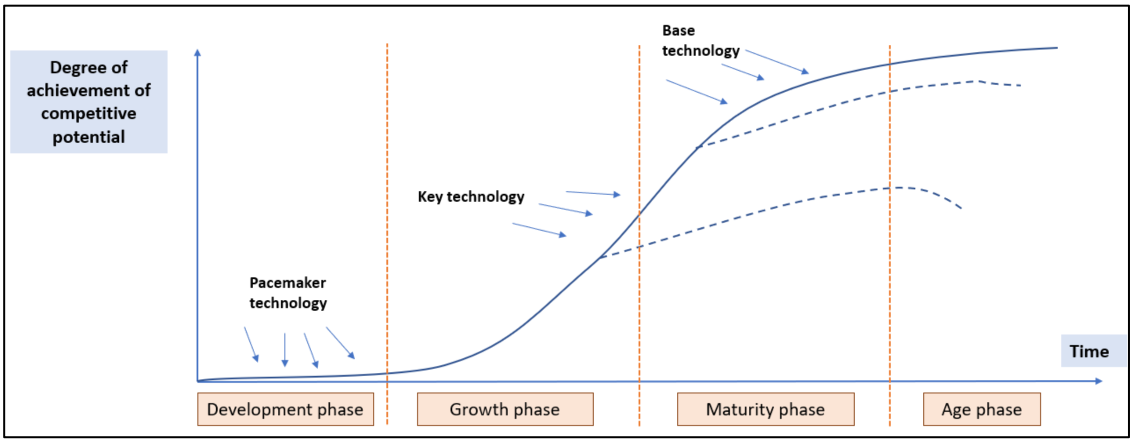

Figure 24:The idealistic representation of the technology life cycle according to Little (1986) (Source: In accordance with Schuh, 2011)

Customer life cycle

The customer life cycle focuses on the needs and requirements of the customer and moves product management towards a more customer-oriented attitude. According to this concept, it is indispensable for product management to analyze customer needs and to be able to react to changing customer needs in time (Stone et al., 2013). The customer relationship cycle, one of the key cycles within the customer life cycle, describes the ideal-typical course of a customer relationship in relation to time and shows the different phases with regard to the intensity of the customer relationship, which can be seen in Figure 25:

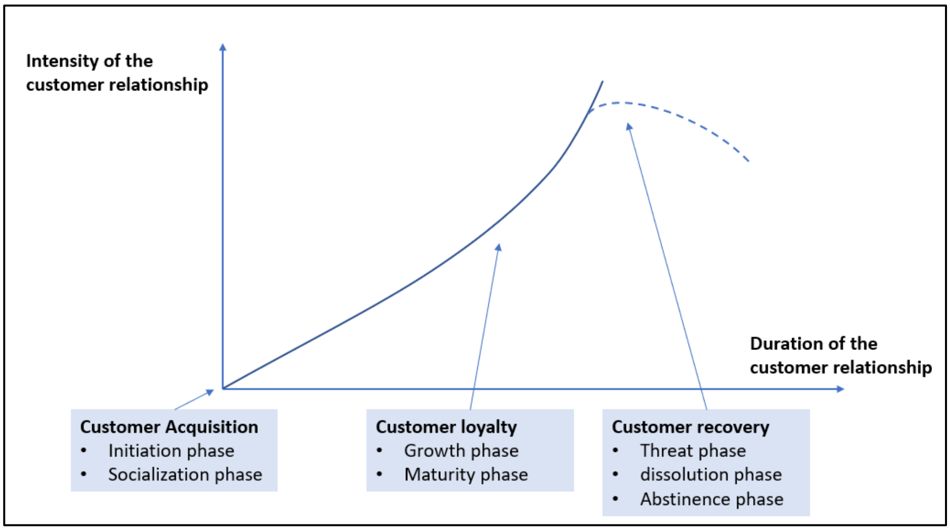

Figure 25: Phases of the customer relationship cycle (Source: In accordance with Stauss, 2006)

From the customer relationship cycle, conclusions and measures can be derived for product management. The concepts from behavioural science described in section 2.2.1.5 which show how important brand personality and brand relationships are for customer loyalty, play an important role here. However, as with all the concepts described so far, this customer-oriented view corresponds to an ideal-typical one. The concrete course, the duration as well as the transitions of the phases also depend on various other factors (Breuer & Perrey, 2011; Stone et al., 2013). Human individuality is often cited in the literature as a further point of criticism of the concept. Not every customer (person) is the same, which is why this black and white pattern is also subject to criticism of its accuracy (Reichertz, 2022).

2.3.2 Current discussion on the product life cycle concept

In principle, the topic of life cycle management is quite novel, and the discussion has hardly been held in this form so far. The concept of the product life cycle has been discussed extensively in the literature, with various aspects and perspectives being examined. The fact that it is now being conducted so intensively is partly due to the fact that development, production, distribution, product use, maintenance and even recycling have become such complicated and complex processes that it is not uncommon to lose track of them. Some of the most important discussions in the literature on the product life cycle are presented below:

Similar to the literature of product management, the discussions around the product life cycle itself are also very pronounced, so that various studies on the history and its classification can already be found in the literature, such as by Cao & Folan (2012) and Holler et al. (2019).

Moreover, the classification of the product life cycle in a company is often done from different functions. For example, Nair (2019) considers the concept of product life cycle as part of the marketing literature, while others such as Lühring (2007) anchor product life cycle only in product development, as this is where 70% - 80% of the costs are incurred. Moreover, discussions often revolve around the appropriate strategies to be applied in the different phases of the product life cycle. These include strategies for market entry, capturing market share, sustaining growth, managing maturity, and extending the product life cycle. In addition to the general discussion between the individual concepts and types of life cycles, the current literature is also primarily concerned with the length of the life cycle, especially in the case of the product life cycle. Many publications assume that the product life cycles of technical products have shortened. Schäfer (2006) in his dissertation sees a trend towards ever shorter cycles and many others such as Keller & Lasch (2020) and Schork (2020) agree that product life cycles are becoming shorter due to competition, shorter time for product development and increasing product diversity. However, various studies also take the opposite view. The literature emphasizes the importance of product differentiation and innovation in maintaining the life cycle of a product. Discussions often revolve around the need for continuous improvement, new features, upgrades, and product innovation to meet changing customer needs and remain competitive. One of the best-known studies is that of the Fraunhofer Institute from 2005, which examined data from 1,157 companies in the German metal and electrical industry. The conclusion was that the shortening of product life cycles is only a perception (Kinkel, 2005). "*If product life cycles had been significantly shorter in the past, companies would have responded by developing new products more quickly and subsequently measurably increased their share of sales. [...] In fact, the share of turnover with new products [...] has fallen*" (German Bundestag, 2016, p. 9). Authors such as Drechsler et al. (2019) and Biermann & Erne (2020) support this statement that the product life cycle has not shortened and see the reason for this in the market, among other things. *"[...] the goal is often no longer to generate a unique selling proposition via physical products alone, but to expand the offer to include comprehensive services*" (Drechsler et al., 2019, p. 323). In this discussion, the customer life cycle is often cited in order to take the needs of the customer into account and bring them into the discussion.

Driven by the many advantages of the different life cycle concepts, several studies are currently dealing with their optimization. For example, certain optimization approaches aim to improve product development, as this represents the largest cost factor (Braess & Seiffert, 2012). Other studies, such as those by Jacobs (2019) and Biermann & Erne (2020), attempt to optimize the life cycle from a purely controlling perspective.

The determination of the time of market entry alone can have a significant impact on the overall market lifecycle profitability of a product. Furthermore, the concept of sustainable life cycle management is in the focus of attention due to the current discussions on climate change. New guiding principles and models are being developed to optimize the relationship between people, products and the environment (Aumayr, 2019; Scholz & Pastoors, 2018).

It can be seen that the literature often examines the impact of technological advances and industry trends on the product life cycle. Discussions highlight the need for companies to adapt and innovate to respond to changing technologies, market disruptions and shifting customer preferences (Cagan, 2017; Ghasemzadeh & Archer, 2019). Therefore, the digital product life cycle has received considerable attention in the literature due to the increasing proliferation of digital products and services. In a similar way, the literature often emphasizes the importance of agile and iterative development methods in the digital product life cycle, as well as the importance of user-centered design and UX throughout the product life cycle (Cagan. 2017; Rosenzweig et al., 2013). Strategies for product launch and growth in the digital sphere also occupy a large field. Topics such as go-to-market strategies, digital marketing tactics and the use of online platforms to promote product growth are discussed (Dwivedi et al., 2019). In addition, discussions address monetization strategies and business models throughout the life cycle of digital products. Topics include subscription models, freemium offers, in-app purchases, advertising, and other approaches to revenue generation (Wirtz et al., 2010; Cagan, 2017; Ghasemzadeh & Archer (2019).

However, it is striking that the current studies on optimization potentials hardly focus on digital-physical products. It is true that the challenges of integrating digital and physical components in the design and development phase are highlighted in the discussions, but the area of the market phase remains untouched. Raubold (2011) notes that this phase is disregarded even though newly developed products must be in the market phase for many years and this phase generates the most revenue for suppliers and define the company (Brockhoff, 1999; Bruhn & Hadwich, 2017). Various scientific studies (Schork, 2020; Schröder & Wegner, 2019; Appius et al., 2017) point out that the dynamics of markets and the pressure to innovate and compete mean that the maintenance and further development of products that are in the market phase play a major role. This is particularly true for products with a long useful life by the customer, such as in transport infrastructure. Product providers in this area usually serve few customer groups and segments, which makes a competitive portfolio essential (Raubold, 2011).

There are initial approaches in the literature regarding the relationship between digital-physical products and the product life cycle, such as Khan & Hafeez (2020). Here, the effects of manufacturing a digital-physical product on the manufacturing processes and the management of the supply chain are examined. Issues such as sourcing components and coordinating production schedules are discussed. The literature also addresses the challenges of managing software updates and maintenance of digital-physical products. Strategies for providing software updates, ensuring compatibility, and addressing security vulnerabilities for both digital and physical components, are discussed (Yousefnezhad et al., 2020; Zhang & Luo, 2018). It is worth noting that discussions on digital-physical products and the product life cycle build on existing discussions on the broader product life cycle and include additional considerations related to the integration of digital and physical elements. This multidimensional aspect brings unique challenges and opportunities that require careful management throughout the product life cycle (Yousefnezhad et al., 2020; Zhang & Luo, 2018).

Section 2.2 and section 2.3 have shown the different forms, theoretical foundations, classifications and characteristics of product management and its concepts. It can be seen that product management can be characterized by many factors and can be lived differently depending on the weighting and interpretation of these factors. Likewise, the activities of the product manager depend strongly on the type of product, the culture, history, and organization of the company as well as the goals. The diverse discussions around the product life cycle also show the complexity in the context of product management. Therefore, based on the different possible interpretations, product management and product manager need to be further delineated. For this, it was important for the researcher to settle on and examine a specific pattern of product management. A general statement that takes into account all factors of product management is hardly possible. Therefore, product management and the product manager in general in the railway industry will be described in the following and underpinned by insights within Siemens Mobility GmbH. This is the starting point for further research in order to be able to reflect the results of the investigation.

2.4 Product management in railway industry

Just like many other industries, Industry 4.0 and the digital transformation are finding their way into the railway system. The rapid development of technologies and data makes it necessary to adapt products, systems and working methods in order to get the most out of them (Shah et al., 2021; Chandra, 2019). In addition to this trend, politics and society also expect far-reaching technological innovations in the railway system. The railway system can make a significant contribution to climate change, so that the demands for innovative solutions in the industry are higher than ever before. The overriding goals are to get more goods onto the railways, to increase passenger numbers and to significantly improve punctuality (European Commission, 2019). To achieve these goals, rail capacity needs to be increased, which is why technological innovations and the digitalization of the rail system represent the greatest levers for increasing capacity. New products and solutions are required to drive the industry forward (Wang et al., 2020). As already described, product management, which is responsible for planning and controlling a product while taking into account all relevant framework and boundary conditions, is of great importance in this context. Compared to other industries, this market is strongly driven by customers and is in an extremely tough, competitive environment (Chandra, 2019). In the industry, competition is concentrated on a few manufacturers, which increases the intensity of competition (European Commission, 2019). To attract new customers or win back existing ones, an attractive as well as innovative product offering is essential. In addition, special conditions and incentives must be offered in order to win the favour of customers. Without an attractive and constantly updated product portfolio, competitiveness is at risk and there is a threat of a decline in sales figures combined with losses on the turnover and profit side (Matys, 2018). The products in the rail infrastructure sector are above all subject to a high level of safety, availability and a long service life. In the following, the described findings from the previous chapter as well as characteristics of the areas of the product life cycle, product management and digital-physical products in the context of the railway industry are shown.

2.4.1 The product life cycle within the railway industry

The product life cycle of a railway product usually consists of several phases, each of which includes a number of activities and objectives. Generally speaking, the phases are oriented towards the usual product life cycle, which are briefly described below with their essential content in the context of the railway industry.

Thus, the research and development phase include the initial research, design, and development of the railway product. This includes activities such as market research, identifying customer needs, defining product requirements, and conducting feasibility studies. This is followed by the design and construction phase. Here, the product concept is translated into detailed designs and technical specifications. The design team works on creating 2D/3D drawings, prototypes and performs simulations (Bracken & Scholten, 2017). The engineers ensure that the product complies with safety standards, regulatory requirements, and industry specifications (Siemens Mobility, 2021). This is essential as railway products undergo rigorous testing to ensure their performance, reliability and compliance with safety and regulatory standards. The tests can include functional tests, performance tests and safety assessments. Once the product has passed the required tests, it can receive the necessary certifications and approvals to operate in the rail industry (Shah et al., 2021; Guo & Yang, 2017; Siemens Mobility, 2021). This is followed by the market launch, where the previously identified marketing and sales strategies are implemented to promote the product to potential customers and increase sales. The product is then introduced to the market and feedback is obtained from customers to assess the initial performance and acceptance of the product. Once the product has gained a foothold in the market, the growth phase focuses on expanding its reach and gaining a larger customer base (Shah et al., 2021). Product managers gather customer feedback, analyze market trends, and identify opportunities for product improvements or new features. Regular updates and improvements are made to meet evolving customer needs and remain competitive in the market. At this stage of saturation, the product reaches a stable phase with a well-established customer base. The focus is on maintaining and optimizing the performance, reliability, and customer satisfaction of the product. Regular maintenance, updates and bug fixes ensure that the product continues to meet customer expectations. The last phase corresponds to the usual decline phase. The focus is on managing the end-of-life process of the product, including discontinuing production, supporting existing customers and managing any necessary product renewals or upgrades (Shah et al., 2021; Guo & Yang, 2017; Siemens Mobility, 2021).

Of course, again, the duration of each phase may vary depending on the type of rail product, market conditions and industry dynamics. Even though the activities in the phases and the phases themselves are based on the general phases of the product life cycle, there are some unique characteristics of the product life cycle in the railway industry compared to other industries. These particularities arise from the complexity of railway systems, the long product life cycle, regulatory requirements, and the need for extensive safety measures. Some of these special features of the product life cycle in the railway industry are described below:

Long product life cycles:

Railway products, such as those from infrastructure, have significantly longer life cycles compared to many other industries. The extensive investment required to design, manufacture, and deploy railway equipment requires longer usage periods to achieve a return on investment. A hardware changeover of a physical product is therefore associated with a high effort and cost for the railway operator, which is why operators often demand a product availability of around 20 years. The products can remain in service for several decades with proper maintenance and regular upgrades (Chandra, 2019).

Technological continuity:

Compared to the software industry, technological change in the rail industry is relatively slow. The introduction of new technologies in the rail industry is usually gradual, as rigorous testing, safety certifications and compatibility of existing systems are required. As a result, the market phase often stretches over several years (Zampino et al., 2017; Chandra, 2019).

Strict compliance with legal regulations:

The railway industry is subject to strict safety and regulatory frameworks. Extensive safety standards and certifications must be met throughout the product life cycle to ensure the reliability and safety of railway operations. Being compliant with these regulations affects the development, testing and implementation phases and requires a lot of detailed work and thorough documentation (Zampino et al., 2017; Chandra, 2019; Siemens Mobility, 2021).

Life cycle management and maintenance:

The maintenance and management of railway products throughout their life cycle is critical for safety and operational reasons. Railway assets need to be regularly inspected, maintained, and occasionally replaced or overhauled to ensure optimal performance, reliability, and compliance with safety standards. Life cycle management activities, including preventive and predictive maintenance, play a critical role in minimizing downtime and maximizing asset utilization. In addition, compared to other areas, product managers must have a thorough understanding of a product's dependencies and impact on its environment. As mentioned, individual products are embedded in an overall system, which often has several direct dependencies on other systems Ansell et al., 2019).

Understanding these specificities is crucial for railway industry stakeholders, including manufacturers, operators and regulators, and define the product life cycle. This is because it is primarily these specific features that lead to a special product life cycle in the railway industry (Ansell et al., 2019). For example, the maintenance, installation and deinstallation of the large number of individual products in the field is associated with a high level of effort, which is why a long service life of these products in the field has been prescribed (Siemens Mobility, 2021). Due to the strict compatibility aspects and approval processes, the turnover of a product increases only slowly compared to the software industry, as the product launch is usually done via individual lines that cannot be converted at the same time. Another reason for the slow increase is the country-specific approvals of a product. A country approval of an axle counter in Germany, for example, does not mean an approval of the product in another country, sometimes not even with another operator (Siemens Mobility, 2021). Above all, each country has different requirements for the product due to its history and its own safety philosophy, so that the time-consuming process of a country approval can take years. Although the products have to follow a certain predefined process (in Europe, for example, according to CENELEC) during development, there are country-specific requirements that go beyond the product approval according to the process. Nevertheless, the products reach their maturity and saturation phase after a few years (in the example of wayside products after about eight years), as more and more lines in more and more countries are equipped with the product (Siemens Mobility, 2021). In parallel, new products are already being developed during this time, with certain features often being integrated into the field elements in a comprehensive update (Siemens Mobility, 2021). This usually results in an increase proportional to the entire cycle through the update before the product reaches the last phase, degeneration phase. Here, the product is gradually migrated or replaced by the developed products and taken out of the field. The life cycle is shown schematically in Figure 26:

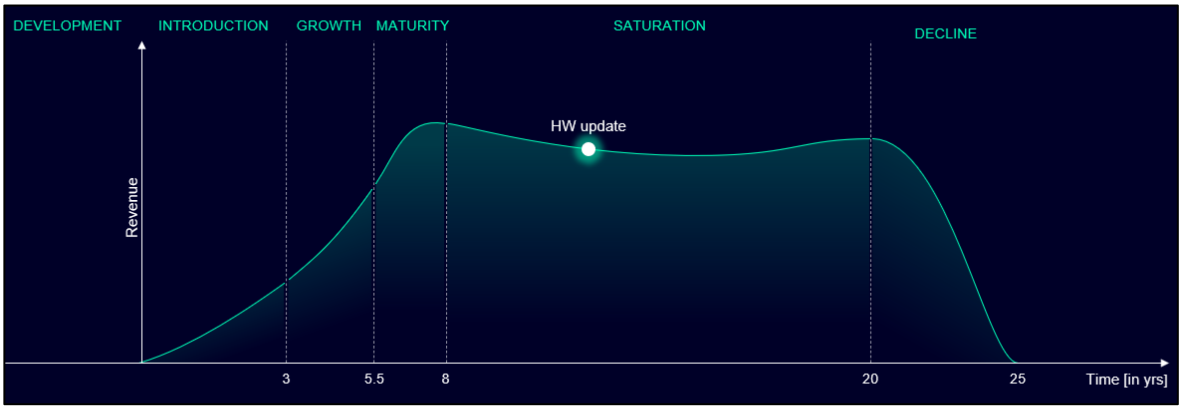

Figure 26:Exemplary product life cycle of a rail infrastructure product (Source: Authors own illustration)

The illustration shows the turnover over time using the axle counter as an example. The main characteristics are the service life of around 25 years, the slow increase in turnover of the product and a larger hardware adjustment in the saturation phase. Other products from the rail infrastructure sector, such as point machines or signals, may deviate from the product life cycle model shown here, but are also subject to the boundary conditions mentioned. A similar product life cycle model therefore also results for these products. In the following, product management within the railway industry and Siemens Mobility GmbH will be described, which has the task of looking after and controlling such products throughout their entire life cycle.

2.4.2 Product management within the railway industry

Just like the product life cycle, product management in the railway sector has some special features compared to other industries. These particularities result, among others, from the specific characteristics of railway products, and from the complexity of the railway ecosystem. For example, according to Shah et al., (2021), in addition to the activities commonly highlighted in the literature, product managers have to consider long-term planning, maintenance strategies and regular upgrades or modernizations throughout the life cycle of the products due to the long product life cycles. Due to high safety requirements, product managers have to navigate a complex web of safety regulations and standards to ensure that their products meet the required safety criteria. Compliance with industry-specific regulations, such as interoperability and compatibility standards, is crucial for product managers to ensure seamless integration and operation within the wider railway network. (Shah et al., 2021; Chandra, 2019).

As mentioned earlier, the individual rail product is embedded in an overall system. Tyler (2017) argues that product managers need to consider and ensure interoperability requirements so that their products can work with existing infrastructure, signaling systems, and rolling stock. This often requires coordination with various stakeholders to ensure compatibility and smooth integration. The coordination aspect can be further extended to rail operators, infrastructure managers, regulators, and technology suppliers. Therefore, effective communication and collaboration with diverse parties are essential to manage the complexity of the rail ecosystem (Guo & Yang, 2017). In addition, product managers need to focus on robust design, quality control and maintenance strategies to ensure the reliability and availability of their products (Chandra, 2019). Finally, in addition to the technical aspects, there are budgetary aspects across the product life cycle.

Product managers in the rail industry need to consider not only the upfront costs of designing and manufacturing their products, but also the life cycle costs associated with maintenance, upgrades, and eventual decommissioning. Balancing upfront investment with long-term cost efficiency is critical to making informed decisions about product features, materials, and maintenance strategies (Guo & Yang, 2017; Chandra, 2019).

These specificities make product management in the rail industry a complex and challenging task (Guo & Yang, 2017; Shah et al., 2021). Understanding the unique requirements and dynamics of the rail sector is crucial for successful product development, market positioning and customer satisfaction in this industry. To illustrate the aforementioned aspects even more concretely, the role of the product manager and product management from Siemens Mobility GmbH will be examined more specifically. Here, a product manager is usually responsible for several products and assumes the information, planning, control, and coordination tasks shown in Figure 16. The product manager is also responsible for the approval process. As a peculiarity, the monitoring of the approval process in a country can be added here. Furthermore, the product manager is internationally positioned, so that this person bears global responsibility for the product. Although project managers, salespeople and maintainers from the various regions work with the product manager, the budget and strategic responsibility for the product lies with the product manager. In addition, the tasks of the product manager are not divided into a product manager for sales (PLM-S) or technology (PLM-T) as outlined in Figure 2. In this case, one person combines both views and the experts of the respective areas act as an interface to the product manager. Figure 27 graphically depicts this connection with the essential interfaces of product management:

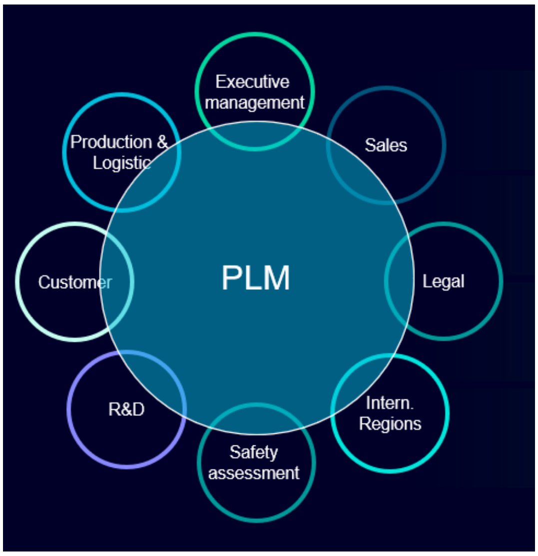

Figure 27:Examplary representation of the interfaces of the product manager at Siemens Mobility GmbH (Source: Authors own illustration)

Organizationally, product management at Siemens Mobility GmbH is based on the matrix organization shown in Figure 11. However, the product managers do not report to the marketing department or any other department. Product management forms its own unit here and is subordinate to the executive management of the respective division. Product management itself is subdivided into different product portfolios with the respective product managers, as shown in Figure 28:

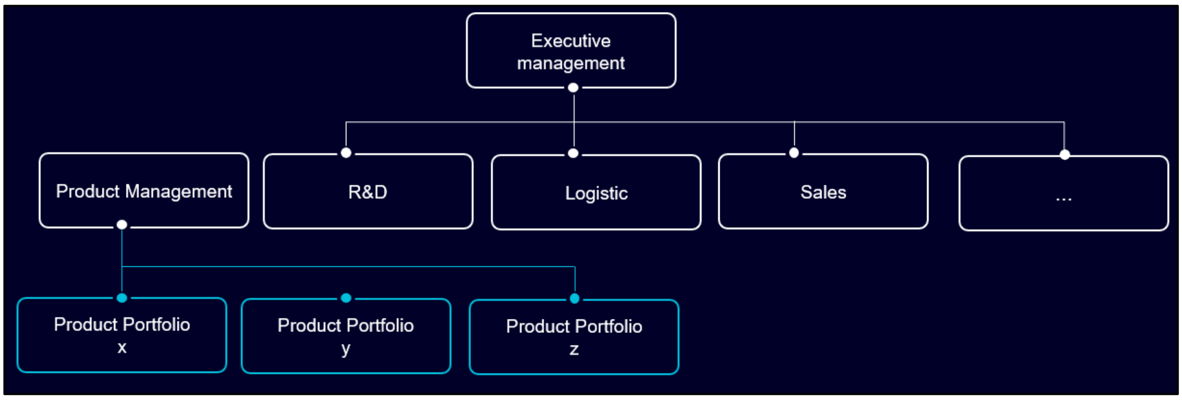

Figure 28:Examplary representation of organisational product management at Siemens Mobility GmbH (Source: In accordance with Koppelmann, 2013)

The product portfolio is defined by Schicker & Strassl (2019, p. 3) as follows: "*A product portfolio is a complete compilation of all products planned, offered as well as discontinued by a company (or a strategic business unit). The product portfolio includes tangible goods, services and hybrid service bundles [...]"*. The product portfolio consists of product managers of a product family (in the example of the axle counter, it is the sensor technology) and manages, controls and designs the product portfolio. The product managers determine the functions, activities and manage the budget in relation to their products but are not authorized to issue instructions to other departments. Often, the product management has to use its powers of persuasion to generate the other departments for its purposes, but at the same time the product manager has the informal power through budget and interface with the management.

As described here, this study will take a closer look at a product management organization and its specific framework conditions. This will establish an understanding into the functioning, dynamics, and challenges of a specific department within an organization in order to then better understand possible improvement potentials based on this company. After all, by focusing on one department, researchers can gain specific insights that can provide recommendations for improvement or contribute to the scientific literature in a particular area. This aspect has been demonstrated for years by several researchers who have focused on one department or product.

For example, the study by Utterback & Abernathy (1975) who focused on the challenges and opportunities of product management in the context of agile development methods, Gemünden et al. (2008) who investigated the challenges of managing innovation projects with high complexity and thus provided insights into effective project management strategies, or Conforto et al. (2016) who investigated the impact of agile principles on project success. These examples support the approach of focusing on a specific department in order to draw conclusions from it as well.

2.4.3 Digital-physical products in the context of railway industry

Digital-physical products play an important role in the rail industry as they offer several key benefits and address specific challenges. Overall, digital-physical products are helping the rail industry by improving safety, operational efficiency, passenger experience, asset management, capacity utilization and data-driven decision-making. They enable the transformation of traditional railway systems into modern, connected, and intelligent transport networks (Lui & Yan, 2018).

Wang et al. (2020) provide an overview of digital-physical systems in the railway industry in their article. The overview highlights the benefits and challenges of implementing digital-physical products in the railway sector. For example, digital-physical products optimize train operations, infrastructure maintenance and resource allocation. Real-time data analytics, predictive maintenance and automated control systems help minimize delays, improve scheduling, and increase overall operational efficiency. This leads to better use of resources and lower costs. Liu & Yan (2018) again highlight the optimization of railway operations. Digital-physical products help to maximize the capacity and efficiency of the railway network, which ultimately leads to higher network capacity and smoother operations. Another key aspect regarding digital-physical products is the promotion of interoperability and connectivity within the railway ecosystem. According to Wang et al. (2020) and Siemens Mobility (2021), standardized interfaces, data sharing and communication protocols allow different subsystems to interact seamlessly. The last aspect to be mentioned here is advanced asset management (Bravo & Lueddecke, 2021). Digital technologies facilitate condition monitoring and predictive maintenance of railway assets. Sensors, data analysis and remote monitoring enable proactive maintenance that identifies potential faults before they lead to significant disruptions. This leads to higher asset reliability, reduced downtime and optimized life cycle management (Bravo & Lueddecke, 2021). The aspect of advanced asset management has also been taken up within Siemens Mobility.

Therefore, a so-called Asset Performance Monitoring Tool (APM tool) was developed as a pilot. The APM tool is a modular end-to-end solution that uses the Industrial Internet of Things (IIoT) to monitor the performance of railway infrastructure elements. In this process, hundreds of diagnostic data are extracted and logged from the track vacancy detection system. "*From their first day of life together with some data from the asset environment. Thanks to specific algorithms based on years of experience spent developing and operating these products, the applications helps users define actions in the most efficient and effective manner*" (Bravo & Lueddecke, 2021, p. 45). For example, after the failure analysis, the tool suggests solutions to failure causes. The tool picks up the data provided by the product, so to speak, and presents it visually. This enables, among other things, real-time monitoring of plant conditions, analysis of performance as well as plant health. Furthermore, field signal data can be collected and integrated to derive analyses and visualizations to improve plant reliability and availability. In addition, it is intended to be a software-as-a-service solution in the railway sector that offers further functionalities to the customer (Bravo & Lueddecke, 2021).

Digital-physical products and their services will create added value for numerous players in the rail industry and contribute to the implementation of new mobility concepts in the future (Pieriegud, 2018). However, the transformation itself but also the change of business processes and the management of new products remains a challenge. "*Digital transformation goes far beyond the digitization of data and processes. Rather, it is about continuous adaptation to change in a turbulent environment. This holds opportunities and threats for every industry, not least the rail industry. The challenge to be met in the coming years is not only the switch from electromechanical to electronic devices, followed by the switch to digital components [...] but above all a general change in mentality [...]*" (Pieriegud, 2018, p. 54). The question therefore arises to what extent digital-physical products lead to a change along the product life cycle. A detailed investigation is needed into the impact of digital-physical products on product management and the possibilities for managing them optimally. This investigation of the interaction between digital-physical products in the framework of the product life cycle model and product management is the aim of this research work.

2.5 Boundary of existing literature

The literature review has shown that many researchers have focused on different aspects of digital-physical products and product management. For example, the focus in digital-physical products is on the definition and in the product development of the products whereas in product management the focus is on purely digital aspects. In the following, the limitations of the literature in relation to this thesis will be summarized.

2.5.1 Boundaries of the literature on digital-physical products

One of the cornerstones of the literature on digital-physical products focuses on the definition of products (Yoo et al., 2012; Porter & Heppelmann, 2014; Wunderlich et al., 2015; Novales et al., 2016). The discussion about the characteristics of such products, the optimal definition and differentiation from other terminologies are in the foreground. Another aspect is the benefit and added value of these products (Muehlhaeuser, 2008; Sabou et al. 2009; Bauernhansl et al., 2014; Gentner & Oßwald, 2017). As mentioned above, the proliferation of the internet as a communication environment, the increasing availability and longevity of the latest sensors create diverse opportunities for manufacturers and customers. This change leads to an increasing complexity in the company and has an influence on existing processes and models as well as on the corporate strategy (Sabou et al. 2009; Gentner & Oßwald, 2017). Various researchers are therefore investigating whether the company as a whole is positioned for the new world. This is because digital-physical products must now be manufactured, distributed and marketed in addition to the previous products. This raises the question of the added value and internal investment costs of these products. As a concrete example of the potential added value of digital-physical products, the research of Roecker & Mocker (2018) is cited here, which mirrors digital-physical products in companies in the creative industries. Roecker & Mocker (2018) investigated the economic significance and benefits of digital-physical products in the creative industries, as well as the challenges surrounding digital-physical products. As a result, it can be stated that the products still have a low economic significance but are considered to be strategically high. Further findings were that companies have to deal with a high creation effort and usage difficulties on the customer side and that digital enrichment does not always lead directly to higher turnover. The decisive factors were the areas of application with real customer benefits, and the success criterion was "*direct support for customers in the often still complicated use and the hiring of employees with special technical skills*"(Roecker & Mocker, 2018, pp. 3). The research shows that digital-physical products cannot taken for granted and need to be actively managed.

As can be seen from the research, it is also necessary to first determine whether and how the added value of these products will turn out in other sectors. It may well be that there is no need for digital-physical products at the moment (Roecker & Mocker, 2018). In the literature, the investigation of complexity and the discussion about its reduction usually also refers to product development (Hendler, 2019; Hoffmann, 2020). In this context, classic development is often contrasted with new agile development methods and its transformation is discussed (Hendler, 2019).

The examination of complexity and the influence of digital-physical products on the five classic phases of the product life cycle have hardly been discussed. Although there are considerations and opinions that changes should also be made outside of product development and that company processes as well as entire departments need to be restructured, these have not yet been discussed extensively. Based on this, a first narrowing down of the literature regarding digital-physical products can be made, namely that the so far insufficient discussion about the influence of digital-physical products outside of product development is rarely considered.

2.5.2 Limitation of the literature on product management

In the discussion on digital-physical products, product management is considered to play a major role as it deals with the management of products and product-related services during the product life cycle from market maturity to product elimination from the market (Aumyar, 2019). The literature review has shown that product management cannot be defined uniformly due to various external and internal factors. Product management differs according to industry, technology and can be discussed from three different scientific disciplines. Because of this, the literature in the field of product management focuses on certain aspects. It is noticeable that the current literature on product management focuses on the purely new world. For example, Tkalich et al. (2021), who aim to optimize agile product management in agile companies, or Namatherdhala (2022), who focuses on the connection between AI and product management. Nevertheless, despite the widespread adoption of product management, surprisingly little attention has been paid to the study of the transition phase between physical and digital products. Mainly because various studies have shown that many companies are not yet ready or have various dependencies on the old world (Roecker & Moecker, 2018), as in the railway industry. Setting up a new product management without taking legacy systems into account is not easily possible here for both legal and financial reasons.

The reason for questioning product management for digital-physical products is based on the increasing spread of digital products and services, which entails both opportunities and challenges (Gentner & Oßwald, 2017). While digital-physical products are not new in themselves, the main difference lies in the interconnectedness of the systems. The digital ecosystem is now more mature, so that the products and processes as well as the entire value creation networks can be controlled almost in real time (Plass, 2020). As a result, the number of new digital services is constantly growing. In addition, the shift to digital offerings within the railway industry is a long-term trend, as digitizing a product does not immediately increase its perceived value (Yoo et al., 2012). The changing needs of the target customer have to be identified and the digital offering has to address these needs (Bahrenburg, 2019). Over the last few years, these offerings have become more and more elaborated and have in some cases become state of the art or a USP for products (Plass, 2020). It is to be expected that more and more digital offerings will come onto the market in the coming years, so that companies will be confronted with the challenge of consistently creating a scalable benefit for the clientele with these digital solutions to the physical product (Plass, 2020; Bahrenburg, 2019). This is because each type of these services creates a set of needs that need to be properly managed and addressed (Hofmann, 2020; Keite, 2022). Digital offerings are subject to iterative development, so companies need adapted product management to respond to the needs of their customer base (Keite, 2022). This leads to a second limit in the literature as the consideration of product management within the transition phase from physical to purely digital products and the influences of digital-physical products on this area of the company are only insufficiently discussed. Although authors such as Gentner & Oßwald (2017) deal with the influences of Industry 4.0 on product management, the discussion can be expanded further.

2.5.3 Limitation on the literature of the product life cycle

Furthermore, the concepts and models of product management were presented in the literature review. Particular emphasis was placed on the concept of life cycle management and its product life cycle model, as this plays an essential role in product management. Similar to the discussion on product management, there are various discussions with different emphases. Discussions have crystallized around, for example, classification (Holler et al., 2019), sustainability (Scholz & Pastoors, 2018) or the length of the product life cycle (Drechsler et al., 2019; Keller & Lasch, 2020). Especially the discussions about the shortening of the product life cycle are aimed at the context of purely digital products.

In addition, there are also publications, such as by Subramonian et al. (2021), which focus on the digitalization of the supply chain and the associated product life cycle. The aspects of digitization related to the product life cycle are touched upon, but there is little focus on the market phase of the cycle. This corresponds to the market entry to the withdrawal of a product. Especially for products that are subject to a long useful life due to various factors from the very beginning, this phase is of great importance. This is also the case in the rail infrastructure sector, where products are subject to a product life cycle of around 25 years (Siemens Mobility, 2021). This aspect is closely related to the lack of consideration of digital-physical products outside of development. These products help to create new opportunities during the market phase and thus influence the previous management of the products. Due to this, previous strategic measures and also activities of the product management and the product manager can change (Shah et al., 2021). In principle, the investigation of optimizations in the handling of products within the market phase receives less attention than, for example, product development. However, the discussion is rising again due to the introduction of digital-physical products (Wang et al. 2020; Liu & Yan, 2018). In general, the concepts of product management are insufficiently reflected in digitalization. Although previous researchers such as Gentner & Oßwald (2017), or digital-physical products relate to product management, the concepts of the latter are hardly illuminated. A deeper analysis of these is essential, as the concepts define the actual managing of products and correspond to the daily tools of the product manager (Aumayr, 2019). Nevertheless, the study of the product life cycle does not remain untouched either. In connection with the product life cycle and digitalization, some companies refer to the so-called digital twin, as does the automotive industry. Here a physical object is reproduced as a virtual model (Tao et al., 2019). The object under study is equipped with various sensors so that operators can, for example, better understand how their machines work and react in different situations (Tao et al., 2019). It encompasses both the physical and digital aspects of the unit and enables real-time monitoring, analysis and simulation of its behavior and performance. The primary objective of a digital twin is to create a virtual platform for monitoring, analyzing, and optimizing the performance of its physical counterpart. So, in a sense, a twin is created in parallel with the product life cycle that can help in decision-making (Uhlemann et al., 2017). Although digital twins help in the course of the product life cycle and reduce the complexity of dealing with products, they are primarily only a representation. A digital-physical product, on the other hand, refers to a physical product that has been enhanced or extended with digital functions or capabilities. It combines physical components with embedded sensors, connectivity, and software to enable additional functionality, data collection and communication.

The purpose of a digital-physical product is to enhance the user experience, provide additional functionality and enable connectivity and communication capabilities (Uhlemann et al., 2017). Therefore, it combines the benefits of physical products with digital technology to provide better performance, customizability, and interconnectivity (Tao et al., 2019; Eckhart & Ekelhart, 2019).

Although both digital twins and digital-physical products involve the integration of digital technology with physical objects, they differ in terms of their main purpose, relationship with the physical entity, data interaction and scope. When discussing the influence of digitalization on the product life cycle and its change, it is important to consider the understanding of these two concepts. While both contribute to a change in the product life cycle, the focus in this study is on the relationship between digital-physical products and the product life cycle model. Another aspect of the change in the product lifecycle model due to digitalization is the use of new tools along the product life cycle to manage information density (Leng et al., 2020). Blockchain technology can be identified as a key buzzword here. It is proposed to regulate the significant and growing volume of information of the interaction of all participants in the product life cycle through the tools of blockchain technology. Thus, smart contracts, when the specified conditions are met, eliminate the need for intermediaries and enable trustless interactions (Leng et al., 2020). This approach also explores changing or adapting the product life cycle in a particular way. According to Tao et al. (2019), it tries to simplify the emerging complexity of digitalization through various solutions. Nevertheless, simplification does not correspond to improved product management. The optimal benefit is inevitably not extracted from digital-physical products.

A change in the product life cycle through digitalization or through new technological possibilities is discussed in many different ways. It is therefore crucial from which perspective the product life cycle should be viewed. The focus of this study is on digital-physical products with an eye to managing them efficiently and effectively. Understanding how digital-physical interact in relation to the product life cycle is an essential part of this. With the understanding of this relationship, artificial intelligence and other technologies can then help to facilitate practical management. As a conclusion, the literature touches on the discussions of the changes in product management and the product manager but does not go into detail about the concepts of life cycle management.

2.5.4 Limitation of existing approaches

In principle, the discussion about digital-physical products and a change in corporate structures driven by them is present in the current literature. According to Lerch & Gotsch (2015, p. 50), digital-physical products will change the value creation processes and "*also greatly increase the number of actors involved in the value creation process, the complexity of the products and the resources and competences required to create and support them*". Lerch & Gotsch (2015) appeals for an individual approach in this context, in that industrial companies first identify their potential for the digitalization of services. This includes reflecting on internal capabilities, but also the latent needs of customers and markets. "*Simply asking these questions can move firms along the transformation path*" (Lerch & Gotsch, 2015, p. 50). After answering the questions, offers can be developed and isolated departments can be specifically aligned accordingly.

What is more concrete are the approaches of Porter & Heppelmann, who cite practical examples around this discussion. Porter & Heppelmann (2015, p. 18) have already argued that "*smart, connected products will need to coexist with traditional products for a sustained period*" and that change should be evolutionary, not revolutionary. In doing so, Porter & Heppelmann (2015) present three approaches to how companies can restructure themselves to best propagate digital-physical products internally and externally. One approach corresponds to a separate new unit accountable for profit and loss and is entrusted with supporting the company's strategy for digital-physical products. Another approach would be a center of excellence that holds key knowledge about the new products and has no profit and loss responsibility. The third approach "*involves convening a committee of thought leaders across the various business units, who champion opportunities, share expertise, and facilitate collaboration*" (Porter & Heppelmann, 2015, p. 18). Furthermore, the study by Genter & Oßwald (2017) should be mentioned here, which specifically mirrored Industry 4.0 to product management.

It was found that changes along the product management process presented are necessary in order to effectively meet the requirements of Industry 4.0. In addition, it is confirmed that product management assumes a core function in the company in order to take on Industry 4.0 requirements. These examples show that companies and their departments need to change in order to be able to manage these products effectively in the future. Therefore, these general derivations towards product management are a good start, but nevertheless these approaches need to be further concretized. The studies call for a change in departments but do not answer to the concrete question of how the changes can be implemented.

As shown in section 2.2, however, product management is a complex organizational form with individual arrangements, focal points, and philosophies, so that further elaboration is necessary. Therefore, authors such as for example Porter & Heppelmann (2015) and Aumayr (2019) call for further research to better outline these changes. The researcher takes up this call for research and focuses on the changes of digital-physical products at the product management level. The researcher thus joins the general framework of changes in product management of digital-physical products, but unlike previous research, this research does not reflect the products on the company itself or on specific departments such as product management. Rather, digital-physical products are placed in relation to the standardized concepts and models of product management, in this case the product life cycle model. The product life cycle model is a pioneering strategic tool of product management and is considered the essential model in the context of product management (Bruhn & Hadwich, 2017). Conclusions are drawn about the product management and the product manager via the change in the concept. Figure 29 illustrates this approach with a comparison of other research in a pictorial and simplified way:

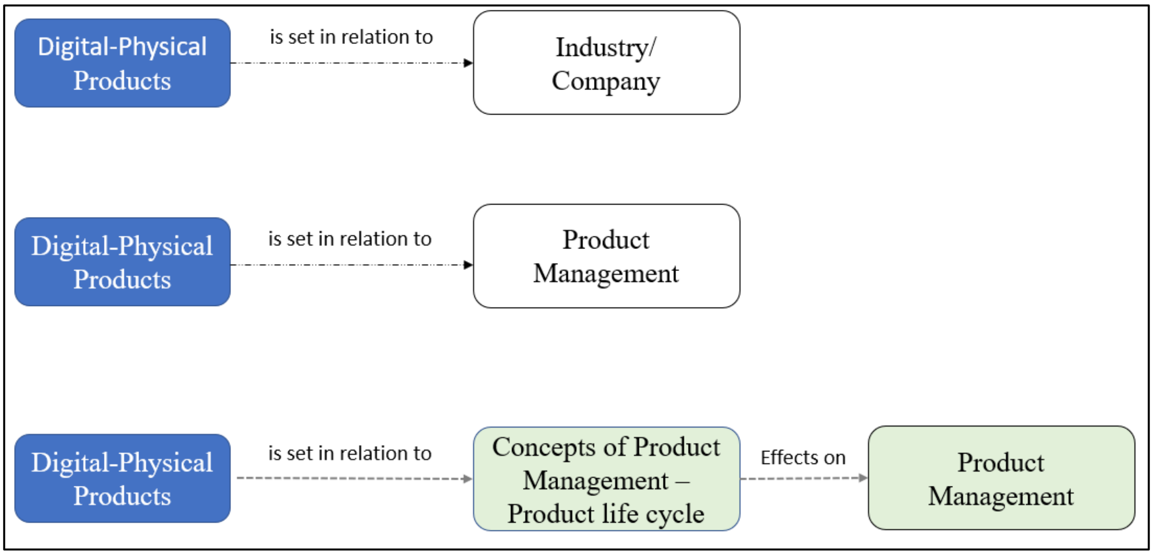

Figure 29: Schematic representation of the differences to previous research (Source: Authors own illustration)

According to Keite (2022), the product management thought matrix remains, but modernization is necessary in relation to digitalization. This aspect is supported by Bahrenburg (2019), who thinks that product management is the essential part of this transformation. In order to shed more light on a modernization of product management, the researcher focuses on the mirroring of concepts within product management and derives conclusions regarding a change. Furthermore, the loose reflection on the product life cycle model would be too theoretical, as all products have an individual product life cycle.

Therefore, this is set within the framework of the railway industry, more specifically in the rail infrastructure, as these products are generally subject to the same boundary conditions and can be researched in a practical manner. Thus, a more precise generalization can be presented, even if the products still have an individual life cycle.

2.5.5 Starting point for this research

The discussion of digital-physical products themselves, their connection with the product life cycle and management, has hardly been considered in the literature. In summary, a product life cycle model for digital-physical products has not yet been discussed or outlined. The starting point of this study is therefore the classic product life cycle model. The interaction of digital-physical products will now be examined within the framework of the product life cycle model. In addition, the effects of the change in the product life cycle model on product management and the product manager are examined. This study will help to fill the gaps mentioned above by deepening the understanding of the relation between digital-physical products and the product life cycle concept. The literature research revealed that product management and its concepts are too diverse to be narrowed down. Based on the railway infrastructure, the course of the cycle with its characteristics was presented and fundamental aspects on the part of product management and its life cycle were shown. The researcher's knowledge from his work at Siemens Mobility GmbH was also incorporated. In addition, current developments of digital-physical products were explained in this context. These descriptions serve as a basis for the further investigation, on the basis of which the results are to be mirrored.

2.6 Concluding Summary

In this chapter, the literature relevant to this thesis was presented and discussed. The aim was to give the reader an overview of the main topics that are relevant to the study. For this purpose, the chapter gave an overview of the different aspects of a product and described the concept of the digital-physical products and presented the current literature on it. Furthermore, the different influences, theories and challenges of product management and product managers were presented, discussed and reasons given why a uniform definition is hardly possible. Special attention was paid to the product life cycle model, which was discussed around its current literature. The knowledge gained was expanded to include a description of product management, the product life cycle model and digital-physical products from practice. On the one hand, because the literature review revealed that product management and its concepts are too multifaceted, so that they have to be narrowed down. On the other and, because the study focuses on the railway industry in general and on the company Siemens Mobility GmbH in particular. Therefore, it was necessary to list the boundary conditions for the further investigation. The chapter concluded with a description of the limitations of the current literature in relation to the question addressed here. In doing so, the current discussions of the individual sub-areas were summarized and narrowed down and thus the starting point for the present research was worked out. The research philosophy, research design and methods used for this study are now described in detail in Chapter 3.

3 Research Methodology

This chapter outlines the development of the research philosophy, strategy and methods to support the study. The philosophical approach associated with meaningful research design forms the basis of the study as the worldview adopted influences how the study should be conducted and interpreted (Patton, 2002). “*The process of exploring and understanding the research philosophy required reflexivity on your own beliefs and actions as well as those of others*” (Schell, 2020, p. 73). Therefore, there is no absolute right or wrong research approach, but researchers have to choose the approach that can answer their research question and problem (Gerson & Horowitz 2002). Therefore, the choice of research design can be understood as an overall strategy and plays an essential role in obtaining the desired information and influencing research activities (Ghauri & Grønhaug 2002). The strategic selection of research methods then makes it possible to investigate a research problem in the best possible way. The aim of this chapter is to critically justify the research philosophy (section 3.1), the research approach (section 3.2) as well as research strategy (section 3.3) and the choice of methodology (section 3.4). Furthermore, the data analysis process (section 3.5) and finally the rigour (section 3.6) as well as ethical considerations (section 3.7) of the underlying study are described.

3.1 Research Philosophy

The research philosophy corresponds to a scheme of the researcher's thinking in order to gain new and reliable knowledge about particular research. That means, “*it is the basis of the research. It involves the choice of research strategy, formulation of the problem, data, processing, and analysis*” (Rajagopaul, 2022, p. 132). According to Holden and Lynch (2004), a relation between the choice of method should be related to the philosophical standpoint of the researcher and the phenomena being researched. The reason for this is that consciousness of the philosophical stance improves the quality of the research and enhances the creativity of the researcher. (Holden & Lynch, 2004). Several philosophical approaches are possible in the field of management research. For example, there is the direction of positivism, interpretivism and pragmatism, as well as constructivism. However, before the individual paradigms are analyzed and discussed, the concepts of ontology as well as epistemology, which form the basis of the research paradigms (Grix, 2004), will be described.

Ontology

Ontology as a scientific discipline within philosophy corresponds to the doctrine of being. According to Crotty (1998, p.10), ontology is concerned with the *'what is', with the nature of existence, with the structure of reality as such*". Saunders et al. (2019) suggest that there are two ways of looking at ontology in business studies, namely via objectivism and subjectivism. Objectivism exists outside of and independent of social actors. This means the researchers who hold the perspective of objectivism believe that the entity of a phenomenon exists and can be measured independently of social factors. On the other hand, subjectivism states that social phenomena dependent on social actors. (Creswell, 2013; Saunders et al., 2019).

Epistemology

Another major philosophical stance is epistemology, which is the question of how appropriate knowledge is created and shared (Gray, 2010). "*Epistemology is a method of understanding and explaining how we know what we know*" (Crotty, 2003, p. 3). Epistemology is involved with the study and reasons of knowledge, especially in terms of its limits and validity (Crotty, 2003). Saunders et al. (2019) define two main types of researchers known as 'resource' and 'feeling' researchers. On the one hand, the resource researcher views reality as represented by objects that are real such as cars, laptops or actual employees. Therefore, evidence can be collected and measured. On the other hand, emotion researchers believe that people's feelings, attitudes and perceptions cannot be seen, changed or measured and therefore must be interpreted by the researcher (Saunders et al., 2019). Since the aim of this study is to understand the relationship between digital-physical products and the product life cycle model and product management, this led the researcher to a subjective perspective. With the help of perspectives and experiences of experts in the field, the objectives can be revealed, and consequently the researcher needs to listen and understand their views to achieve the objectives of his study. Consequently, subjectivism is more appropriate for this research to address this matter because "*the value of subjectivist research is that it reveals how individuals' experiences shape their perceptions of the world*" (Moon & Blackman, 2014).

Starting from the ontological and epistemological position, the following section discusses the four main paradigms, which are based on ontology and epistemology as mentioned earlier and justifies the choice of constructivism as the paradigm for this thesis.

3.1.1 Research paradigm

A research paradigm is "*the set of shared beliefs and agreements among scientists about how problems should be understood and approached*" (Kuhn, 1962, p. 43). Our actions in the world, including our actions as researchers, cannot occur without reference to these paradigms because "*paradigms represent a distillation of what we think (but cannot prove) about the world*" (Lincoln & Guba, 1985, p.15). A research paradigm is therefore an approach to conducting research and includes the principles, values, procedures and rules that guide the researcher's thinking and behaviour. Every research uses one of the research paradigms as a guide for developing the research methodology and conducting the research project in a way that is as valid and appropriate as possible. There are two predominant research paradigms that fundamentally influence the overall approach to the design of management research. Authors have proposed different terminologies to distinguish between these two viewpoints, e.g., Lincoln & Guba (1998) use the terms 'scientific' and 'naturalistic', while Easterby-Smith et al. (2002) and Creswell (2003) use 'positivist' and 'interpretivist'. Most research paradigms originate from one of the two research approaches and although there are basically two dominant research paradigms, several other paradigms have developed from these two, especially in management research, such as pragmatism and constructivism (Warren, 2015; Schell, 2020).

Positivism

The positivist approach to research refers to the philosophical stance of natural scientists, who argue “*that the social world exists externally and can be measured through an objective approach, rather than being deduced subjectively through reflection or an analysis of feelings”* (Le, 2020, p. 75). Researchers holding a positivist philosophy prefer to assess data objectively. This means looking for regularities and causal relationships in the data in order to ultimately create generalizations (Johnson & Gill, 2010). Creswell (2003) points out that positivism advocates a deterministic philosophy about the relationship between cause and outcome. Therefore, research questions are approached through the process of discovery, and the researcher attempts to evaluate the cause that might lead to an outcome, for instance through experimentation. Furthermore, positivist researchers are often connected with quantitative research due to the use of existing theories to ultimately develop hypotheses. These hypotheses are tested and fully or partially confirmed or disproved (Saunders et al., 2019).

The major contention with the paradigm is that research using a positivist philosophy underestimates the importance of human interaction and value systems to research findings (Sritanyarat et al., 2010).

Interpretivism

The interpretivism paradigm, argues that the social world of economics is very complicated to be resolved into simple dependencies (Saunders et al., 2009). Interpretivism aims to criticize positivism, taking the subjective perspective as its starting point (Saunders et al., 2019). The interpretivist perspective is therefore characteristic of qualitative research (Creswell, 2003). Thus, Creswell (2003) emphasizes that people differ from objects because they create meaning. Moreover, different people who have different education, culture, backgrounds and living conditions create different meanings. Because of this, physical phenomena cannot be studied with the same method as social constructions (Flower, 2009). The interpretivist often focuses on specific "*contexts, such as the place where people work and live, to understand their culture and history*" (Le, 2020, p. 75). Saunders et al. (2019) state that it is necessary to adopt an empathic stance and accept the challenge of entering the research field and understanding the participants' world from their perspective. Unlike positivism, interpretivism does not seek to test hypotheses, but its purpose is to create deeper ways of understanding and interpreting social worlds. (Polkinghorne, 1988).

In research, these two philosophies are found at opposite ends of the spectrum of social research (Warren, 2015). Neither philosophy matched the beliefs and assumptions of the researcher as they were two extreme positions. The researcher therefore analyzed and reflected on the paradigm of pragmatism as well as constructivism, as both pragmatism and constructivism are situated in the middle of the philosophical spectrum.

Pragmatism

Pragmatism focuses mainly on problem solving and bypasses the approach that the function of thinking is to describe or reflect reality. When solving a concrete problem, pragmatism is mostly resorted to because it offers methodological freedom (Kelemen & Rumens, 2008). "*Pragmatism also helps to shed light on how research approaches can be mixed fruitfully (Hoshmand, 2003); the bottom line is that research approaches should be mixed in ways that offer the best opportunities for answering important research questions*" (Johnson & Onwuegbuzie, 2004, p.16). Pragmatism is also characterized by a mixed methods approach and therefore includes both qualitative and quantitative research methods.

Constructivism

The paradigm of constructivism used for this research, on the other hand, is defined by Crotty (1998, p. 42) as "*the view that all knowledge, and thus all meaningful reality as such, depends on human practices constructed in and out of the interaction between people and their world, and developed and transmitted in an essentially social context*". Therefore, meaning is constructed and "*our individual reality and meaning are always a construction of our perception and our memory [...]*" (Reber, 2016, p. 112). Thereby, through interaction with other participants and the social context of life, these perspectives are created. Therefore, the constructivist approach is often used to study the process of interaction between individuals (Fosnot, 2013). The results of any study depend largely on the participants' view of a situation as part of their experience (Fosnot, 2013). Thus, from an ontological point of view, it can be stated that there are several truths since constructivism is not embedded in a materialistic worldview. Moreover, "*the belief in and acceptance of multiple social realities leads to the conclusions that knowledge is relativistic (i.e., knowledge and realities are time, space and context dependent), that enquiry should be naturalistic, and that interpretivism (rather than scientific methods and empiricism) is the appropriate framework for bringing to light and exploring these realities*" (Bisman, 2012, p. 6). Figure 30 again depicts the essential elements of the research paradigms:

	Positivism	Pragmatism	Constructivism	Interpretivism
Ontological stance	There is a single reality	Reality is constantly renegotiated, debated, interpreted	There are multiple realities	There are multiple realities
Epistemological stance	Can be measured and known	Best method to use is the one that solves the problem	Knowledge is constructed. Reality can be constructed	Knowledge is interpreted. Reality can be understood
Key elements	• Determination • Empirical observation and measurement • Theory verification	• Consequences of actions • Problem-centered • Real-world practice oriented	• Co-constructed • Socially constructed reality • Theory generation	• Interpretation • In-depth investigation • Theory generation

Figure 30:The comparison of different research paradigms (Source: In accordance with Warren, 2015)

The crucial difference between the two paradigms in the context given here is that the researcher does not exclusively try to solve a problem by all means possible. Rather, the focus is on understanding the relationship between digital-physical products and that between the product life cycle and product management. The study investigates the way digital-physical products interact within the traditional product life cycle and, while confronting the researcher with specific problems and challenges, the focus is nevertheless on exploring and extending the existing product life cycle model and product management. Indirectly, this may lead to problem solving, but it is not exclusively and directly focused on solving problems. Constructivism prompts the researchers to look for a complex view rather than limiting themselves to a small research area or set of ideas (Duffy & Jonassen, 2013). This also gives the researcher the opportunity to make significant contributions to the widely discussed digital product management within the confines of the philosophical standpoint of constructivism. Under the guise of pragmatism, this would not be envisaged because "*for a pragmatic researcher, research begins with a problem and aims to provide practical solutions for practitioners to that problem*" (Saunders et al., 2009, p. 143). In contrast, constructivism supports the study in providing both scientific and practical results. In addition, "*adopting a constructivist approach allows the researcher to give meaning to the way things are, and to identify factors that otherwise could not be easily exposed or described through metrics and statistics […]*" (Bisman, 2012, p. 6). Constructivism is therefore best suited to this study, which aims to build a more comprehensive model of the relationships between the factors that influence the process (Bisman, 2012).

3.1.2 Role of the researcher

In order to develop the research philosophy, the researcher also uses what is known as reflexivity. In this context, reflexivity corresponds to an attitude that systematically pays attention to the context of knowledge construction. Particular attention is paid to the subjectivity of the researcher throughout the research process (Malterud, 2001). This is because the awareness and interpretation of the researcher's role is also an important feature in the elaboration of the research design. The researcher's position, namely being a part of the product management, influences the choice of the research, the methods that have been considered most appropriate for this purpose, the results as well as the formulation of the conclusions (Malterud, 2001). Reflection during the research process was indispensable to recognise and manage the complexity of the factors involved. In addition, the researcher took on different roles during this study, such as facilitator, interviewer or colleague, so reflection was important to separate these roles as well. The challenge was to constantly adapt to many different situations and to be aware of one's current role in order not to harm people or the organization in any way. In particular adopting the role of a practitioner researcher meant understanding the complexity of the organization, but also simplified research access within the organization (Saunders et al., 2019). A constant optimization of the research design resulted from the continuous reflection regarding the ontology and epistemology and the contextual concepts. The same applies to the strategic research approach, which is explained in the following section 3.2 for the implementation of the study.

3.2 Research approach

Depending on how much is known about the topic in current research, there are, purely by definition, different types of research such as exploratory, descriptive, explanatory and causal investigation (Flick, 2019). The type of investigation and the current state of research on the topic are important criteria that strongly influence the choice of research method (Siedhoff, 2019). The present study is an exploratory study, as the research field is still quite under-researched under the given conditions, and initial findings can be obtained. The focus is on finding ideas and insights and not necessarily on collecting statistically accurate data (Dietterich, 1990). In addition, an exploratory study is flexible and adaptable, which gives researchers some latitude and allows the focus to be adjusted as the research project progresses through data generation (Saunders et al., 2019). Generating knowledge in science usually requires a structured approach to research, in which there are at least two ways of proceeding: Induction and Deduction (Mey & Mruck, 2010). Inductive approaches investigate an object and draw theoretical conclusions from it. The aim is to make a general statement with the help of an individual case (Breuer & Schreier, 2010). Both terms are often used in connection with quantitative and qualitative research (Baldaccino & Draper, 2001). Exploring unknown phenomena and developing new theories and models is the aim of qualitative research. This approach tends strongly towards an inductive approach (Flick, 2019). In contrast to qualitative research, the quantitative research process ideally follows a predetermined pattern and deductive hypotheses are tested in the research process (Baldaccino & Draper, 2001).

The research approach of this thesis will be inductive, as the objectives of the study will be effectively achieved through face-to-face interviews with the participants, so that the resulting data will be based on feelings, values, experiences and, most importantly, opinions. Expert interviews and interaction through the focus groups will help to build a relationship to obtain detailed information and quality information (Saunders et al., 2019). Another reason for choosing the qualitative method as the main research method is that the research approach aims to co-construct knowledge between the researcher and the participant and aims to understand the meaning behind the participants' actions through data (Saunders et al., 2019). Deeper questions and sub-questions are needed to understand the participants and the relationships between them. Again, this can only be accomplished by way of qualitative research methods. Furthermore, this approach is supported by Denzin and Lincoln (2011) and Creswell (2003), who all recommend that the inductive approach is conducted using qualitative methods.

3.3 Research strategy

The present research framework corresponds to explorative, qualitative research with a constructivist philosophy. Besides the research approach, the definition of the research strategy is an inevitable point. Saunders et al. (2019) and Creswell (2003) mention experiments, action research, case studies and many others as possible research strategies. The researcher analyzed the research strategies, and after intensive reflection the case study was selected for this research. Therefore, the case study as a research strategy is presented below in section 3.3.1 and justified in the section 3.3.2 after that.

3.3.1 Case study research

The case study is an approach to social research that already differs significantly in its basic characteristics from other empirical master techniques (Borchardt & Göthlich, 2007). The focus is on the search for a truth that applies as widely as possible (Hunt, 1991). A suitable definition of the case study research method is provided by Yin (1994, p. 23): "*A case study is an empirical enquiry that:*

- *Investigates a contemporary phenomenon within its real-life context; when*
- *The boundaries between phenomenon and context are not clearly evident; and in which*
- *Multiple sources of evidence are used*".

The definition by Yin (1994) already makes it clear that the case study method does not focus on a specific and singular survey technique or evaluation technique but is to be understood as a process that focuses on the collection and description of a concrete practical challenge. The aim is to capture the specific situation as realistically as possible, to describe it comprehensively in its peculiarities and to present it vividly. Interrelationships, constellations, and networks of effects should be examined from as many sides as possible (Borchardt & Göthlich, 2007). Although various master techniques are characterized precisely by the fact that they are based on the analysis of data from one source of information, the case study method requires the collection of different information. These will then be evaluated within the analysis using various methods and results in a multi-dimensional picture of the respective case situation (Eisenhardt, 1989). For example, the methods of expert interviews and the secondary analysis of company documents are combined with the techniques of document analysis or even participant observation (Jäger & Reinecke 2009). Thus, the approach of the case study method is characterized by a particular flexibility towards the object of investigation.

It is particularly suitable for research questions that focus on new phenomena in management research or phenomena that have previously only been covered in rudimentary approaches, or questions that are to be considered in a narrow corporate context (Bonoma, 1985). Furthermore, Saunders et al. (2009) point out that the case study strategy is often used to obtain answers to the research questions starting with how, what and why. Therefore, case study research can use qualitative or quantitative methods, but usually case study research is classified under the qualitative research paradigm (Schögel & Tomczak, 2009). Yin (2009) distinguishes between four types of case study designs, which are schematically illustrated in Figure 31. According to Yin (2009) the types refer to two different dimensions, namely single case in comparison to multiple cases and holistic case in comparison to embedded case:

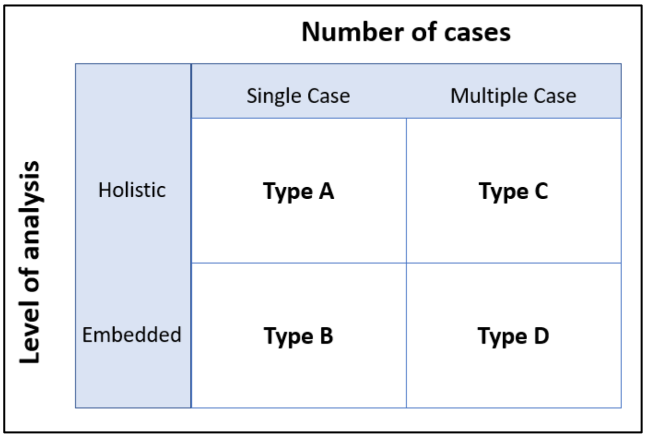

Figure 31: Types of case study (In accordance with Yin, 2013; Schell, 2020)

Type (A)

In single case design, usually only one case is studied on a holistic level. Often this is used when it is considered typical or gives the researcher the opportunity to investigate the phenomenon, which has been insufficiently studied so far. In addition, "*a single case study is merely the precursor to further studies and may perhaps be a pilot for later multiple study*" (Schell, 2020, p. 80).

Type (B)

According to Schell (2020, p. 80) "*Within a single case study there may be a number of different units of analysis and perspectives*".

Type (C)

If the aim is to improve reliability or generalizability, then the multiple case study approach is preferred. It also provides a holistic perspective unless multiple units of analysis are present or taken into account (Yin, 2009).

Type (D)

If multiple units of analysis are used compared to type C, then it is referred to an embedded multiple case study, which allows for greater sensitivity. (Yin, 2009).

The in-depth analysis within a case study with one or more cases makes it possible in particular to identify, describe and explain cause-effect relationships that are not accessible for a purely quantitative analysis (Wichmann et al., 2008). Here, case studies are particularly suitable for producing detailed and context-dependent knowledge (Flyvbjerg, 2011). Although a prediction or unlimited transfer to other contexts is not possible, a transfer of practical knowledge and thus learning for other contexts and situations is. Flyvbjerg (2011) summarizes five key advantages and strengths of case studies (Figure 32). These are above all the analytical depth of a case study, its high conceptual validity or construct validity, the understanding of context and process in their context, and the understanding of linkages between a trigger and a triggered event. The final strength for Flyvbjerg (2011) is the function of case studies in generating new hypotheses and research questions from their observation of complex real-life contexts (Flyvbjerg, 2011).

Strengths	Weaknesses
Analytical depth	Selection Bias
High construct validity	Weak understanding of the occurrence of a phenomenon in other contexts
Generation of new hypotheses and research questions	Statistical significance mostly unknown or unclear
Understanding context and process	
Understanding the link between cause and outcome	

Figure 32:Strengths and weaknesses of the case study according to Flyvberg (Source: Flyvberg, 2011)

According to Flyvbjerg (2011), the weaknesses of the method include three aspects. The first and frequently expressed disadvantage is selection bias, which can lead to over- or underestimation of the importance of relationships and interactions. Accordingly, careful case selection is important. Moreover, a case study provides only limited knowledge about whether the observed phenomena also occur in other contexts. For example, if one city is selected and studied, then no direct conclusions can be drawn about other cities. Flyvbjerg (2011) sees the final disadvantage in the fact that the statistical significance of case study results is usually unknown or unclear. What is generated is contextual knowledge about complex contexts in their real environment.

However, this knowledge does not allow statements about the probability of finding similar contexts in other contexts. Finally, it is mentioned that despite the non-linear approach of case studies, the demand for a high transparency of the research process requires a systematic-structured process (Yin, 1994). The process of a case study, shown in Figure 33, is characterized by some specific features. Although the case study follows a certain process, the individual steps are not necessarily to be worked through in a stringent process from A to Z. The case study is not a linear process (Yin, 1994).

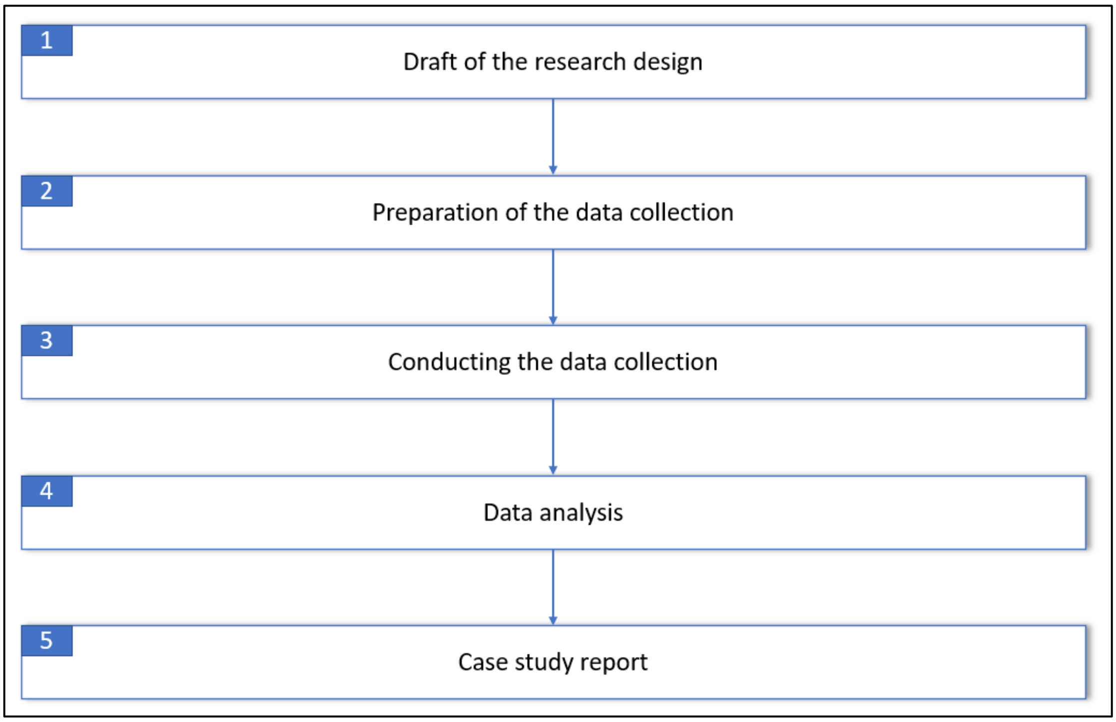

Figure 33: The process of case study according to Yin (Source: In accordance with Yin, 1994)

The following section 3.3.2 will justify the choice of the case study as the research strategy used for this study. Furthermore, the following sections follow the research process presented in Figure 33.

3.3.2 Justification for the case study

The overall objective of this study is to understand digital-physical products in the context of the product life cycle and its impact on product management. The increasing influence of digitalization and changing customer behavior make the modification of the current product lifecycle model within the company a prerequisite for the company's continued success. The study was conducted in the environment of the global manufacturer of rail infrastructure products Siemens Mobility GmbH Rail Infrastructure in its head office in Germany. Through direct research within the company, the author had access to experts and customers.

Based on this, the different strategies for the research project were analyzed and the case study was selected as the research strategy for this research. As an idea, the action research approach was also considered, but this idea was discarded. On the one hand, the aim of action research is to develop practice-related hypotheses based on a concrete problem and, if possible, with the participation of those affected, and on the other hand, to plan and implement suitable intervention measures on site and finally to test their effectiveness (Reason & Bradbury, 2001).

The researcher analyzed his current position in the company and contrasted this with the research approach. It was noticed that the dynamics of action research or real change in a process could lead to unexpected and uncontrolled problems, and thus pose too high a risk for this study. This is because the researcher in his current position does not have the power to change a process without further management approval as well as additionally approved budget. The researcher only has the possibility to investigate a theoretical change, but not the real implementation, which is not in line with action research. Furthermore, the company would be added in the research as a direct stakeholder, and this might also lead to an increase in the complexity of the research project.

Besides the mentioned boundary conditions of the researcher, the aim of the research does not fit the action research approach, mainly because action research focuses on the sole specific research question with the purpose of improving practice (Schmuck, 2006). Furthermore, problem identification is done in collaboration between the researchers and practitioners until a unified view is reached (Pine, 2008). Along this line, "*the aim of practical action research is to improve practice by applying the personal wisdom of participants*" (Pine, 2008, p. 76). These principles of action research are not consistent with the research aim and questions of this study. The reason is that the problem definition here is derived from a gap in the scientific literature and does not arise from dialogue between participants and the researcher. Another reason is the intention of the methods used. Although expert interviews, focus groups, observations can also be used here, in action research people are not only subjects but partners in the research process (Reason & Bradbury, 2001). The research emerges through a joint process of reflection between the research partners. Participants involved in the research help to define the problem, collect data and the research findings are fed back to them to ultimately improve practice. The methods are used to identify the root cause and then to address the problem (Pine, 2008). The aims of the study here relate to the exploration and understanding of a complex issue. In addition, the researcher does not participate directly in the research study and would rather conduct an in-depth investigation of a particular phenomenon.

This is to understand the complex issues by collecting and recording data, for example with expert interviews and focus groups, on the phenomenon. Case study research is about description rather than direct determination of cause and effect (Saunders et al., 2019), which is in line with the research objective. Although the dynamic and flexible approach of action research seemed very interesting at the beginning, after intensive reflection it bore too many risks for the research project. Therefore, based on the findings of the literature review and the continuous critical reflection of the researcher the case study was chosen. With the help of the case study, the different perspectives, knowledge and expertise of the participants can be integrated in the best possible way. This aspect underpins the research project, as the different opinions of internal experts from sales, top management and product management will be investigated and integrated on the impact of digital-physical products on the current product life cycle model as well as product management. Furthermore, the case study allows for multiple perspectives to be taken on a phenomena (Saunders et al., 2019) and thus provides the opportunity to examine the current environment, develop a new theoretical product life cycle model for digital-physical and explore its impact on product management. In addition, Patton (2001, p. 447) points out that "*the purpose of a case study is to gather comprehensive, systematic and in-depth information about a phenomenon*", which also applies to the research project. Elam et al. (2013, p. 76) argue that "*the term case study is used in a variety of ways, but the key defining characteristics of a case study are that it involves multiple perspectives (whether through single or multiple data collection methods) and is rooted in a specific context that is considered crucial to understanding the phenomenon under study*". The context-specific character of this study refers to the product life cycle model within the Rail Infrastructure Division of Siemens Mobility GmbH. From this point of view, the phenomenon was investigated and analyzed, and conclusions drawn about the specific context. The phenomenon under investigation were digital-physical products in the company mentioned. This phenomenon, which is rooted in a specific context, was explored in more depth and its relationship to the existing product life cycle model and product management was analyzed. This study thus explores the relationships between phenomenon and real given context, which is a typical feature of a case study. This is because the case study approach helps to capture the specificity and complexity of an individual case (Stake, 2010) and "*to examine a contemporary phenomenon in depth in its real-life context*" (Keskin et al., 2020, p. 105). In addition, the open-ended and methodologically flexible approach of case study research can generate insights into theory and practice and offers the researcher some flexibility in context. In general, the choice of case study increases "*flexibility for the research phenomenon and consist of an immense benefit, especially for an exploratory study*" (Schell, 2020, p. 81).

In doing the case study, the product management organization as well as the specific framework conditions will be discussed in more detail. As described, this will awaken a better understanding of the functioning and challenges of a specific department. This allows the researcher to gain specific insights and provide recommendations for improvement for that particular area (Utterback & Abernathy, 1975; Gemünden et al., 2008). In addition to the detailed investigation of the product management organization, representative products of the rail infrastructure will also have to be examined more closely. Authors such as Shi et al. (2016), who derive potential solutions for railway maintenance and safety via wireless sensor networks, or Mangram (2012), who discuss the strategic marketing plan of Tesla products, are just a few examples from the literature that make general deductions about representative products. These exemplary studies further underpin the research strategy, which is consistent with the philosophy of constructivism and the qualitative-inductive approach that underpins this research.

In selecting the case study as a research strategy, it is still necessary to clarify which type of case study design is to support the research project. Section 3.3.2 highlighted four different case study designs. The research project relies on the embedded single case study design (Type B). The single case study serves to explore a new field of investigation. "*If a phenomenon is to be studied on which there is little or no research, intensive analyzes of individual cases can help to generate hypotheses or identify central variables*" (Harrison & Treagust, 2000, p. 108). In this research, an existing model, the product life cycle model for physical products and an existing organization (product management) are questioned by mirroring them to new circumstances (digital-physical products). Therefore, the research strategy therefore makes it possible to question the existing theory and to develop or expand a new theory. However, this research is not directly concerned with developing a theory as such or confirming an existing theory but is rather problem- and practice-oriented (Warren, 2015). For theory building based on the further development of the product life cycle model, the single-case analytical approach is a useful research approach, as it allows for an in-depth consideration of the individual case and for drawing a holistic and realistic picture. Moreover, a single case was chosen for this research because the organization examined represents an extreme case that is worth documenting and analyzing (Yin, 2009). The specificity of the case is that the company is bringing digital-physical products into the field for the first time and thus has no experience in managing such products.

As already mentioned, the second dimension, holistic versus embedded, is related to the unit of analysis. Yin (2009) understands unit of analysis as any unit within a defined case that can be logically distinguished from the case itself by its own focus of investigation. In relation to the study, expert interviews are used to gain a holistic picture of the added value of digital-physical products and to understand their influence on the product life cycle.

The data collected here focuses on the first research question. In terms of the study, data will be collected from the perspective of users of digital-physical products who only use them for a specific purpose (e.g., sales) and often only interface with the overall product life cycle model. The data within this unit of analysis is collected through semi-structured expert interviews with e.g., salespeople, developers, and top managers, as these areas have a specific interface with product management and the life cycle. The collection of data from different perspectives on the relationship between digital-physical products and the product life cycle as well as product management will help to better understand the characteristics of digital-physical products. In addition, in-depth interviews with experts at the respective interfaces are needed to show the influences of digital-physical products at this point of intersection and ultimately to explore the influence on the phases of the product life cycle.

The focus group data concentrates on the other two research questions, namely the interaction of digital-physical products within the product life cycle model and its impact on product management. This data comes from the product managers' perspective, i.e., the owner's view of the phenomenon. In other words, the data is collected by product managers who manage digital-physical products and are responsible for them throughout the product life cycle. The way digital-physical products behave during the product life cycle and how this affects product management can be determined via experts who are responsible for these products. The aim is not to achieve agreement between the participants in the discussion, but to shed light on as many different facets of a topic as possible (Littig & Wallace, 1997). In this way, data on digital-physical products with its holistic relation to the product life cycle and product management can be obtained from the responsible persons. The aim of this method is to dig deeper into a particular topic by obtaining first-hand information from the actual stakeholders. These are experts who are concerned with the phenomenon under investigation and have certain opinions on the subject. Figure 34 schematically depicts the relationships between user and owner perspectives.

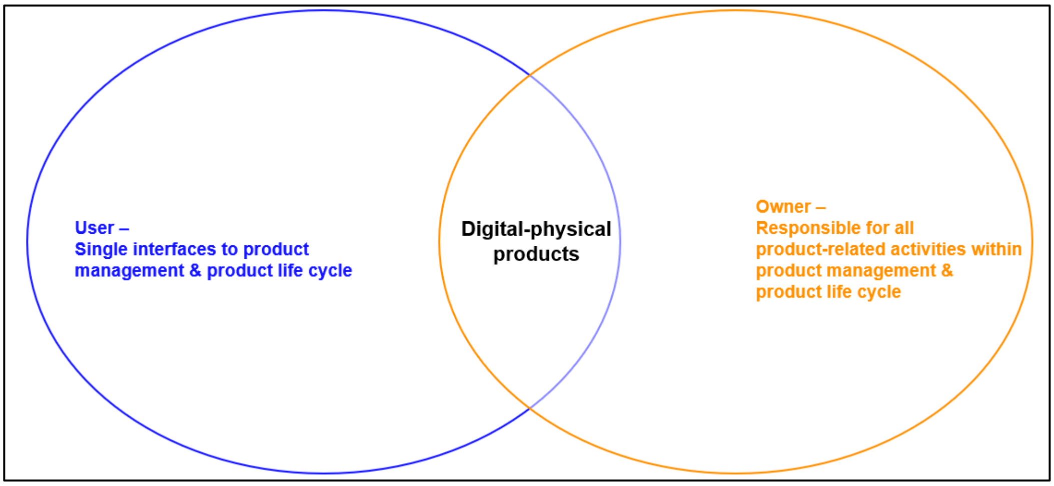

Figure 34:The two perspectives on the phenomenon of research (Source: Authors own illustration)

Both methods and both views are intended to provide a holistic view and identify different aspects of the phenomena. Taken together, the two qualitative methods can help the researcher gain a more comprehensive understanding regarding the research question and shed light on the findings in a broader and deeper way (Lambert and Loiselle 2008). Flyvberg (2011) argues that splitting the case into multiple objects of analysis and creating an integrated case study is justified when there are multiple entities within the case, each making a relevant contribution to the research, and when they are considered and analyzed separately. Objects of analysis are always a subset of a higher-level case.

Through the complementary perspective described here, a reference to triangulation was also made. In the social sciences, triangulation refers to a procedure to obtain a multi-layered understanding of a research object (Flick, 2008). The aim of triangulation is thus to gain deeper knowledge: "*Triangulation involves taking different perspectives on an object under study*" (Flick, 2008, p.12). Triangulation is recommended when conducting case studies and is understood to offer validity through convergence of findings, sources, or methods. Triangulation has long been regarded as a means of achieving some degree of validity or confidence in the study's findings (Eisenhardt, 1989; Yin, 2009). In this way, data triangulation in research involves bringing together data from different sources to gain a more comprehensive understanding of the phenomenon under study. For example, the expert interviews collected data from sales, development, and top management regarding the impact of digital-physical products on the product life cycle. The focus group methodology included data from different product managers with different ownership of products as well as different focus (operational and strategic) in the study. By collecting and reviewing data from different sources, the researcher can ensure that the findings are not limited to a single perspective.

Therefore, as shown in Figure 34, the data was collected from the users and owners regarding digital-physical products, and these were compared with each other. Comparing and analyzing the information gathered from these interviews can help identify common themes, patterns, or contradictions (Yin, 2018; Patton, 1989; Flick, 2008).

In summary, the choice of the case study resulted from an analytical and reflective approach. Coupled with a constructivist approach, it allows for a variety of designs to answer the research question. Embedded in a case study, the overlap between data analysis and data collection could similarly allow the constructivist author to maintain both, subjectivity and objectivity, and adapt it during the research process (Bhatta, 2018). The results of the literature review supported the possibility of using a multi-method data collection approach to investigate the case study. "*Defining a case as a bounded system simply requires a researcher to focus on the details of a case and analyze its context*" (Langley & Royer, 2006, p. 82). This study will thus use the inductive-qualitative research approach and the case study will serve as a strategy as it helps to look at a case from multiple perspectives to understand and explain its specificity.

3.4 Data collection

After the research design has been established in terms of the research question, the researcher must consider which data are needed to solve the question and how the data collection should be organized. This phase sets the crucial course for how the case study work will be conducted. The data collection process is a series of connected activities that are aimed to collect relevant data to answer the research questions. Common methods of data collection in case study research include (Borchardt & Göthlich, 2007; Lamnek, 2000):

- Documentation and archival materials from public institutions, research institutes or consultancies,
- Interviews and discussions with experts,
- Direct or participant observation and
- Focus groups

In the actual work in the field, it is necessary to use different data sources and to determine the appropriate analytical instruments in advance. As mentioned, the researcher used semi-structured expert interviews and the focus group method to collect primary data for the study. A study conducted by Lambert & Loiselle (2008) on the combination of both research methods shows "*that many researchers favour the combination of these two methods.*

Although focus groups and individual interviews are independent data collection methods; their combination can be advantageous to researchers as complementary views of the phenomenon may be generated" (Lambert & Loiselle, 2008, p. 230). This aspect is the main reason for combining the two methods in this study, as the unit of analysis is to be studied from two different perspectives (user and owner view). With the help of both methods and the resulting complementary view, different parts of the phenomenon of interest are to be uncovered and contribute to a more comprehensive understanding as well as to broadening the breadth and depth of the findings. Taken together, the two qualitative methods can help researchers gain a more comprehensive understanding of the research question (Lambert & Loiselle, 2008). Both methods will be described in the next section as well as the rationale for its choice for the study. However, before discussing the rationale and design of the research methods, this subsection will conclude with an overview, shown in Table 1, of the research philosophy, approach and strategy used and the research methods employed:

Research area	Choices for this research project
Ontology	The belief that there are multiple constructed realities
Epistemology	The belief that the knower and the known are inseparable
Paradigm	Constructivism
Approach	Inductive
Choice of methodology	Qualitative
Strategy	Embedded Single Case
Methods	Semi-structured expert interviews & focus groups

Table 1: The summary of the research methodology for this research (Source: Authors own illustration)

3.4.1 Semi-structured interviews

According to Helfferich (2022) guided expert interviews are a common and methodologically widespread method for obtaining qualitative data. In this context, expert interviews are defined "*by the special target group of interviewees and by the special research interest in expert knowledge as a special kind of knowledge*" (Baur & Blasius, 2019, p. 669). Questions about the background and framework can often be answered better with interviews than through document study (Hopf, 2016). Through the interview, the knowledge, experiences or also perspectives of the participants are to be collected. In the process, the course of the conversation is mainly controlled and shaped by the interviewee (Bortz & Döring, 1995). This enables deeper and broader insights into the research topic (Bortz & Döring, 1995).

An essential feature of qualitative expert interviews is their openness and flexibility, which is reinforced by the narrative character of the procedure. Persons who possess exclusive knowledge and are usually members of a specific organization or institution can be considered as experts (Gläser & Laudel, 2010). This special knowledge can be either contextual knowledge and/or operational knowledge (Meuser & Nagel, 2009). For scientific research, the insider knowledge of experts is of particular interest because they can express their informal knowledge about processes, plans and decision-making structures of their organization in language and thus make the knowledge accessible to research (Meuser & Nagel, 2009). Empirical studies are fundamentally characterized by the quality criteria of objectivity, validity and reliability (repeatability). Compared to quantitative methods, expert interviews are subject to greater subjectivity on the part of the interview participants (Hopf, 2016). Therefore, the traceability of the methods used, the interpretation of the information collected and thus the transferability of the results to other applications is not possible without restrictions. To mitigate these disadvantages of qualitative research methods, an interview guide is used as an aid and a recording is made during the expert interviews (Flick, 2019).

In this way, the greatest possible objectivity and quality of the results is targeted. A guided interview ensures that aspects of interest can be addressed and that the goal of comparability of the interview results is guaranteed (Flick, 2019). Guided interviews are mainly used exploratively, either to generate hypotheses or as a pretest in the development of a standardized questionnaire in combination with quantitative research. At the same time, they can also be used for qualitative analysis of smaller groups or individual cases, as is the case here (Stier, 1999). King et al. (2018) point out that in qualitative research there are the semi-structured and unstructured interviews. The crucial point here is that the interviewee is always free to answer a question asked; no answer categories are predetermined. In the non-standardized (open) interview, both the formulation of the question and the sequence of questions is left to the interviewer. The interviewer can respond flexibly to what is said and develop new relevant questions. Only a framework topic is given. In the semi-standardized interview or guideline interview, the formulation of the questions is thought out in advance and recorded in a guideline, but not when the questions must be asked. In the semi-structured interview, the interviewees are guided thematically without restricting them. A thematically oriented guideline with questions can be prepared in advance, but its processing during the interview should be flexible (Helfferich, 2022).

3.4.1.1 Justification of the semi-structured interview

Expert interviews are among the most frequently used qualitative research methods for reconstructing complex bodies of knowledge about a subject under investigation (Raubold, 2011). The experiential horizons of experts help to gain access to specific and hitherto hardly explored knowledge and enable deeper and broader insights. Experts can help with their respective expertise to "*get a vivid picture of the participant's perspective on the research topic*" (Meuser & Nagel, 2009, p. 23).

With the help of expert interviews, data was collected with regard to the first research question and thus the added value of digital-physical products was worked out and their influence on the product life cycle was enquired about. Selected experts with a specific interface (e.g., marketing) to product management were explicitly asked which possibilities these new products offer, and which impact they could have on the existing product lifecycle model of Siemens Mobility Rail Infrastructure from their point of view. The data collected helped to understand the characteristics of digital-physical products and to which extent they interfere with the existing product life cycle. Furthermore, the use of the method is underpinned by the fact that the aim of expert interviews is "*to gain information about certain facts that cannot (or not so easily) be obtained by other means*" (Wassermann, 2015, p. 55). Since this study is about the further development of an internal company model, it is difficult to obtain information through other channels. In addition, the semi-structured interviews are suitable for questions about the background and framework conditions and thus help to gain deeper and broader insights into the research topic. In order to counteract the subjectivity mentioned above, the interview guide was used as an aid. In this way, the greatest possible objectivity and quality of the results was sought. Flick (2019) argues that in semi-structured interviews, the interviewer should have basic knowledge of the topic area. This also applies to the researcher, as he is part of the organization and works in the area of product management. Precisely because of this, the researcher has a clear idea of the questions to be asked, which also underlines the use of semi-structured interviews (Schell, 2020). The expert interviews were conducted in two parts.

The first part focused on standardized questions based on an interview guide, the second part in open discourse. This combination was expected to produce the highest possible quality of results. The purpose of this methodology is to gather different opinions, best practices and viewpoints, evaluate them and create an overall picture (Meuser & Nagel, 2019). The question is how many interviews can be considered sufficient. On the one hand, when approaching the topic, it quickly becomes apparent that the number of contacts specialized in the topic is limited from the outset.

Experts are knowledgeable persons who, as actors in the field of investigation, have specific knowledge of action and experience (Helfferich, 2022). Digital-physical products are still considered quite new within the organization and therefore the expertise and experience about these products in the organization is limited. Especially the knowledge about the specific requirements for these products from the market can only be assigned to limited departments, such as sales or top management. On the other hand, engagement with some PhD studies related to life cycle management (Raubold, 2011; Bertrand et al., 2018) has shown that a sample size of ten and twelve participants is sufficient to understand this specific phenomenon in a specific context. On this basis and considering the given boundary conditions, the researcher intended to recruit a maximum of 15 experts from Siemens Mobility GmbH Rail Infrastructure. The reason for this is that, on the one hand, with this number a pluralism of perspectives and thus also the purpose of the methodology can be ensured. On the other hand, this number of expert interviews is a realistic value to achieve validated results (Raubold, 2011). The selection of experts should meet two criteria in particular. Firstly, experts should come from as diverse a range of fields as possible in order to be able to consider the added value and impact of digital-physical products from different perspectives. Secondly, it is important that the respective persons have some relation to digital-physical products and the product life cycle model as well as product management. The difference is that the participants do not have to know or understand the model in its entirety, but that a certain interface has to be presented to them. In this way, a pluralism of perspectives related to the object of study can be ensured.

3.4.1.2 Design and execution of semi-structured interviews

The design was based on the structure mentioned by Kaiser (2014) and is illustrated in Figure 35. It begins with the design of the interview guide and is concluded by the recording of the respective interview:

Figure 35:Procedure of an expert interview according to Kaiser (Source: Kaiser, 2014)

The first step in conducting expert interviews is the preparation of the interview guide. It is the instrument of data collection, but at the same time also the result of translating the research problem and theoretical assumptions into concrete interview questions that are comprehensible and answerable in terms of the experts' world of experience. The form of the semi-structured interview guide was constructed as flexible, resulting in dialogue during the interview and thus easy transition from question to question. This was deliberately designed to maximize the richness of the data (Turner 2010). In preparing the interview guide, the research questions, and guidelines of the expert interviews of tangential studies were used to derive questions for the own interview guide. In addition, the individual research questions were used as a basis. Figure 36 shows that the researcher first established individual categories based on the research question. The individual question categories are then followed by individual main questions that fall into this question category and question.

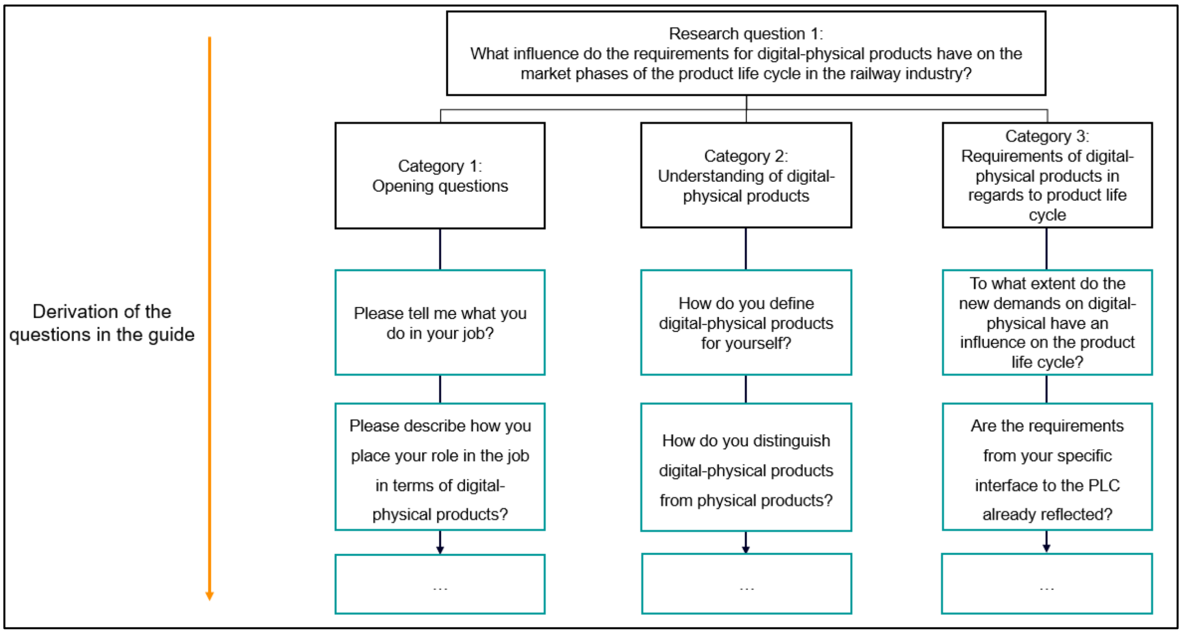

Figure 36: Overview of the development of the interview questions (Source: Authors own illustration)

As mentioned, the findings and patterns of Raubold (2011), Moecker & Roecker (2018) and Gentner & Oßwald (2017) were used to derive the categories and questions. The aforementioned studies and their interview guidelines form a good basis for setting up the question categories and deriving the corresponding questions for this study. Furthermore, follow-up questions were also used, on the one hand to make the main questions more understandable for the participants and on the other hand to gain deeper insights into a question. (Baumbusch 2010). Although some follow-up questions were designed in advance, they were also asked spontaneously based on the participants' answers (Whiting 2008, Turner 2010). It should be noted that the order of the interview questions was not decided before each interview. The researcher selected the order of interview questions based on the actual situations in the interview (Whiting, 2008). After the preparation of the guide, the researcher selected and contacted interview partners. The researcher recruited a total of twelve interview participants for the study. All participants work in direct contact with product management and have experience with digital-physical products. The participants are listed in the Table 2 below with their respective department name, the researcher's anonymization key and the interview day and time:

Department	Experience in area [years]	Specific relation to product management	Label for participant	Interview
Sales	> 5	Product support in his/her responsible countries	IntExpert-1	05.05.2022 10:00h
R&D	>12	PM as stakeholder for current developments	IntExpert-2	16.05.2022 16:00h
Sales	>25	Product support in his/her responsible countries	IntExpert-3	17.05.2022 08:30h
Top Management	>3	Superior management of product management	IntExpert-4	18.05.2022 18:30h
Marketing	>10	Regular coordination of future marketing measures	IntExpert-5	25.05.2022 15:30h
Factory	>20	Regular coordination of current production process	IntExpert-6	30.05.2022 14:15h
R&D	>5	Consultation on future development projects	IntExpert-7	08.06.2022 09:00h
Bid	>8	Support for product-specific offers	IntExpert-8	09.06.2022 10:00h
Head of Sales	>4	Regular coordination with PM for future sales strategies	IntExpert-9	09.06.2022 17:15h
Business Development	>7	Planning strategic country entries	IntExpert-10	13.06.2022 08:30h
Marketing	>4	Coordination of current marketing activities	IntExpert-11	13.06.2022 12:00h
Top Management	>5	Stakeholder of PM	IntExpert-12	15.06.2022 18:00h

Table 2: Participants list and interview schedule (Source: Authors own illustration)

The participants were asked to take part by email and were contacted by phone before the meeting to explain the topics to be discussed during the interview. The interviews were all conducted using a company video conferencing tool, but always without video. Prior to conducting each interview, all participants were briefed by telephone on the background and purpose of the research as well as on the procedures to be followed during the interview. Participants were also assured that the names of the interviewees and the companies would be kept confidential. All interviews were conducted either in German or English, recorded with the help of a dictaphone and subsequently transcribed. In addition, notes were taken during the interviews and afterwards, summarizing important information about the interviewed expert, the interview process and about organizational aspects of the interview. These notes did not serve to secure the data and should therefore not be confused with the transcription or the memory protocol.

By taking this step, the researcher followed the recommendation of Kaiser (2014), who argues that these kinds of notes "*contain information about the atmosphere of the interview, the reactions of the interviewee, the extent to which questions were answered and, if applicable, further information obtained in the interview that could be of importance for the research process. This record can play an important role in later phases and in the comparative analysis of different interviews because it still allows an assessment of the quality of the respective interview even after longer periods of time*" (Kaiser, 2014, pp. 86). All interviews were conducted over a period between 30 minutes and 60 minutes. The interview with each participant was conducted according to a similar pattern and the approach of Hesse-Biber & Leavy (2006). This included small talk, a brief introduction to the topic with a reminder that participation is voluntary and anonymous, opening questions, key questions and closing questions. The most important part of the interview process was to ask key questions, i.e., questions specifically designed to acquire important data to answer the research question. The researcher often asked many follow-up questions in this step to obtain more specific data (Hesse-Biber & Leavy, 2006). As this was the most important part of the whole interview process, the interview questions focused on answering the first research question. As previously described, some of these steps can be processed parallelly, thereby optimizing the overall processing time of the data collection. The researcher followed this pattern and transcribed mostly shortly after the conducted expert interviews.

3.4.2 Focus group method

A focus group is a moderated and focused discussion of a group of people which is intended to offer a clear plus in “*information through the mutual exchange and confrontation with perceptions, opinions and ideas of other discussion participants*” (Stotten et al., 2019; p. 8). The interaction in the group is particularly important to gather as many opinions and perspectives as possible and to work out the most important criteria (Schulz et al., 2012). The method serves to collect data "*through group interaction on a topic determined by the researcher. In essence, it is the researcher’s interest that provides the focus, whereas the data themselves come from the group interaction"* (Morgan, 1997, p. 6). Consensus between the participants in the discussion is not the goal, rather different facets of a topic should be brought up (Littig & Wallace, 1997). In order to structure the discussion process, a guideline is used which, similar to qualitative individual interviews, serves as a guide for the moderator and ensures that all important aspects are addressed throughout the focus group.

Furthermore, it helps with the comparability of the results if several focus groups with different groups of participants are conducted on one question. "*Thus, the focus group is a combination of two social science instruments: the focused interview and the group discussion*" (Dürrenberger et al., 1999, p. 12). By now, focus groups are not only conducted face-to-face, but also online (Prickarz & Urbahn 2002). In the literature, focus groups and group discussion are not systematized and defined uniformly (Flick et al., 1995; Lamnek, 2000). As a common denominator and rough approximation, both techniques can be described as "*a moderated discussion of a group focused on a topic or a problem […]*" (Stotten et al., 2019, p. 8). The central difference between the focus group method and the group discussion method, however, is the level of meaning that is targeted. This is because group discussions target the second level of meaning, i.e., deeper latent structures of meaning. This level of meaning explores, for example, the milieus of certain groups and the experienced practice or implicit everyday knowledge of the group members (Bohnsack & Nentwig-Gesemann 2010).

The result of the group discussion is the explication of collective experiences and perspectives that have already emerged among the group members (Przyborski & Riegler, 2010). "*Focus groups remain at the first level of information and are therefore very suitable for the analysis of e.g., organizational processes or structural analyses*" (Kocak & Pawlowski, 2021, p. 53). Furthermore, what is special about focus groups is the combination of a group discussion with a focus on a specific topic which is brought into the group through an information input (e.g., short presentation on the topic, film excerpt, etc.). Only rarely are focus groups used as a stand-alone method in the research process, but mostly as part of a multi-method design (Breitenfelder et al. 2004). "*A strength of qualitative methods in general and focus groups in particular lies in exploration, i.e., in generating rather than testing hypotheses. This is one reason why focus groups are often used in the exploratory phase of qualitative research*" (Bürki, 2000, pp. 101). Focus groups are often used when it would also be possible to conduct focused interviews (Flick, 2006). Nevertheless, there are certain advantages of focus groups over individual interviews as stated by Pant (2022, p. 69):

- *"Spontaneous expression in the group. This could stimulate new ideas that remain hidden in individual discussions […].*
- *A focus group could be more productive since participants have the opportunity to switch between active and passive participation in comparison to an individual interview since moderator effects could be minimized due to the group size*".
- In addition, it seems more difficult for individuals to credibly and persistently express socially desirable opinions in front of a group (Dürrenberger et al., 1999; Göll, 2009).

Thus, the basic idea is that there are valuable group dynamic effects in focus groups to positively influence the participant's involvement to provide information (Vogl, 2019). This is attributed, among other things, to the fact that expressing oneself in a group is closer to everyday experiences than isolated formulation in an individual interview (Littig & Wallace 1997). It is also possible and feasible to combine individual interviews and focus groups in multi-method designs. This combination is carried out in this study to gain deeper insight into a phenomenon on the one hand, but also to bring together different perspectives or behaviours at the same time (Morgan, 1997).

3.4.1.4 Justification of the focus group method

Focus groups are a qualitative method that focuses on questions to generate hypotheses on hitherto little researched or complex issues, and the discussion is intended to shed light on various facets (Göll, 2009). This is exactly what the researcher wants to achieve with this method, because in this way it is possible for the researcher to get first-hand information from actual actors and to delve even deeper into a particular topic. The use of the focus groups was aimed at collecting data regarding the second and third research questions. The focus group participants were product managers from different product areas who are aware of the challenges mentioned in chapters one and two, work with the product life cycle model on a daily basis, but also have expertise in digital-physical products. Through their daily work with digital-physical products in the context of product management and the product life cycle model, these experts were able to collect data on the peculiarities of digital-physical products in regard to that context. The researcher believes that a structured discussion between these experts on the phenomenon under study can produce more valuable data than individual interviews. However, this is also due to the phenomenon under study itself. After all, the product life cycle model is a complex but also guiding process for all product managers in the organization. Depending on the (technical) product itself, the market position of the respective product and the respective product competition, but also the respective internal interfaces to sales, marketing and development, the model is lived and defined differently. Based on these different perspectives, the research aims at entering into an open discussion with the participants in order to analyze a further development of the model but also the effects of the further development on product management. The results of the discussions then not only reflect the individual opinions of the participants, but also include the exchange and discussion processes of the participants among themselves and thus obtain a special synergetic quality (Göll, 2009). In this respect, focus groups are characterized by a comparatively high density and depth of information (Sims, 2006).

The group situation and the accompanying interaction and communication of the participants with each other offers the advantage that the participants inspire each other with their statements and topics can be dealt with much more comprehensively, diversely and partly more creatively in this way than in individual interviews. "*Due to the strong dialogue orientation and an open and flexible interview style, which allows for inquiries and deepening of topics, deeper insights can be gained with focus groups than is possible with fixed questionnaires, for example*" (Henseling et al., 2006, p. 4). It is important to define the topics clearly and precisely so that interactive discussions can be encouraged between participants to gather relevant information (Henseling et al., 2006). In general, focus groups are a suitable approach wherever the aim is to gain an in-depth and comprehensive insight into the world of the phenomenon under investigation and/or to discover existing problems (Onwuegbuzie et a., 2009).

Since group dynamic processes, especially the exchange between the discussion participants, have a significant influence on the results of focus groups, the composition of the groups plays a central role (Romm, 2014). Therefore, the definition of the target group and the recruitment of participants in a focus group project are of great importance. As a rule, focus groups are conducted with relatively homogeneous groups (Romm, 2014). This means that the participants have a similar background regarding certain project-specific criteria (e.g., in terms of profession). Nevertheless, the panelists should differ in at least one characteristic in order to obtain a wider range of opinions (Côté-Arsenault & Morrison-Beedy, 2005). Homogeneity makes it easier for participants to engage in conversation with each other, as they have common points of contact (Krüger, 1999). In this study, the participants were product managers from one organization. Thus, a homogeneous group was formed, and the differentiator was characterized by the responsibility for a different product. Krüger & Casey (2009) and Romm (2014) argue that a group size of three to five participants is ideal. If the number of participants is too large, the speaking time for each individual could be too short, and if the group is too small, it can quickly lead to a drying up of the exchange during the focus group interview. Like the boundary conditions of the expert interviews, the number of eligible participants for the workshop is also quite manageable, so the researcher followed the aforementioned recommendation of three to five. There were two focus groups in total. The main reason for this is that a four-to-five-hour discussion with more than five participants would be very exhausting for both participants and moderator and would also be too complex to handle in terms of analyzing the amount of data (Morgan, 1997). Therefore, the focus group was divided into two groups each to counteract the reasons mentioned above.

3.4.2.1 Design and execution of the focus group

The structure of the focus group was based on the recommendations of Schulz et al. (2012) which divides the structure of the focus groups into three phases. The first phase is about determining the group, the role of the moderator and the preparation of the focus group in terms of content and organization. The preparation also included the creation of a guideline for the focus group, which was derived in a similar way as the expert interviews. However, the focus was on the second and third research questions, from which question categories and then main questions and follow-up questions were derived. The guidelines by Schell (2022) and Nascimento et al. (2019) served as a basis here. The complete guide is attached in Appendix E. The second phase involves conducting the focus groups and the third phase corresponds to the evaluation. The two focus groups are listed below in Table 3 with the orientation of the respective product manager, the anonymization key of the researcher as well as the date and time:

<table>
<tr><th colspan="4">Focus Group 1</th></tr>
<tr><th>Orientation of the product manager</th><th>Experience in area [years]</th><th>Label for participant</th><th>Interview</th></tr>
<tr><td>Operational</td><td>>5</td><td>PM1</td><td rowspan="3">23.05.2022 08:30h</td></tr>
<tr><td>Strategic</td><td>>6</td><td>PM2</td></tr>
<tr><td>Strategic</td><td>>11</td><td>PM3</td></tr>
<tr><th colspan="4">Focus Group 2</th></tr>
<tr><th>Orientation of the product manager</th><th>Experience in area [years]</th><th>Label for participant</th><th>Interview</th></tr>
<tr><td>Strategic</td><td>>7</td><td>PM1</td><td rowspan="4">01.06.2022 15:00h</td></tr>
<tr><td>Operational</td><td>>22</td><td>PM2</td></tr>
<tr><td>Operational</td><td>>18</td><td>PM3</td></tr>
<tr><td>Strategic</td><td>>7</td><td>PM4</td></tr>
</table>

Table 3: Participants list and focus group date (Source: Authors own illustration)

The researcher wanted to enter an open discussion with product managers to understand a further development of the model, but also the impact of the further development on product management. Therefore, the researcher specifically contacted technical-operational, sales and strategic product managers within the company. In addition, the researcher made sure that the product managers contacted had at least five years of experience in the field, so that the individual phases of the product life cycle were known. The researcher recruited a total of seven participants for the study. All of the participants work as product managers and have experience with digital-physical products. As described, the seven participants were divided into two groups. The researcher took care to create a group that was as heterogeneous as possible. The focus of the respective product managers (technical, sales, strategic) was deliberately mixed.

The process of contacting the focus group participants was very similar to that of the interviews. The participants were also asked to participate by email, and background information and questions about the research were clarified with the participants in a separate meeting. One meeting was conducted in German (Focus Group 1) and the other in English (Focus Group 2). Both meetings were recorded using a company video conferencing tool, but always without video. The participants were also assured that the names of the interviewees and the companies would be kept confidential. In addition, the researcher took his own notes during the focus groups and immediately after the interview the researcher summarized important information about the interview, the interview process, and organizational aspects of the focus group. The meetings were recorded with the help of a dictation machine and then transcribed. All meetings were conducted over a period of between 60 minutes and 90 minutes and again followed a similar pattern. They started with small talk, a short introduction to the topic with a reminder that participation is voluntary and anonymous, a transition phase, a discussion and a closing phase. The most important tool for the researcher during the meetings was the guide. In principle, no special training was necessary for the researcher for his role as moderator, as he had already attended internal training courses and held various workshops in his daily work. The guideline, however, determined the direction and the degree of structuring of the discussion alongside the moderator. It ranges from a keyword catalogue to a standardized guideline with formulated questions. In addition to content-related aspects, it also addresses formal peculiarities of focus groups, for example in relation to different phases of a group discussion (strangeness, orientation, adaptation, familiarity, conformity, dying down of the discussion). Below is an excerpt of the guide (full guide in Appendix E), which is divided into mainly three sections:

Introductory Phase:

The author introduced himself and explained the objectives of the research and the data collection procedure. In addition, the researcher informed the participants about ethical issues, such as confidentiality of data, permission to use a dictation machine and explained that of course the session can be ended at any time if they feel uncomfortable. It was also pointed out that participants did not have to respond to every question and that what was said must be kept confidential and respected. After the initial introduction, participants were asked to introduce themselves and introduce their focus within product management, their product responsibilities and their relation to digital-physical products. The introduction phase also included a presentation of the agenda for the meeting as well as the research project and its context.

Transition and discussion phase:

The aim of the transition phase was to get an introduction to the topic to make the participants feel more comfortable and to enable them to share their perspectives and experiences when the author mentioned key topics. In addition, there were general questions in this phase related to the main topic (Hesse-Biber & Leavy, 2010). These questions aimed to identify the importance of and requirements for digital-physical products. In the discussion phase, the key questions were asked, which were specifically designed to obtain important data to answer the research questions. The researcher often asked many follow-up questions in this step to obtain more specific data (Hesse-Biber & Leavy, 2010). As this was the most important part of the whole meeting, the guiding questions focused on answering the second and third research question.

Closing phase:

In the closing phase, the questions were broader and more general. This is because it is important to include some closing questions in the meeting process, as during the time spent discussing the key questions, the relationship between the participants is still connected and distance can be created via the closing questions. In addition, the researcher thanked the participants for their participation and again pointed out the confidentiality and anonymity of the data.

3.5 Data analysis

Qualitative research requires understanding and collecting different aspects as well as data and aims to generate knowledge based on human experience (Sandelowski, 2004). There are various models of analysis, such as thematic analysis, interpretative phenomenological analysis and grounded theory (Charmaz, 2006), to conduct data analysis "*in a rigorous and methodical manner to yield meaningful and useful results*" (Nowell et al., 2017, p. 1). To address the challenge of understanding the meaning of qualitative data and analyzing the co-constructed meanings of the participants (Saunders et al., 2009), the technique of thematic analysis (TA) was used. "*Braun and Clarke (2006) and King (2004) argued that thematic analysis is a useful method for examining the perspectives of different research participants, highlighting similarities and differences, and generating unanticipated insights"* (Nowell et al., 2017, p. 2). Thematic analysis "*forces the researcher to take a well-structured approach to handling the data*" (King et al., 2004, p. 268).

Therefore, in comparison between these methods, thematic analysis is more appropriate for this study as the researcher focuses very much on the content rather than the way the story is told. Moreover, in order to extract people's knowledge or experiences from a range of qualitative data, the thematic analysis is a beneficial research approach (King et al., 2004). Since, in terms of constructivism, the researcher wants to co-construct knowledge, this argument underpins the use of thematic analysis. Furthermore, the researcher used an inductive approach within the thematic analysis. The reason for this is that in the inductive approach the categories are derived from the material without resorting to previously used theoretical structures or concepts. Thus, the data is not attempted to be linked into a pre-existing framework or specific theory, but the themes emerge naturally from the data (Terry et al., 2017; Braun & Clarke, 2013). The researcher's aim was to narrow down the textual elements without distorting the core content and essence of the material (Mayring, 2015). Therefore, this approach of thematic analysis was data-driven (Terry et al., 2017; Braun & Clarke, 2013). This approach underpins an inductive approach, as there was no attempt to fit the themes into a pre-existing coding scheme or the researcher's analytical biases. On the contrary, the overarching aim of using thematic analysis was to identify and interpret data characteristics, resulting in a close relationship between the data and themes. In order to create the themes, the researcher identified, analyzed and reported patterns from the interviews and the focus groups.

In this regard, the researcher followed Miles and Huberman (1994) three-step process model for conducting data analysis. The first step involves data reduction by summarizing initial data. This is followed by the aspect of understanding and ordering, which is carried out in the second step. Now that the data has been summarized, ordered and understood, the third step is to draw conclusions out of it (Miles & Huberman, 1994). In parallel with the steps, the thematic map was used to help visually with the listing of themes and codes. The final version of the thematic map is shown later in chapter 4.

3.5.1 Conversation of the interview data

All interviews and focus groups conducted were transcribed in German. To familiarize himself with the data collected, the researcher first read through all the protocols carefully. This process helped the researcher to interact and be involved in the process of in-depth listening, analysis and interpretation. It also provided a valuable opportunity for the researcher to be actively involved in the data from the first stage of data analysis, allowing for a deeper and more complete understanding of the data as a whole (Hesse-Biber & Leavy, 2010). In addition, the researcher made a conscious decision not to use software to help with the data analysis.

While there are some advantages to using software programs, the programs cannot make sense of the meaning behind the interviewees' conversations and only recognize the iterative processes from the data. However, the researcher wanted to delve into the process of data evaluation (Zamawe, 2015) and as a result opted for a manual method. Moreover, this was the most appropriate approach to obtain reliable information from the participants' point of view. In order to create order within the data and to better understand and compare the data, all interview and focus group questions as well as their answers were clustered in terms of their focus.

In the second step, the researcher created initial codes and organised the data, which also improved understanding about the data (Miles & Huberman, 1994). Braun and Clarke (2013, p. 206) suggest that: "*Coding is a process of identifying aspects of the data that relate to your research question*". The coding involved dividing the information into small categories of data, searching for evidence of the code and then assigning a label to it (Creswell, 2013; Braun & Clarke, 2013). This required the researcher to code everything relevant to answering the research questions from the printed transcript by marking it with annotations and abbreviations (Braun & Clarke, 2013). In this context, the researcher explored all the data collected for each question and summarized the data marked by codes. These codes allowed a compressed overview of the key aspects that recurred in the data. While analyzing the data, the researcher used different colour labels to structure initial commonalities. In addition, the researcher used a standard Excel tool to sort the paragraphs, sentences, comments, etc. with the respective colour label and then examine them in the different themes. Furthermore, theoretical and reflective thoughts were also documented and initial thoughts on possible topics were integrated. This process of reading and reflecting enabled the author to engage more deeply with the data.

The next step was to use the codes created and patterns identified to generate different themes for analysis and interpretation. Braun and Clarke (2006) define a theme as broader than a code and as an idea that picks up on what is important with regard to the respective research question. In addition, multiple codes are usually combined into a single theme. At the same time, certain codes were also discarded again because the codes were too vague or not relevant enough. For example, the code (Basic R - Digital Twin) was dropped after this aspect was declared not to be a basic requirement for digital-physical products during both focus group discussions.

In creating the themes, the researcher followed the guiding principle of Braun & Clarke (2013), namely that the potentially created themes say something helpful about the data for the actual purpose. This is underpinned by McAllister et al. (2018, p. 1) who states that "*Themes are described as recurrent and distinctive features of participants' accounts that characterize particular perceptions and/or experiences that the researcher sees as relevant to the research questions*". For example, when creating themes for the study of the characteristics of digital-physical products, only the data in this context were considered. Effects that were discussed, such as those on development, were not considered further. At the same time, personal choices and interpretations needs to be carefully considered, as thematic analyses are often quite subjective. Therefore, for verification purposes, all themes created were checked repeatedly to guarantee that the themes were a meaningful representation of the data. Therefore, the researcher made some loops by going back to the data set and comparing the themes with the data and discarding and combining some of the themes. In addition, when defining themes, the researcher has paid attention to the wording so that the name for each topic is concise and easy to understand (Schell, 2020). Using these considerations and process, the researcher identified several themes and linked them to the codes. Figure 37 represents a section of the coding framework. The full code framework can be found in Appendix B.

Thematic Analysis - Code Framework			
Theme	**Code**	**Definition**	**Example quote**
Relevance of digital-physical products within the rail industry	Relevance -1	Digital-physical products represent an intermediate step	It's an evolution for me. A sliding step, so to speak, and in the end it is, the relevance will increase.
	Relevance -2	Despite relevance; slow introduction of these products	Think of the example of the ETCS system [...]. Our constraints will prevent the rapid introduction of these value-added products.
	Relevance -3	Enabling digital possibilities	The relevance will increase in the next 5 years as, according to my interpretation, digital services can become enabled.
Basic requirements for digital-physical products	Basic R -1	Cloud based application	Cloud based is core of digital-physical products [...]. Without that you can't use their advantages.
	Basic R -2	Edge Computing	The software complexity becomes bigger and bigger because we have more requirements and we have to constantly patch. Edge computing on all these connectivity layer needs to be included on the physical asset.
	Basic R -3	Cyber security	The capability of IT security must be present in every newly developed product. Whether it is used or not is an open question. But with our lifecycles, it has to be there from the beginning.
	Basic R -4	Monitoring function, diagnostic function & predictive Maintenance	There are three requirements that first of all do not exist in a mechanical product or do not exist in an electronic product. There is a monitoring function, a diagnosis function and a prediction, the prediction. Digital-physical products can cover all three requirements
	Basic R -5	Augmented Reality	For me, augmented reality is not a requirement for tomorrow's products, rather a nice gimmick. The maintainer has to go out anyway and usually the staff is always trained
	Basic R -6	Archivsystem	The use of the archive system helps us to improve our products in the long term, as it stores error events over a certain period of time.
	Basic R -7	Remote Software Update	This function would relieve us as a manufacturer enormously as well as the operator. With the help of the function, the running operation does not have to be disturbed and we save an enormous amount of costs, as no one has to physically stand in front of it anymore.
Economic significance of digital-physical products	Economic -1	Digital-physical products as growth market	This is just the beginning [...] many possibilities will be enabled so that the market for these products will be bigger from year to year.
	Economic -2	Product price increase through digital-physical products	Benefits must be integrated and the product price raised. Otherwise we start pricing every feature and after a few years you won't be able to manage it.
Added value of digital-physical products in the market phase	Value -1	Added value for the operator	[...] leads to a reduction in LCC through improved maintenance.
	Value -2	Added value for the manufacturer	Digital-physical products will extend the value proposition of the physical product".

Figure 37: Extract of code framework (Source: Authors own illustration)

The final step, according to Miles and Huberman (1994), involves drawing data and conclusions. Drawing conclusions means taking a step back to consider what the data analyzed means and assessing its implications for the questions at hand. Based on this, the researcher repeatedly reviewed the connections from the raw interview and focus group data and themes for common patterns and coherent logic. Verification, which is closely related to drawing conclusions, involves reviewing the data as often as necessary to control or verify the emerging conclusions. "*The meanings that emerge from the data must be tested for their plausibility, their firmness, their 'confirmability' - that is, their validity*" (Miles and Huberman, 1994, p. 11).

Section 3.6 describes the aspect of rigour for this research once more in detail. Finally, it should be mentioned that the inductive approach to data collection and analysis enabled consistent transition and identification of themes and patterns. On the one hand, the systematic approach of TA improved the understanding of the collected data and on the other hand, the methodology also helped to better understand the subjective meanings (Saunders et al., 2009). In describing the findings of the data analysis results (Chapter 4), the researcher followed the code frameworks as a guide for writing a consistent report of findings by also integrating direct quotes from the participants (King et al., 2004).

3.6 Rigour of research

Rigour refers to the stages the researcher goes through to prove that the results of a study are justified by the study process used (Mason, 2002; Morse, 2003). Lincoln and Guba (1985) propose four principles, namely credibility, reliability, confirmability, and transferability. Based on these criteria, the determination of the scientific rigour and quality of this study is derived. Credibility is related to the steps taken to ensure that the research contains accurate descriptions of the respondents' views (Vivar et al., 2007). The reference of the findings to other contexts and to what extent they can be transferred refers to the transferability (Shenton, 2004) and reliability refers to the transparency of the study process. Conformity of research is achieved when credibility, transferability and reliability are achieved (Lincoln & Guba, 1985).

Credibility

Through different techniques it is possible to establish the credibility of the findings. Therefore, the researcher used many different aspects to increase credibility in this study. These are shown in table 4 below:

Credibility	• Familiarity with the culture of the participating organization (Shenton, 2004). • The research questions and objectives were derived from the research context questions and a gap in the literature as suggested by Creswell (2013). • A systematic and comprehensive literature review was conducted (Thomas & Harden, 2008). • This study was conducted according to a consistent and appropriate research methodology (Shenton, 2004). • There was a strong link between research questions and interview questions (Tuckett, 2005). • The interviews were recorded and transcribed verbatim (Tuckett, 2005). • An appropriate data analysis approach was applied (Braun & Clarke, 2013) • Transcripts were checked for accuracy (Vivar et al., 2007) • Frequent debriefings between the researcher and his or her two supervisors took place (Shenton, 2004). • The results were supported by quoting the respondents' answers (Vivar et al., 2007) • Research findings were linked to previous literature (Braun & Clarke, 2013) • Previous research findings were reviewed (Shenton, 2004)

Table 4: Overview of the aspects of credibility for this research (Source: Authors own illustration)

The listed points correspond to recognized ways of underpinning the credibility of a qualitative study. For example, the researcher is part of the organization being studied and therefore knows its culture and circumstances well. Other aspects, such as deriving the research questions and objectives from a research gap, using a generally accepted research methodology, recording and transcribing the expert interviews and focus groups, and including quotes from interviewees in the results section, were all carried out and detailed by the researcher. In addition, data triangulation was also included. This is because combining multiple data sources can improve the credibility and validity of the results. In this study, the data collected from expert interviews and focus groups was contrasted with the phenomenon under study and thus examined from multiple perspectives. This reduces the likelihood of bias or error in the research process.

Transferability

Lincoln & Guba (1985) refer to transferability as whether the findings of qualitative research can be applied and generalized to other contexts. In order to achieve transferability, the researcher first aimed to provide sufficient and systematically prepared information about the research context (Lincoln & Guba, 1985; Firestone, 1993). Therefore, the researcher went into great detail in describing the finding under study to ensure potential transferability to other business environments. In doing so, the researcher followed the reasoning of Shenton (2004) and described the phenomenon in sufficient detail to enable the reader to properly understand, delineate and classify it. Furthermore, the researcher has provided in detail, among other things, sufficient information about the organization, the number of participants in the study and the duration of data collection, as well as the data collection methods used in the study itself (Sheton, 2004; Cole & Gardner, 1979). All these descriptions are extremely important for the reader's understanding so that he/she can place the entire study with all its boundary conditions. In addition, the results of the expert interviews were based on narratives and opinions of experts interfacing with product management, and those of the focus groups were based on product managers. The structured approach with the combination of open questions guaranteed the effectiveness and congruence of the interviews and focus groups (Schell, 2020). The answers to the interview questions and focus groups, but also the results of the study itself, can be transferred to digital-physical products in other industries and sectors of mobility service providers, which is discussed in section 5.2. In particular, the results identified in relation to the product life cycle and product management provide guidance for other sectors. Indeed, the research results confirm the importance of rethinking product management in managing this new type of product.

The results also underpin the need to integrate the new requirements into the existing product life cycle in order to capture the voice of the market on the one hand and to realize the more efficient management of smart products on the other. The reflection of the results on a lived practical model shows the practicality in a real business environment of the theoretical model. Moreover, the argumentation of Baur & Blasius (2019) should also be mentioned here. The authors believe that "*the understanding of a phenomenon is gained gradually through several studies, rather than one major project conducted in isolation*" (Shenton, 2004, p. 71). Of course, it also does not mean that studies do not provide fully consistent results if one or more of them are not trustworthy.

"*It may be that they simply reflect multiple realities, and if an understanding of the reasons for the discrepancies can be achieved, this understanding may prove as useful to the reader as the actual reported results*" (Shenton, 2004, p.71). This study, by examining the impact of digital-physical products on the product life cycle as well as product management, provides a basic understanding against which the findings of subsequent work can be compared. Such a stance is consistent with Dervin’s (1997) argument that one of the most important principles in information seeking research should be "*to see every contradiction, inconsistency, diversity not as an error or foreign body, but as fodder for contextual analysis*" (Dervin, 1997, p. 13).

Reliability

Reliability in this context means ensuring that there are no measurement errors and that the same results would be obtained if the study were repeated (replicability). In principle, according to Shenton (2004), the research design can also be considered a prototypical model. This is because if the processes are described in detail, the study can be repeated, even though the same results do not necessarily have to come out of it. In addition, data collection was conducted in places where all participants felt comfortable to share their experiences (Hesse-Biber & Leavy, 2006). This also reduces bias in data collection. Furthermore, the operational details of the data collection, dealing with the details of what was done in the field, were described in detail. Moreover, a continuous as well as reflective evaluation of the project, assessing the effectiveness of the research process, was also cited (Shenton, 2004). By doing this, the researcher intended to check whether the results were still related to the raw data.

Conformity

To achieve confirmability in qualitative research, it is important to present as an outcome the aspects of the participants. The presentation of the results should not refer to the researcher’s relationship, advantages of the like. Therefore, to promote confirmability and reduce researcher bias, triangulation should be considered here as well. Shenton (2004) argues that the choices made, and the underlying methods used should be explained and critiqued in the research report, which was done by the researcher. By critically questioning throughout the process in terms of subjectivity, but also consistently documenting, describing procedures, and reviewing data, the researcher has presented transparency to allow another researcher to replicate the findings.

3.7 Ethical consideration

Saunders et al. (2009) and Gray, (2010), state that research ethics is about "*the appropriateness of the researcher`s behaviour in relation to the subjects of the research or those who are affected by it*" (Schell, 2020, p. 120). The research involved access to primary data through interviews and focus groups. Thus, the manner of data collection and the ethical issues involved had to be considered for this research (Saunders et al., 2009). In doing so, the researcher referred to the comments of Babbie (2012), who identifies ethical challenges in social research: these include confidentiality and anonymity, voluntary participation, no cheating, institutional review boards and avoiding harm to participants. The researcher added to this the professional ethics of the University of Worcester. Therefore, the entire process of developing this work was guided by the University of Worcester's Research Ethics Subcommittee, which gave full ethical approval for this research. The ethical considerations for the study were based on the University of Worcester guidelines. For example, the research had to be justified, informed consent had to be obtained from participants, their participation had to be voluntary, confidentiality had to be ensured and risks to participants arising from the study had to be minimized. In addition to university regulations, national laws (e.g., the Common Law Duty of Confidence, the General Data Protection Regulation and the Concordat on Research Integrity) and company-specific regulations were also taken into account. As the main methods of data collection were expert interviews and focus groups, it was important that participation was voluntary and that none of the participants were pressured by the questions or the environment. To decrease this risk, data collection was conducted in an environment that felt safe and familiar to participants.

During data collection, each participant's rhetorical skills, background and experience were taken into account, so interviews and focus groups had to be prepared individually (Turner, 2010). Questions were peer-reviewed by the researcher's supervisors to avoid biasing participants in any particular direction and to ensure the most objective data collection and analysis possible. Each participant received a pre-prepared information sheet from the university and attended a pre-meeting where they had the opportunity to ask questions as well as receive initial information on the topic. During the Covid-19 pandemic, it was also important to consider the safety regulations of the university and the company and to minimize the risk of possible infection for both the participants and the researcher. Hence, no interviews or focus groups were conducted in person, only online. The confidentiality and security of the data was ensured by storing it on a laptop that was only used for the research work.

This laptop was locked with a highly secure password and all data was stored with an additional password. All other devices needed for the work were also password protected. The processed data was transferred to the university's OneDrive, which has two-way authentication. The primary data for the research was recorded using an audio recorder without a Wi-Fi connection. Once the interviews and focus groups were completed, they were stored on a secure laptop and hard drive kept in a private office with low risk of loss or theft. The data will be retained for the minimum period required by the University of Worcester of two years or until the successful award of the degree, after which it will be deleted. Ethical policies and procedures were essential to ensure a safe and fair data collection process and to help the university protect its reputation. The major challenge was to find the right balance between following all the rules and guidelines and ensuring the quality of the data. By working closely with the researcher's supervisors, researching the literature and materials provided by the university, and frequently interacting with other fellow students, a valuable compromise was found.

3.8 Conclusion

This research was conducted based on a conceptual framework underpinned by a constructivist philosophy. Semi-structured expert interviews with twelve participants and two focus groups were conducted to obtain detailed information on how to achieve the objectives of this study. Data analysis was carried out after data collection was completed and the author used a manual method to analyze the data. This method helped the author to gain a deeper understanding of the relation between digital-physical products and the product life cycle as well as product management. The transcripts were all written in German and in parallel with the data collection. The process of data analysis consisted of three steps: Data sifting, data reduction through coding, selection and identification of themes and as a conclusion the drawing of data and conclusions. In the next chapter 4, the results of the data analysis results are presented.

4 Data Analysis Results & Findings

In this chapter, the data obtained from the expert interviews and the focus groups are summarized and described according to the designated themes and codes. The qualitative data obtained from the data collection is presented through illustrative quotes to show the range of participants who contributed to the study (Anderson, 2010). The structure of this section is based on the three research questions and describes the themes as well as codes associated with each question. Thus, in section 4.1, the results of the interview round are presented and based on this, the first research question is answered. The results from the two focus groups are used to answer the second and third research questions. Section 4.2 presents the changes in the product life cycle model and section 4.3 the results on product management.

Furthermore, the section is based on Pratt's (2009) comments that researchers should balance theory and data and avoid presenting qualitative research as quantitative research. The data obtained is presented and interpreted rather than just shown. This is also in line with the constructivist value system, which is to create a contextual understanding of a particular issue or problem through interpretation and construction of meaning (Creswell, 2013).

However, before the description of the individual themes and the results of the data analysis findings are presented, in the following an overview of the individual themes will be shown through the thematic map used during the data analysis. With the help of the thematic map, the themes derived from the analysis and their characteristic codes can be visualized in a mind map (Braun & Clarke, 2013). Finally, the derived themes can then be further interpreted, placed in the context of the research question, and compared with the literature, which will take place in Chapter 5. Figure 38 graphically represents the four themes with their main codes from the interview rounds, and figure 39 graphically represents the four themes with their codes from the focus groups:

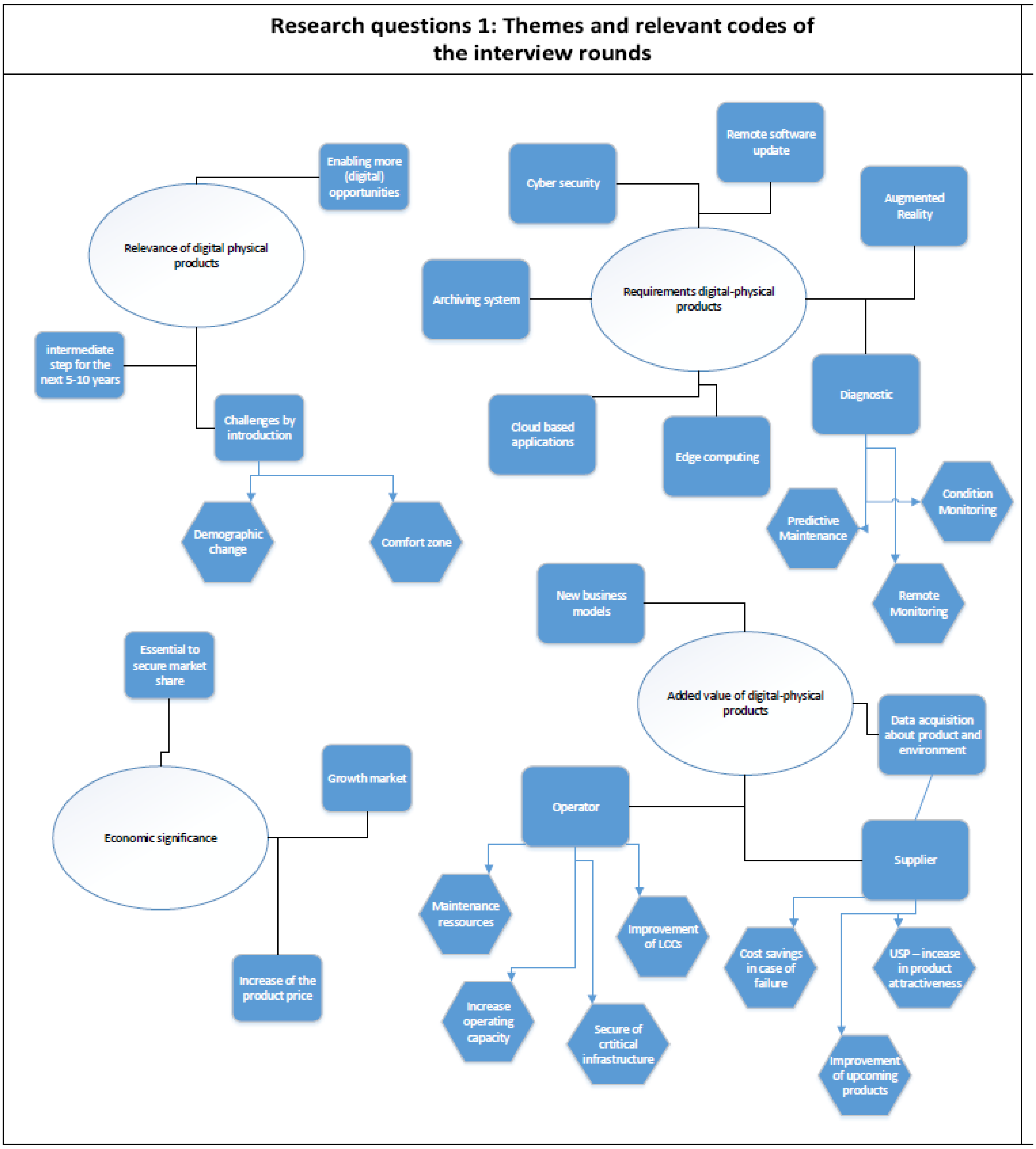

Figure 38: Thematic map from the data of the expert interviews for the first research question (Source: Authors own illustration)

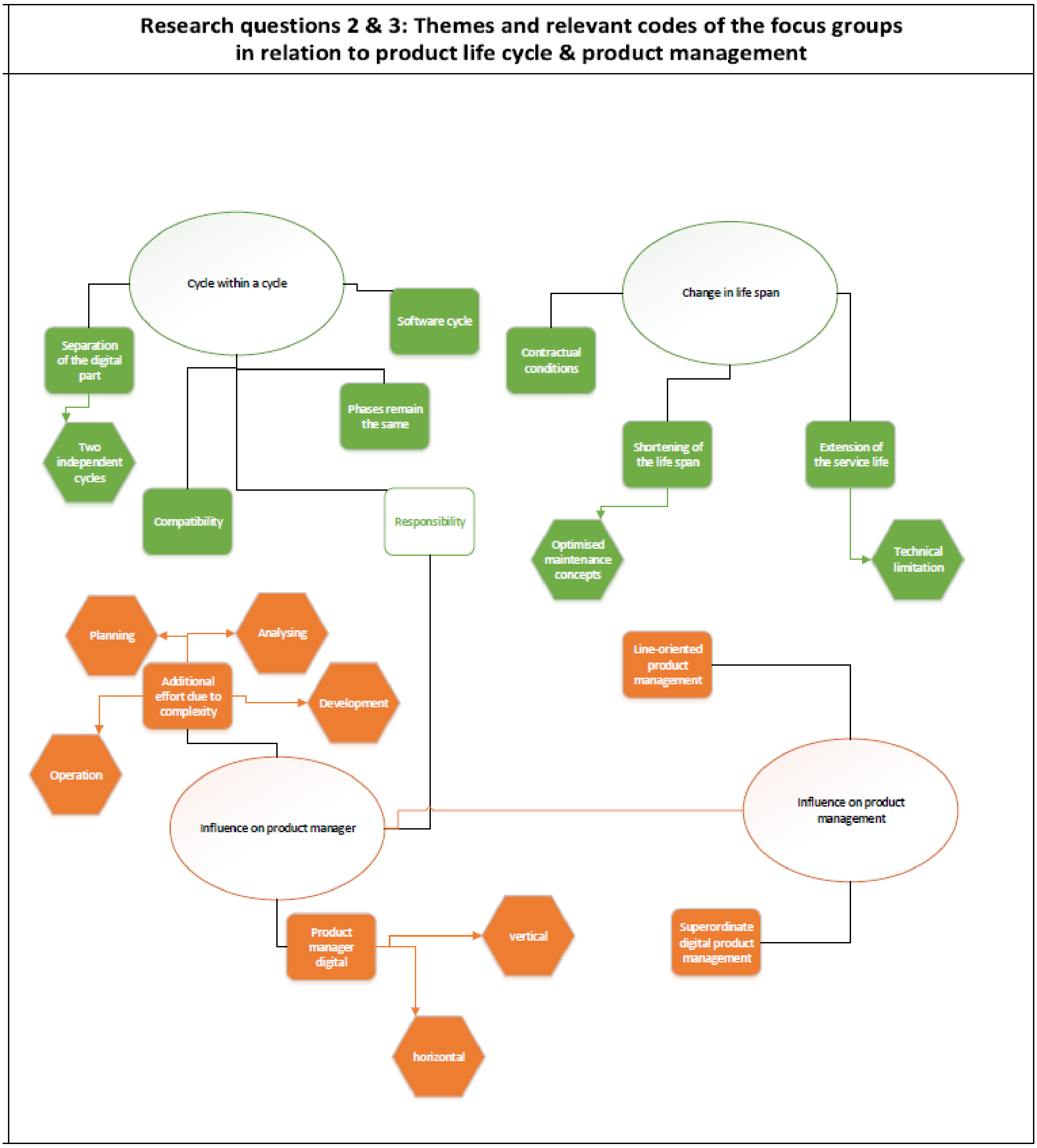

Figure 39: Thematic map from the data of the two focus groups for the second and third research questions (Source: Authors own illustration)

In an iterative process, the key words and phrases were used to derive the underlying themes which are finally visualized here in a mind map. The focus of the thematic map shown here is on semantic themes, which means "*within the explicit or surface meanings of the data and the analyst is not looking for anything beyond what a participant has said or what has been written*" (Braun & Clarke, 2006, p. 84). In both figures, the circles represent the themes. The connected rectangles correspond to the relevant codes of the respective themes and in a few cases the connected diamonds correspond to the sub-codes associated with the codes.

In addition, there is also a relationship between different codes and themes, but due to lack of clarity, this was not shown in depth, and only the essential relationships were depicted. Furthermore, in addition to the themes and associated codes, the thematic map also illustrates in colour the different results derived from the expert interviews and focus groups. This clarifies which results were derived from the interviews and which from the focus groups. As described, the focus of the first research questions was on the added value of digital-physical products and their influence on the product life cycle. The data collected helped to understand the characteristics and requirements of digital-physical products. These are marked in blue in the Figure 38.

The data from the focus groups, which concentrated on the second and third research questions, aimed at a revised product life cycle model for digital-physical products. With the help of the different perspectives of product experts, the nature of digital-physical products within the product life cycle model could be understood and demonstrated. Furthermore, data was also collected regarding the implications for product management. The potential change in product management through a customized product life cycle is a key factor to strengthen the optimal handling of digital-physical products. The themes identified from the focus groups are shown in Figure 39 green and orange. The individual topics are now described in more detail below.

4.1 Findings of the expert interviews

In addition to a better understanding of the added value and the requirements of digital-physical products, their influence on the product life cycle was investigated. In the context of the first research question, a total of four themes emerged from the expert interviews. In addition to the relevance and economic significance of digital-physical products, the participants identified various requirements in digital-physical products that differ from physical products. The requirements, which are often presented in technical detail and specific to the railway industry, were simplified and described more superficially for better understanding. In addition, some of the requirements mentioned must be taken into account as early as in product development, although they only come to effect in the use phase. The fourth topic includes the added value of digital-physical products on the product life cycle mentioned by the experts.

4.1.1 Relevance of digital-physical products within the railway industry

The experts in the interviews emphasized that digital-physical products were initially an intermediate step. Digital-physical products clearly represent the bridge between physical products and digital products and will dominate and change the market over the next five to ten years, as these types of products "*provide more information about one's own condition and data and information*" (IntExpert-1) for the first time. The enabling of digital possibilities in a physical product or the possibilities to obtain information about the activities in the product, the function and the process corresponded to the most frequently mentioned characteristics of digital-physical products. At the same time, many experts have described these products as an intermediate step since the collection of data could lead to a reduction of physical products at a certain point in the future. Interview participant IntExpert-2 referred to this as a third layer: "*But I can imagine that perhaps the third layer will manage without hardware, that in the future, due to the diverse data sources, there will perhaps no longer be any hardware that is specific to an application. [...] In the end, you only work with it on the basis of the data that you generate and receive, so you no longer need a specific sensor system, for example".* Although this theory was not developed further, the relevance of digital-physical products in the present time can also be derived from it. Addressing this intermediate step is essential for maintaining and gaining market share and not "*taking care of and implementing digital solutions in physical products could mean that we will no longer sell products*" (IntExpert-3).

In connection with the relevance of the products, the challenges that are slowing down the initiation of this intermediate step were highlighted simultaneously. On the one hand, the generally conservative structure of the rail industry was emphasized, in which safety takes precedence over everything else. The aspect of safety itself was not discussed, but many experts saw the reason behind it in the comfort zone of humans. IntExpert-11 added: "*Many people stick to what they know, as it is safe and long-proven technology, and initially close their minds to new possibilities. This makes entry difficult for digital-physical products*". In this context, demographic change was cited, which leads to a certain dichotomy with regard to digital solutions. On the other hand, the comfort zone arises due to the installed base and the technical environment itself. Electromechanical products and relay interlockings still represent the largest share of rail transport solutions installed in the world (Grigoryev, 2015). Retrofitting or replacing these systems involves enormous cost and effort, which means that progress in installation of digital-physical products is slow. Nevertheless, all experts are sure that "*requirements already exist that can only be solved with digital-physical products and that the railway industry will develop extremely in the next few years*" (IntExpert-7).

4.1.2 Economic significance of digital-physical products

The economic significance of digital-physical products was rated as high by almost all interview partners. Two interview partners saw the future market in purely digital products, whereby most interviewees saw digital-physical products as a growth market and attached growing economic importance to digital-physical products. Eight interviewees expected very rapid growth in digital-physical products within the next five years. Most experts assumed that digital-physical products would be standard in the future. The question about cost estimation for digital-physical products resulted in different approaches and opinions. Above all, the two possibilities, on the one hand an increase in the product price or on the other hand an annual lump sum, were emphasized. The discussion and justification for a price increase was based on the added value of the customer. IntExpert-7 said: "*But of course you also have to bring real value. For example, the customer can really simplify his processes and thus really divide the human factor out of this process. So, if he needed five maintenance staff before, he now only needs four - then we have to charge money for that and increase the product price*". One of the experts (IntExpert-1) thought that the product price should not be increased and that the added value should be used as a USP and thus as a competitive advantage. "*Many of the requirements are already state of the art and replacing preventive cases to corrective ones doesn't save you the person in the first place*". Enriching physical products with digital components can increase the attractiveness of products. According to IntExpert-1, the consideration of increasing the product price should depend on the defined business model and take into account the entire product life cycle.

4.1.3 Basic requirements for digital-physical products

In the case of digital-physical products, experts say that certain features must already be taken into account and implemented during development. Otherwise, certain requirements that lead to new business models during product use cannot be met. This refers to requirements such as increased data storage from the start or the possibility of IT security. Since systems are connected to other systems, according to IntExpert-12, "*requirements engineers should consider everything, which means future product developments have to be able to specify and model connectivity, distribution, flexibility, self-adaptation and the use of large amounts of data originating from physical products*". The needs for basic requirements for digital-physical products that the experts rated as most important are briefly explained below.

Access to cloud-based applications

According to the experts, the decision for the cloud corresponds to a strategic decision and not necessarily in terms of budget. The amount of data required will increase over time, so digital-physical products should be connected to the cloud. The interview participant IntExpert-6 believes that this requirement is necessary for the success of digital-physical products: "*One of the biggest trends [...] most of the logic and most of the functions are going to be software-driven, and you do not need the hardware logic to tell you what to do. In addition, you need cloud-based application to save all data. Otherwise, this whole thing will not fly*". It also offers numerous advantages in economic terms, such as the scalability of digital resources or the reduction of product maintenance and the associated costs.

Edge computing

The processing and calculation of data volumes has increased in recent years due to the continuous growth of IoT devices in the railway sector. This pushes the demands on network bandwidth to their limits, with possible effects on response times. These response times, in turn, are an essential factor for safe and reliable railway operations. According to Bravo & Lueddecke (2021, p. 42) "*by moving certain application services to the edge (of the physical asset), it is possible to pre-process the data, manage assets remotely and keep critical functions IT-secured, while improving response times"*. This idea was brought forth by IntExpert-7, for example, who saw edge computing as a key factor: "*I think the products are going to change in the direction that the edge computing is going to be close to the asset that we have today. It's what we are really doing already, like trying to bring these data-driven products inside our physical asset in the module*".

Cybersecurity

An attack on the security, availability or reliability of the railway system can have far-reaching consequences for a country in terms of logistics, as railway infrastructure is still an essential strategic component of a country's critical infrastructure (Bravo & Lüddecke, 2021). Because of this, cyber security is considered of great importance. Moreover, cybersecurity is a continuous development, "*as hacking methods become more sophisticated and targeted every day*" (Bravo & Lueddecke, 2021, p.42). For this very reason, various participants referred to continuous maintenance and further development of the function, including interview participant IntExpert-4: "*IT security, for example [...] that is becoming a new function, you have to take care of it continuously. Because as far as security is concerned, you have to be able to provide continuous maintenance and updates quickly*".

According to the experts, it is crucial to ensure the end-to-end security of signaling systems through a secure architecture and extensible cybersecurity solutions.

Monitoring function, diagnostic function & predictive maintenance

In the expert interviews, the terms monitoring, diagnosis and predictive maintenance in a modified form. The interview participant IntExpert-4 defined it as follows: "*There are three requirements that first of all do not exist in a mechanical product or do not exist in an electronic product. There is a monitoring function, a diagnosis function and a prediction, the prediction. Digital-physical products can cover all three requirements".* The monitoring function is the simplest of the three stages and is already partly present in the electronic products. The question of the product's condition is usually determined by a target/actual comparison of the operating data.

The diagnosis represents the next step and is defined by an assigned required action. The expert IntExpert-2 described the diagnosis using a switch drive as an example: "*If something is not running as planned, that you can say - what is it now? So, if the point machine is malfunctioning, it's the clutch, the motor or the setting slide. That would be a form of diagnosis, because if the fault is known, then the right people can be sent to the right corner with the skills and tools needed to solve it*". All the experts saw this as the principal argument for the customer, because eventually this can improve the maintenance and servicing concept and thus save costs for the operator. Predictive maintenance was described as the supreme discipline here. In the event of a component failure in the field, delay minutes associated with costs for the operator occur. Predictive maintenance solutions allow maintenance and replacement of spare parts to take place before a failure occurs, thus exceeding the conventional possibilities of condition monitoring. Preventive diagnostics are based on data that are determined through permanent condition monitoring of the product. By converting this data into algorithms and load-dependent analyses, patterns and incidents can be generated. The data of the fault patterns can be compared with current operating data, whereby potential faults can be predicted. According to the interview expert (IntExpert-5), the implementation of these requirements offers the greatest advantage for digital-physical products and will be a basic requirement in the future. Finally, the products without the possibility of diagnosis will be pushed out of the market: "*So I think diagnosis will be the key for the next 5 years. None of our customers will buy a product without a certain kind of diagnosis anymore*" (IntExpert-5). The importance of these three aspects was also underpinned by another argument, namely the demographic change evident in the industry.

Many experts saw the actual reason for the necessity and discussion of digital-physical products in this aspect, as did IntExpert-3: *"[...] the maintainers of the future will be much younger in age than we are today. They will often not have the experience. They will have a much more diverse environment and technologies to contend with. It is therefore even more important that the new products are as easy to use as possible, that the user does not have to read the manual, that the maintainer knows immediately what is broken, that he or she knows immediately what he or she has to do, [...]*". In the discussion about the requirements, all interviewees emphasized that the company is not primarily concerned with earning money from pure data, but rather with using data to obtain and generate information that benefits the customer in the form of services. This assessment shows that, regardless of the defined business model, great market potential is assumed in the area of this application in particular, since there is added value for the customer. Figure 40 is based on a sketch by an expert (IntExpert-10) and schematically depicts the three requirements mentioned with a brief definition and the added value of the respective requirement:

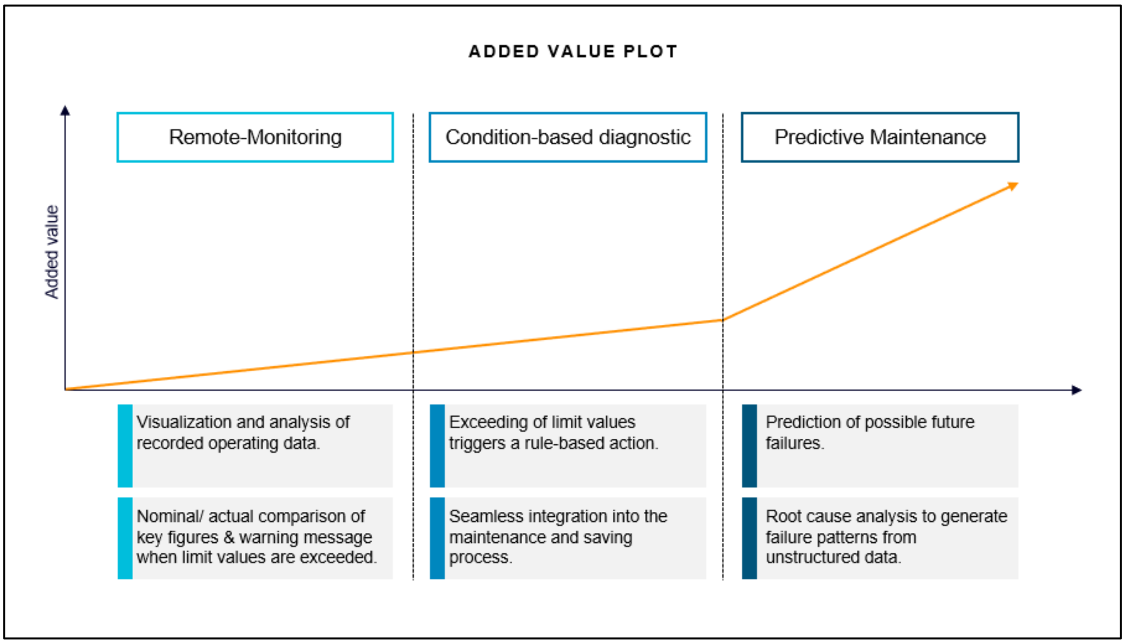

Figure 40:Overview of the dependency of the added value of monitoring, diagnosis and predictive maintenance function (Source: Authors own illustration)

The participant IntExpert-9 is of the opinion that it is precisely the fulfilment of these requirements, which can be successfully implemented by digital-physical products, that results in a great added value for the customer, as the availability of the plant can be increased. The participant IntExpert-1 said: "*[...] and that means the customer can run at a higher capacity, i.e., the cycle times are shortened. Because, if my plant is always running at 100% and I know before it fails, then I can utilize the installed infrastructure more. Higher utilization leads to more profits*".

Implementing the requirement may lead to new service offerings. While most respondents felt that maintenance services are already offered today, they are not yet mature enough. Installations, training or data services are realistic service offerings that can prove to be quite profitable for the company offering them. However, with the implementation of the aforementioned requirements and the addition of financing models such as pay-per-use, the cash flow will be distributed away from the purely physical product along the entire product life cycle.

Augmented reality

Augmented reality (AR) is the computerized extension of perceived, usually visual, conditions. By means of IT solutions developed for this purpose, additional information such as text, diagrams, holograms, images or videos are superimposed on the user's field of vision via AR glasses or monitors. With the help of this possibility, according to IntExpert-3, the maintenance and servicing staff could be supported so that the duration of the activities could be shortened.. This in turn is reflected in the lifecycle costs and improves the railway operator's bottom line. According to IntExpert-8: *"[...] if you are standing in front of the switch and you have to maintain, repair, etc., then you should receive the information, i.e., the data, with further instructions via a tablet. Then you can also assign maintenance people who are not so routine with this and ultimately save costs".* In connection with this requirement, three participants pointed out the increasing complexity of products. Experts have to pass on their knowledge and support colleagues and customers even in times of a shortage of skilled workers. Therefore, it is even more important that the new products are as simple to use as possible and "*the maintainer knows immediately what is broken, what he has to do, what tools he needs before he has to go out there and pile the snow around*" (IntExpert-2). An augmented reality app can be used to link entirely separate digital and physical products in a new way and close the gap between purely physical products and purely digital apps. Nonetheless, these requirements were also seen by some participants as a "gimmick" which do not offer any real added value to the customer. For example, IntExpert-11 mentioned: "*For me, augmented reality is not a requirement for tomorrow's products, rather a nice gimmick. The maintainer has to go out anyway and usually the staff is always trained*". One interviewee (IntExpert-6) in turn mentioned the use of an augmented reality app as a sales-promoting tool. The lack of significant added value through digital enrichment becomes particularly problematic when there are simpler, less complex or simply cheaper, purely digital or purely physical substitutes.

However, as these substitutes do not exist currently, there is certainly added value in integrating such a requirement. The participant IntExpert-6 explained: "*Due to the lack of alternatives, it makes sense to digitally enrich the maintenance and servicing concepts*".

Archive system

Another requirement that is spread over the entire product life cycle is an integrated archiving system. All data should be able to be stored and archived for a certain period of time (often a minimum of 30 days was used). Although this requirement is already fulfilled by some physical products with the help of an additional laptop, the issue here is the simple use of the data without additional hardware tools. This aspect is closely related to data backup in the cloud. In addition to the company's own use of the data for product improvement, the requirements according to IntExpert-3 are aimed at proof against claims by third parties. Especially in the case of product safety defects or accidents, for example, claims by third parties can be averted in this way. "*It can happen that an accident occurs because, for example, a level crossing barrier allegedly did not close. And now someone comes up to you and sues you, saying your system was not closed. Then you can prove - here is my archive system, you see the level crossing was closed. I am not the guilty party*". Besides the claims and the protection of one's own rights, the archive system also helps to identify real field values. According to the experts, these in turn can be incorporated into life cycle costing (LCC) and create competitive advantages for the manufacturer as well as improved maintenance planning for the operator.

Remote Software Update

Loading a software update remotely is already the state of the art in many industries. Within the railway industry, this requirement is not so straightforward to carry out, as these are safety-critical products in the field with specific expert assessments. Every adaptation of the elements in the field must be approved by an expert, and it must also be ensured that the loading of the new software runs and functions without errors. Especially during the fourth interview with IntExpert-4, this requirement was mentioned as one of the core requirements for digital-physical products: "*With the help of remote software updates, new business models could be derived, and our costs could be reduced enormously. Especially in the case of product safety defects. In the past, we had to replace all components or update them on site*". The experts believe that remote software updates could save costs on the manufacturer's side. Although the process of assessment could not be avoided, according to experts, the time and cost savings outweigh the costs.

Here, as well, the possibility of remote software updates needs to be implemented during product development, but the added value of the function for manufacturers and operators only appears when the product is used.

4.1.4 Added value of digital-physical products in the market phase

In addition to the topics of relevance, economic significance and basic requirements for digital-physical products, the added value of digital-physical products was also discussed. Digital-physical products give companies the opportunity to distinguish themselves from the competition and can increase sales over the life cycle. Besides these two aspects, digital-physical products have many more benefits. One of them may for example be based on the extraction of data. According to IntExpert-7, data are "*the raw materials of tomorrow*", and manufacturers are able, with the help of digital-physical products, to obtain data about the physical component but also about its environment for the first time and to store and analyze it over a longer period of time. This in turn can help to access new markets and target groups, as problems in the environment but also in one's own product can be recognized and solved. IntExpert-10 argued that the "*operator can improve its overall system with the help of the data obtained and ultimately increase cycle times"*. Another benefit was related to monitoring, diagnosis and predictive maintenance. Enriching physical products with monitoring or diagnostic functions saves the operator personnel and increases the cycle time in operation, especially through predictive maintenance. The manufacturer, in turn, can continuously improve his or her product with the help of these functions.

Furthermore, this function offers the possibility and flexibility to establish new business models. Another major added value is that these products can be used to create means of tackling the consequences of demographic change. The lack of experience of younger colleagues can be helped by the simplicity and support provided by the products in the field. In addition, the products offer commissioning support and can reduce the installation time of products. A number of benefits can be derived from the above requirements for digital-physical products that could create an advantage for manufacturers and operators in the rail industry. Table 5 provides a summary overview of this and presents the added value described (apart from the obvious increase in turnover) and a key quote from an expert:

Added value via digital-physical products	Key quotes	Expert
Added value of the operator		
Saving on maintenance personnel	*"Then the supreme discipline - prediction. I know beforehand when things are going to break and can send someone out beforehand. This enables me to deploy staff in a more targeted way and save money".*	IntExpert-2
Improved time & organization management	*"[…] So I can put a maintenance team directly in the right corner and know who to send out first. Do I send someone out to look after the track bed or the drive, different people and that they perhaps have the right qualifications, what tools they have with them as information".*	IntExpert-1
Increase in operational availability	*If you ask the infrastructure manager, he will say, that he wants to achieve the highest possible availability of the facilities through this [diagnosis]".*	IntExpert-1
Improvement of the life cycle costs	*"Digital-physical products allow me to reduce my repair times and increase my availability. Calculated over 25 years, I can improve my LCCs enormously".*	IntExpert-4
Securing the critical infrastructure	"*Cyber-attacks are a problem nowadays and will be even more so in the future. Our products can be used safely in the field by integrating IT security features*".	IntExpert-8
Added value for the manufacturer		
Cost saving on bugs	*"[...] so this function [remote software update] can help us save costs in case of problems in the field. No longer does a technician have to drive long distances to press a cable and two buttons".*	IntExpert-11
Flexibility in business models	*"This allows us to break free from the rigid structure and provide customers with customized solutions as well as more flexibility in designing the model".*	IntExpert-11
Increased attractiveness of the physical product	*"Digital-physical products will extend the value proposition of the physical product".*	IntExpert-9

Data extraction	*"Obtaining data about the product and the environment are the basis for opening up new markets and our new developments".*	IntExpert-6
Improvement of the downstream products	*"Through the diagnostic function, we can become sustainably better and build our system more available".*	IntExpert-7

Table 5: Overview of the added value of digital-physical products in the context of the railway industry (Authors own illustration)

In summary, it can be stated from the expert interviews that digital-physical products will have a high relevance in the next five to ten years. Previous structures, processes and ways of thinking can be changed and breached for the first time with the help of digital-physical products. At the same time, new demands are being placed on these products, resulting in new benefits for both operators and manufacturers. It is striking that the benefits, apart from the possibility of an increase in sales along the product life cycle, arise primarily for those people who are directly involved with the product. Furthermore, many of the described requirements cannot be assigned individually to one phase of the product life cycle. Often the requirements are spread over several phases of the product life cycle or are repeated in the individual phases.

4.2 Findings of the focus groups in relation to the product life cycle

The product life cycle model is a concept in business administration that describes the process from the market launch or completion of a marketable good until its removal from the market (Matys, 2018). Section 2.4 described the product life cycle with its characteristics for the railway industry. During the focus groups, participants were asked about the relevance of this cycle in relation to digital-physical products and how it changes as a result.

4.2.1 Change in the lifetime

The discussion about changing the product life cycle usually begins with the aspect of shortening or lengthening the product life cycle. This aspect, which has already been widely discussed in the literature, was intended to serve as a starting point for the discussion. Most of the experts would like to see a shortening of the life cycle, but immediately pointed to the contractual obligations that force the products to be maintained for around 25 years during the project. For example, a participant in focus group 2 (FG 2-3) mentioned: "*[...] a shortening of the product life cycle to maybe ten years would change our whole business and would open up a lot of opportunities for us.*

But the problem is that it is not us who decide, but the customer - and the customer is not interested in constantly replacing embedded products. Therefore, he interprets the contracts this way and will not want to change them". During the discussion, the researcher initially tried to disregard the contractual framework and asked whether the simple benefit of digital-physical products could lead to a change in length.

The product managers of both focus groups argued that digital-physical products would actually extend the product life cycle. The reason for this is that with the help of digital-physical products, maintenance intervals can be optimized as well as failures can be prevented through predictive maintenance. The maintenance concepts could therefore be optimally adapted to the respective product and thus extend the duration in the field. As FG 1-3 mentions: "*The life cycles can be extended through the optimized maintenance concepts. We then know more about the products in the field and could act better*". Some experts, especially from the technical field, disagreed with the extension of the product life cycle, arguing that optimally coordinated maintenance concepts are not decisive for this. Firstly, it was argued that due to constantly advancing technology, it was possible to react faster. Participant FG 1-1 mentioned: "*I think the industry will move in an opposite direction. As you can react faster, as you can save energy, as you can reduce also the volume of these physical components, you are at the end reducing the reliability, but you are compensating with the digital data-driven part that will enable you to react faster to know what's going on*". Secondly, reference was made to the electronics and mechanics installed in the products. Electronic systems fail randomly and are subject to what is called a Mean Time Between Failure (MTBF) value. The MTBF value is defined as the time between two failures of an assembly or unit and is used to calculate electronic components (Grzechca & Szczeponik, 2020). Mechanical parts are subject to wear and can be defined relatively precisely in functional and circulation tests. Based on this, FG 2-3 argued: "*You can calculate maintenance up and down, we have an MTBF and a certain wear on installed components. These systems will fail at some point after new installation and between 20 to 30 years, because electronic systems always fail randomly, or the wear of the mechanical system is reached. From this point of view, we can do little with maintenance or predictive maintenance*". This means that even if the framework conditions were ignored, a similarly long product life cycle would remain as the hardware reaches its limits. An extension of the product life cycle by way of the use of a digital component in a physical product cannot therefore be assumed across the board, as further product-specific factors have to be taken into account. Moreover, it was argued during the interview that while the hardware should remain largely the same, the non-safety-relevant functions of the product, mostly the digital part, have to be constantly innovated.

During this discussion, it became increasingly clear that the digital component should be considered separately from the physical component, even if it is the same product. A cycle within a cycle was often mentioned, which will be considered in more detail in the next paragraph. This section should end with a consensus among the experts regarding an assessment of whether the current product life cycle reflects the digital aspects: *"[...] quite a firm opinion, that is where the industry is going. The current layer is the digitalization of the installed base and will still be with us for the next 5-10 years in our product life cycles. Because our product lifecycle model reflects the traditional physical product. It doesn't take into account the digital at all*".

4.2.2 A cycle in a cycle

An essential aspect mentioned during the data collection was the so-called cycle within a cycle. For some experts a second cycle results from the fact that the structures of the railway operator are also changing. A major reason for this is the demographic change: "*The one stakeholder at the customer has a focus on the product, i.e., the physical product, and wants the product to always remain stable and safe. That is the first layer. Other stakeholders at the customer, often younger software developers and computer scientists who want to further process the data of our products, are interested in the data [...] and want to get more and more digital information from the product*". According to experts, this is one of the reasons why the product life cycle of a digital-physical product should be split to effectively serve both stakeholders. A further argument for introducing an additional cycle is the exponentially increasing opportunities digitalization offers, as mentioned earlier. According to FG 1-1, the digital part of a product is constantly subject to revolutionary changes and more and more opportunities will arise at ever shorter intervals, making it necessary to react quickly to them. The experts stated that it should be possible to carry out updates quickly and without complications. Participant FG 2-2 formulated this as follows: "*The digital part always has to be renewed because this world is simply faster. The separation into two cycles is therefore quite justified*". The additional cycle would refer purely to the digital part of the product. In response to the question of what this new cycle might look like or what characteristics it would have, the usual cornerstones of a software cycle were often mentioned.

According to Ruparelia (2010), the software cycle is divided into six phases. The first phase is the analysis phase, where the needs and requirements necessary for the development of the software are defined.

In the planning phase the needs are concretized and documented. The development phase includes the programming and coding of the software and with software tests carried out, the quality is increased, and the product is cleared of bugs. After the product is bug-free and has reached the required quality, the installation of the software on the application follows. It is necessary to ensure that the hardware and software requirements are met for the operation of the software developed and tested. Subsequently the software has been deployed, the software cycle concludes with a maintenance and monitoring phase, during which the software is cleared of any errors that occur and new functions are added to the existing software. Figure 41 graphically depicts the typical software life cycle referenced by most experts:

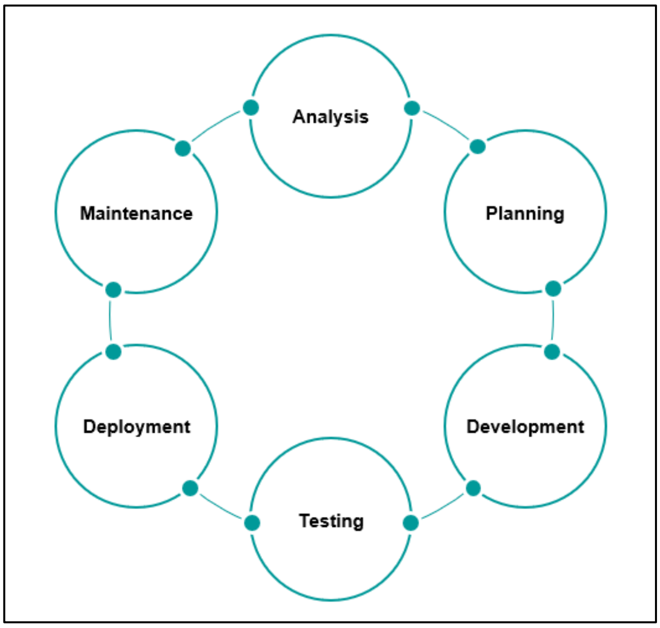

Figure 41: Exemplary representation of the software life cycle (Source: In accordance with Ruparelia, 2010)

In addition to the discussion about the nature of the cycle, questions were also asked about its interpretation in relation to the traditional product life cycle. There were various approaches to interpretation, with two in particular emerging during the experts' discussion. One view corresponds to the often completely independent cycle. For example, one expert (FG 2-3) argued that due to the exponentially increasing requirements in each individual phase of the hardware cycle, a separate software cycle would have to be introduced. "*So to speak, each phase has its own cycle. Each phase has its own peculiarities that differ between physical and digital. Therefore, there could also be several cycles". * Many experts believe that the hardware part or the safe part of the product does not need to be considered further and can be excluded, e.g., FG 1-1: "*But why would I want to change the sensor? That is the physical part of the product and I would only change it if it is absolutely necessary, for example due to standards or critical market requirements*".

Two of the participants also raised the idea of two contracts for the same product. In this way, the individual stakeholders could be addressed in a more targeted way and greater added value could be generated for them. This was opposed by the view of other product managers. They argued that a division into two parts cannot be beneficial for a product. Two different and independent cycles bear the risk of a lack of compatibility among each other, which could have an impact on the safety of the product, among other things. Focus group participant FG 2-1 said in this regard, "*the physical part is moving a bit more into the background and the digital is coming more and more to the fore. But both still have to be coordinated, play with each other, so to speak, and understand each other*". When discussing the compatibility of the two cycles, two experts raised fundamental doubts about separating the cycles. The reason was that the permanent updating of the software requires increased computing power of the hardware: "*But if you update the operating system every few years and apply security patches once or twice a year [...] that means that in a period of five years the computing unit on which the application runs has no more power, in a manner of speaking [...]. You have to upgrade the hardware because the software requires more and more computing power. That requires alignment*". According to focus group participants, the complete separation of cycles would significantly increase the monitoring as well as the coordination effort between all departments. Conversely, the question of responsibility arises. According to FG 1-1, responsibility is not divisible and there has to be one person who technically represents the product to the outside world. Especially in B2B business, trust and the customer relationship are an essential factor. The participant of FG 2-4 is of the opinion that the trust as well as the customer relationship could suffer due to the strict separation: "*Would then always two people from the company Siemens go to the same person and ask about his problems? He would also throw his hands up in horror. Now someone is coming over again. A fortnight ago I told my colleagues at Siemens what my problem was"*. During the discussion, the researcher also tried to understand whether it was sufficient to add a cycle or whether the phases would have to change fundamentally. The experts replied that the activities of the product manager would certainly change, but not the phases. The introduction, growth, maturity, saturation and degeneration phases would continue to exist as they do now. Nevertheless, the sales would change, depending on the business model applied, and so would the course of the curve. However, as with the traditional product life cycle, this would also depend on the product as well as the situation.

Based on the answers and discussions, the researcher deduces that a change in the product life cycle model needs to take place. Although the experts voiced different opinions in the discussions about the length of the product life cycle, it has emerged that the current product life cycle model does not reflect the digital part of the physical product. Since the product life cycle model has the overall task of serving as a strategic support for decisions and deriving actions, it can lead to wrong decisions. In this context, the experts see a further cycle as necessary.

4.3 Findings from the focus groups in relation to product management

Chapter 2 described the different forms of product management and the product manager. Depending on the corporate philosophy, product management and the role of the product manager can be interpreted differently. The researcher wanted to investigate not only the effects of digital-physical products on the traditional product life cycle, but also the effects of digital-physical products on product management and the people who carry them out. Indeed, the design of the product management and product manager contributes significantly to the success of a product. The last part of the data collection therefore focused on the change of product management and product managers caused by digital-physical products. The results of the data collection regarding this aspect are presented below.

4.3.1 Influence on the product manager through digital-physical products

The role of the product manager was a frequently discussed aspect in the data collection. Initially, a unified stance emerged among the participants that the complexity of managing the product would increase. A participant in focus group two (FG 2-1) thought that it was difficult for current product managers, who for example have been managing a product for more than ten years, to suddenly deal with digital ways of looking at things: "*Because in addition to the technical issues, you also have to set up new business models, a new way of working and many other things - and you don't learn these skills overnight*". Although no further skills are necessary per se, such as programming, there are other values in addition to the traditional functions, which should now be additionally managed. To determine these values, the researcher referred to the software cycle described by the participants and asked how this would affect the product manager. The experts made it clear that the product manager would have to make an increased management effort with the introduction of a software cycle.

For example, he needs to make his previous structure of requirements management or market and customer analysis more agile, as this was mainly carried out once during new development for physical products. Furthermore, the product manager has to participate in more milestone meetings and other internal arrangements due to the increased development activities than before. The results are summarized in Table 6:

Process Stage	Description	Additional tasks of the product manager
Analysis	This phase is used to define the needs and requirements required to carry out the development of software.	• Extension and increased workload in market and customer analysis • Restructuring of requirements management necessary
Planning	The objective of this step is to define and document software needs. It includes everything which should be designed and developed during the project life cycle.	• Increased budget discussion • Definition of new business models
Development	This phase includes programming and coding of the software. The aim of coding is to produce high quality software system in the desired programming language which runs error free and with high efficiency.	• Monitoring additional development activities through milestone planning and other processes • Building a deeper understanding with the technology
Testing	Software testing is done to make the product error and bug free and as a result, obtain a good quality software.	• Additional monitoring and coordination work
Deployment	This phase includes installing the software on the application. It has to be ensured that hardware and software requirements to run the developed and tested software are fulfilled.	• Strategic planning for the application in the field • Several consultations with higher-level system or project manager necessary
Monitor & Learn (Maintenance)	This phase is crucial after deployment of software since it aims to remove errors or bugs and add new features to existing software implemented on user system.	• Support of the system in the field (in case of defects) • Obtaining feedback from customers/project • Deriving new possibilities from data in the field

Table 6: Overview of the additional tasks for a product manager through the software life cycle (Source: Authors own illustration)

Combining both worlds is extremely demanding and based on this, most participants asked for an additional person to deal with and understand the new values. Focus group participant FG 2-4 said: "*A person with an understanding of this ([the digital world] is necessary if we really want to drive the issue*". At the same time, the question of ownership of a product arose. Many experts noted that in the end there could not be more points of contact to a product.

Ideally, a person needs to have a clear idea of "*what we do, why we do it, why we don't do certain things*" (FG 1-2). In answering this question, some of the experts referred to the content-related focus of the product manager, including participant FG 2-2: "*I think the safety-relevant person has a bit of the heavyweight, because he always carries the sword of Damocles of the approval of the process. It feels like he will always have a bit more weight in his voice, but in the end; it only sells together in the market*". One focus group (FP-1) emphasized that the set-up in two product managers working together already exists and is implemented in practice, namely between the so-called PLM-S and the PLM-T (cf. section 2.2). Similar close coordination between the product managers is required here, regardless of responsibility. Discussions were also held on whether the PLM-T should not change to a PLM-D. Up to now, the PLM-T has been responsible for the technical tasks and, for example, has defined the technical roadmap. An additional person would not be necessary if the PLM-S had an overview of the (new) business models and the PLM-T familiarized himself with the technology. Participant FG 1-1 commented: "*That's why I like the PLM-S, PLM-T split, because the most important person is the person that is interfacing with your deep core technical know-how, which is your PLM-T. That guy is your sidekick. That guy is your sidekick. On your left hand are all the other points of contact that you have for all the other specialties, either safety, security, and all the other stuff. But this is your right hand and if we modify the PLM-T to a so-called PLM-D, then it could work as well*". Figure 42 shows the set-up schematically and in accordance with Figure 17.

		Technical and content-related orientation	
		technology	**market/ competition**
PM - Positioning	**strategic**	Product Manager Sales	
	operativ	Product Manger Digital	

Figure 42:Extension of the classification of the product manager to the orientation of digitalisation (Source: Authors own illustration)

However, this view was not shared by most experts, citing the complexity of the remaining physical part of the product. Participant FG 1-1 mentioned: "*Of course, you can have added more and more task upon a PLM for a particular functionality that you are looking after. But railways are a complex business. And to expect that you would just have one technical person taking care of the entire thing.*

I don't think that would work, but you would need to have different people". This means that the PLM-T should not be replaced by a digital product manager but installed in addition. According to some experts, the PLM-T could deal with the hardware and software of the physical product and the PLM-D would be responsible for the technical and digital part of the product. Moreover, personnel costs were also pointed out during the discussion. Doubling or tripling the number of people working on a product would not be profitable for the company. Also, according to FG 1-3, hiring more people for a problem is not always the solution. On this basis, a different approach was discussed. The experts' idea was to employ one person for the digital part of a product family. This way, another person does not have to be assigned for each product, and digital solutions could be used uniformly within a product family. Schematically and exemplarily, this approach of FG 2-1 is shown in Figure 43 as an extension of the vertical team by an expert for digital products (based on Figure 19).

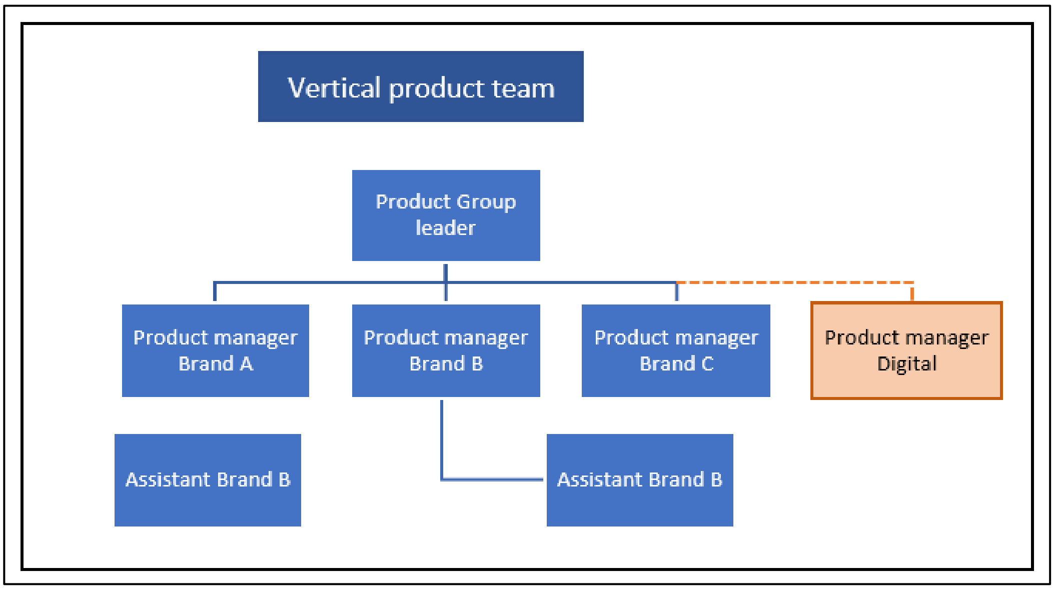

Figure 43:Expansion of the vertical product team with a digital product manager (Source: Authors own illustration)

In this context, FG 1-2 mentioned that "*you also have to consider whether you don't give the digital aspect outside*". This view was shared by very few participants, as outsourcing this aspect could lead to a loss of know-how for the physical product as well as a lack of learning for the future. Participant FG 2-2 replied: "*If we were to outsource this, then we would no longer be able to sell products in the future, as we no longer know and understand our own products*".

Based on the discussion, it can be concluded that a so-called digital product manager is needed to handle the additional tasks resulting from digital-physical products. Ideally, this person should be responsible for several products in order to bundle synergies according to the experts.

This leads directly to a change in organizational product management, which is described in the following subchapter. In this context, it should be mentioned that although the focus of the discussion was on the product manager, other areas of the company were also discussed in isolated cases. It was stated that there was no point in changing individual people in the company or in adding new people. The R&D department or even the sales department have to adapt as well in order for the overall system to function successfully. The researcher did not go into these aspects further and focused on the change in product management.

4.3.2 Effects on the product management through digital-physical products

Similar to the change of the product manager due to digital-physical products, there was consensus among the interview participants and across the focus groups that digital-physical products lead to a change in product management. Some voices often emphasized that the new requirements are still part of a product, but at the same time mentioned that an efficient handling of the products can only be achieved by adapting the product management. Participant FG 2-2 explained it as follows: "*The physical product there is all good, we can do that, and it is our daily bread. For me, this is now a second layer that is added on top and that can no longer be managed in this way. New competences and profiles are required"*. After the question of how product management should position itself from an organizational point of view, there were two extremes. One tendency was not to anchor everything digital in the product silos, but to set it up in a superordinate way. This was justified with the diverse products in the railway environment, which all have to interact with each other. Participant FG 2-3 was of the opinion: "*A central system would help us for the time being. At the moment there are too many parallels, through something superordinate we only offer one system, and not 3 different ones like now*".

Based on this, six of the interviewees argued that there should be a separate department for the digital parts. A digital pool of people, so to speak, from which people can be drawn for the benefit of the products. This approach resembles collaboration-oriented product management. Referring to Figure 11, the product manager draws on the required people as shown in Figure 44. The advantage is that it is still one body that is responsible all aspects of a product and takes care of them. The disadvantage is that the product manager has no authority regarding planning and control activities. "*We are already seeing that our single sources are actually no longer available. The same would happen with the digital world and there would be an internal fight for resources*" (FG 2-3).

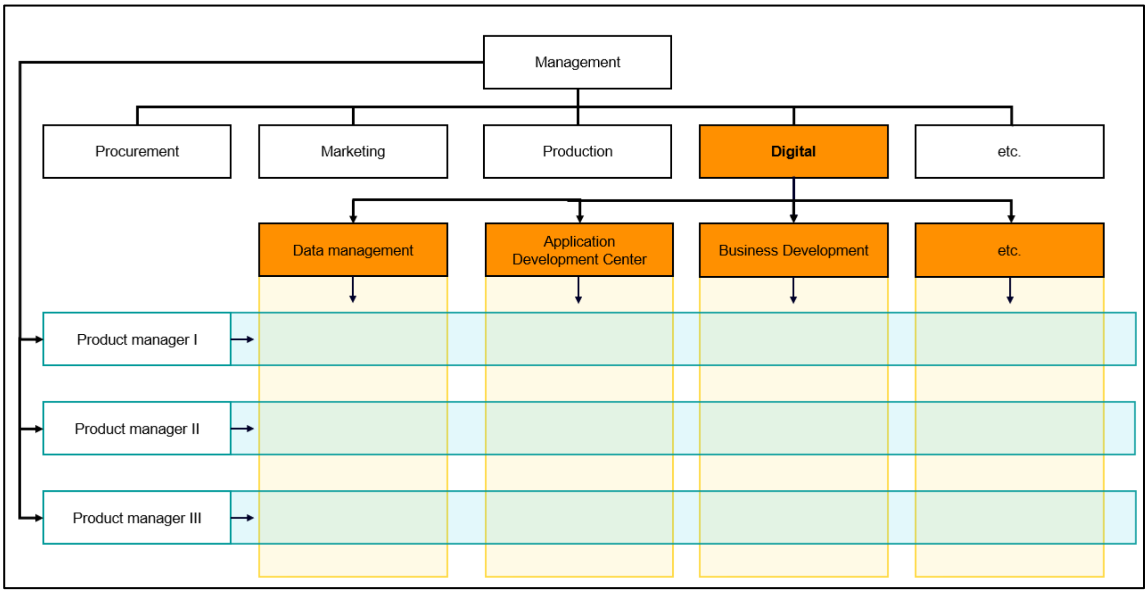

Figure 44:Change of the matrix-oriented product management organisation by a department for digital aspects (Source: Authors own illustration)

The alternative approach discussed was that of line-oriented product management. This would allow very close coordination between those responsible and working on the product and could be used flexibly without external influence. Participant FG 1-1 said: "*product-specific, the optimal proportion can be determined - without external constraints"*. This was countered by the argument already mentioned that there is a danger of having too many individual solutions and that this could lead to customer frustration: "*As one company, we cannot give one customer three different diagnostic tools. It has to be coordinated among each other. Moreover, we only generate blind power if we develop one thing three times*" (FG 2-4). Figure 45 represents the extension of a digital product manager within line-oriented product management (based on Figure 12):

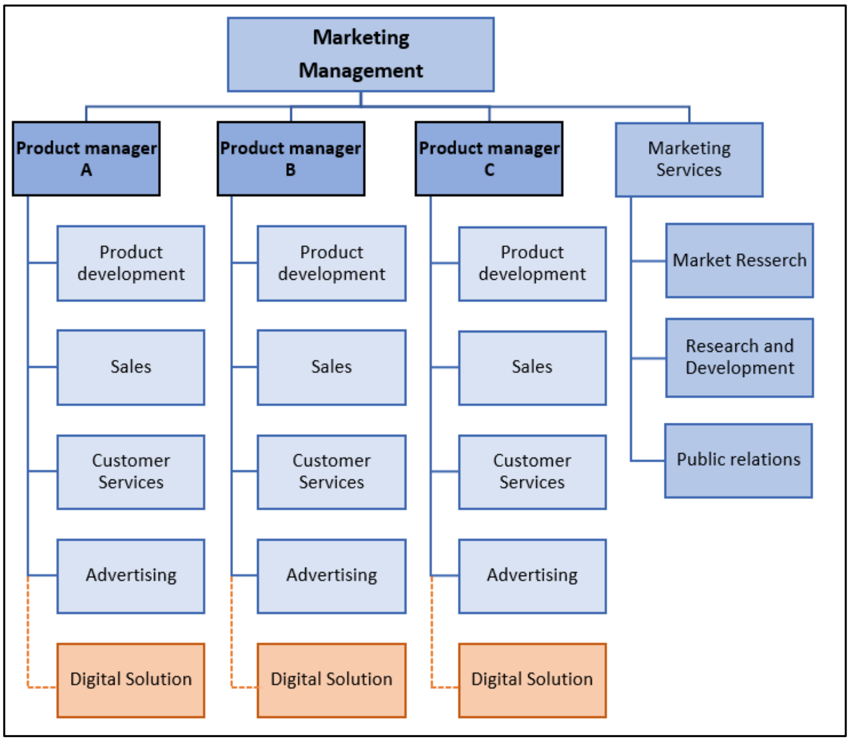

Figure 45: Change of the line-oriented product management organisation by a department for digital aspects (Source: Authors own illustration)

In summary, according to the experts, a change in product management and the product manager has to take place in order to be able to optimally manage digital-physical products. The tendency of the experts was towards centralization of the digital part of a product, as unified solutions can be implemented in this way. In addition, dedicated persons should deal with the digital aspect of the product. The design and the area of responsibility of the person have to be designed taking into account the company's own boundary conditions.

The chapter concludes with a summary of the main similarities and differences in the data collected with regard to digital-physical products. It clearly emerged that, from the point of view of both users and owners, digital-physical products will play a major role in the coming years. The advantages mentioned are visible to and endorsed by all participants and can offer improved functionality through the integration of digital functions. The same applies to the general changes in the respective field. Product managers as well as people from other departments experience changes in their previous job by dealing with digital-physical products. For example, IntExpert 9 said that "*the focus and also the processes within sales will and also need to change and that salespeople will also need to expand their previous technical knowledge*". Noticeable, however, was the degree of complexity. In principle, both sides see that managing is more complex compared to traditional physical products or purely digital offerings.

This aspect was highlighted more significantly among product managers, who repeatedly stressed the need for careful product planning, technical expertise, and effective cross-functional collaboration. "*Whether the successful management of products will work depends largely on cross-functional collaboration - we alone are primarily responsible, but to get all the complexity under control, all departments need to change*" (FG 1-1). Another significant difference here is the introduction of a dedicated person. While the user side had often touched on the further development of the previous product manager, from the product manager's point of view another person was demanded to deal with the digital aspect of the product. Related to this is the different view on the complexity of digital-physical products, but also the question of the responsibility of a product. Thus, IntExpert 9 believed that "*responsibility is not divisible*", whereas FG 2-2 referred to of "*a first transformation step into the new product management*". In summary, conducting interviews with several experts from different backgrounds and conducting two focus groups with different backgrounds of product managers provided diverse insights and perspectives on the research topic. In the following, based on the results determined here, the research questions will be answered, and the results critically discussed.

5 Discussion of Findings

In chapter 2, the different types of life cycle models were shown, and the different characteristics of product management were discussed. In addition, it was emphasized that the management of digital-physical products has been insufficiently illuminated so far and that often intuitive decisions are made by product management when dealing with these products. To counteract this situation, a product life cycle model adapted for digital-physical products is to be set up within the framework of the company Siemens Mobility Rail Infrastructure and the effects of this on the existing product management and the product manager are to be examined. To answer the research questions, the findings from the literature, the expert interviews as well as the focus groups and intensive discussions of the results with other students were taken into account and brought together. This section presents and discusses the answers to the research questions.

5.1 Key findings and responding to the research questions

The following sections present the most important results and specifically answer the three research questions.

5.1.1 The influence of digital-physical products on the product life cycle model

By answering the first research question (What influence do the characteristics of digital-physical products have on the product life cycle model in the railway industry?) the influence of the requirements of digital-physical products on the market phase should be identified. In addition, the added value of digital-physical products within the railway industry should be analyzed. At the same time, these should help to understand better the relation to the product life cycle model. Section 4.1 made it clear that digital-physical products will play a decisive role in market success in the coming years. These types of products add significant value and open up unprecedented opportunities. The participants in the study identified a number of requirements that companies in the rail industry should consider when using digital-physical products in order to ultimately generate an improvement in the bottom line. After all, by enriching physical products with digital components, manufacturers in the industry can change their business models in a more flexible way. With the help of diagnostics or predictive maintenance functions, for example, sales can continue to be generated after the product has been sold, in addition to spare parts because the added value for the customer can be increased.

Savings in personnel, improved time and organizational management and an increase in the cycle time of train operations are some of the advantages for the railway operator. The manufacturer can apply pay-per-use or other models and break the "ship & forget" pattern that has prevailed up to now. In some cases, digital-physical products are also used to enrich physical products with additional information and to connect otherwise disconnected physical and digital products. This is the case, for example, in the use of an augmented reality app that could show maintenance staff virtual instructions to make maintenance quicker and easier. In addition to identifying the added value of these products, which was presented in Table 6, the aim of the research question was to investigate the influence and characteristics of digital-physical products in relation to the product life cycle. This formed the basis for the question of whether the product life cycle model and product management need to change at all and provides an initial basis for new considerations for change. Figure 46 shows a classification of the requirements in the product life cycle and derives the influences from this:

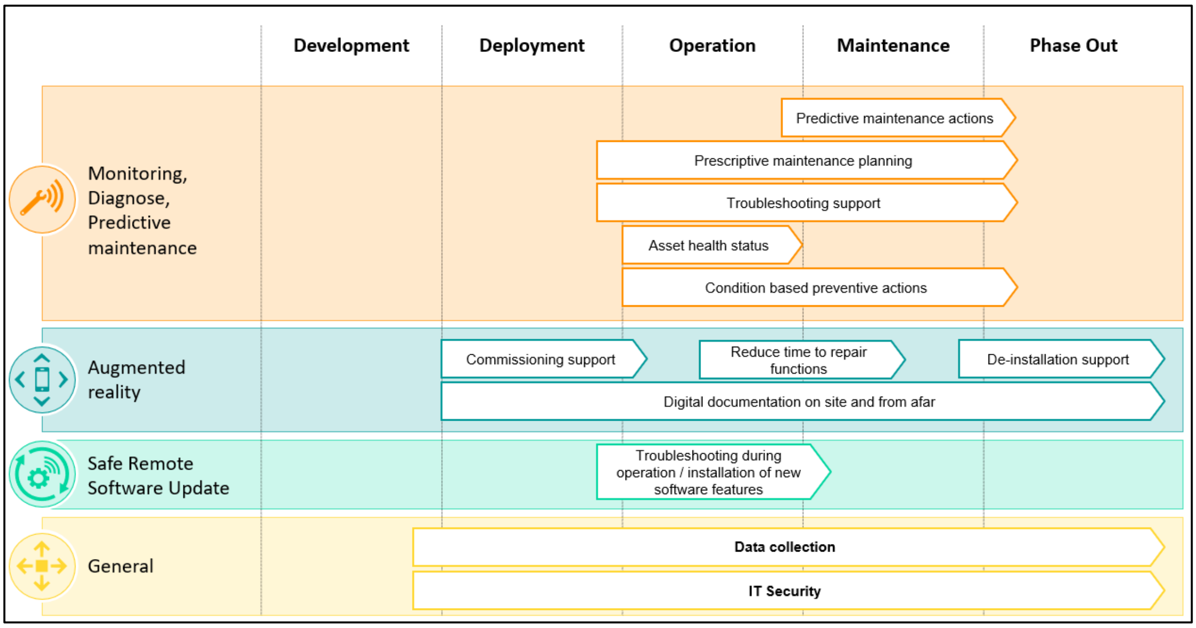

Figure 46: Overview of the influence of requirements on digital-physical products in the individual product life cycle phases (Source: Authors own illustration)

It becomes apparent that digital-physical products intervene in all areas of the market phase of the product life cycle and generate added value. This is further underpinned by Novales et al. (2019) and Hoffmann (2020) who also argue that digital-physical products intervene in the life cycle of a product. In each phase, added benefits can be created for the manufacturer as well as for rail operators. Services gain importance along the life cycle and can thus lead to continuous profits, in addition to the sale of the product. Thus, the benefits of diagnostics are mainly found in the phases of operation and maintenance.

The integration of augmented reality apps can help with commissioning and uninstallation, and completely change previous procedures with pen and paper. In addition, the integration of IT security and edge computing solutions are required throughout the entire product life cycle, ensuring secure operation. Although this shows that potentials can be generated in every phase of the product life cycle through digital-physical products, higher product support can also be derived from this. It shows that digital-physical products will increase cooperation with all departments throughout the product life cycle. More contact points with development, sales, requirements management and marketing will be needed, for example, in relation to development. The background to this is that more development activities will be necessary after the completion of new product development. This is because digital-physical products make new features possible every few years through remote software updates, so development will be more challenged.

After the launch of a product, development nowadays provides technical support only - at least for the first few years. If a new software release is to be brought out every few years, then development must also be carried out in addition to support. Although customer surveys or the evaluation of customer wishes are performed by product management, the technical discussions regarding the implementation take place in cooperation with development. A similar picture emerges on the sales side. Discussions about the potential business models of the individual features and the associated cost calculation or new product presentations require more coordination effort compared to physical products. In connection with the aspect of increased effort, the active management and administration of data in the field is also highlighted. Although error messages, faults, etc. have already been documented for physical products and recycled in the next product development, this type of data collection refers to the active derivation of new opportunities. With the help of structured data management, service models are to be derived or the data resold. The active extraction of data and its structuring requires that data be analyzed and evaluated manually or automatically to build knowledge. This is an activity that has not taken place to this extent so far.

A further influence is exerted by digital-physical products during the phase-out of a product. As the phase-out phase of a product approaches, the product quickly slips into the loss zone. In this phase of the product life cycle, profitability changes through production and supply chains, for example. These have been optimized for a certain quantity, but in the phase out phase they are no longer utilized to capacity, because the quantities fall, and the batch sizes are no longer optimal. The result is higher production costs (Hermann & Huber, 2013).

With the help of digital-physical products, more transparency can be shown in the keeping of error statistics, analyses, and diagnoses and repairs. These help with the widely discussed optimal time of discontinuation of a product, which then can be better predicted. However, it also requires that the last phase of the product life cycle be considered and managed more intensively than before, even though the zenith in terms of sales has already passed. In general, digital-physical products result in a change in the way people have previously dealt with the user phase so far. Old ways of thinking and working have to change and adapt to the products. In conclusion, the requirements for digital-physical products influence the market phase of the previous product life cycle. In addition to various positive benefits for manufacturers and operators, the points of contact between them are also increasing. The internal company processes and responsibilities are also undergoing a change. On the one hand, the functions have to be taken into account technically, and on the other hand, they have to be considered throughout the entire life cycle. For example, data has to be analyzed, business models have to be questioned and renewed, and increased product maintenance needs to be carried out.

As a result, the product life cycle model, which serves as the basis for strategic measures and the people who work with it are also affected by the change. Both aspects are described in more detail in the next two sections.

5.1.2 The extended product life cycle model for digital-physical products

The second research question (How do digital-physical products interact within the framework of the product life cycle model in the context of the railway industry?) aims to establish a revised product life cycle model within Siemens Mobility GmbH. The development of a new product life cycle model for digital-physical products is an important step to ensure market success in the future and to be able to meet customer requirements. The results of the data analysis showed that it is necessary to change this to be able to optimally manage digital-physical products. In addition, it was discussed whether a second cycle was necessary to be able to represent the digital part as detailed as possible. The researcher used the previously applied model from section 2.4.1 as a basis and integrated the knowledge gained from the literature and from the data collection into the extension of the model. The above-mentioned requirements and their classification in the static product life cycle were also taken into consideration. The following Figure 47 shows the extended product life cycle for digital-physical products, followed by a detailed description:

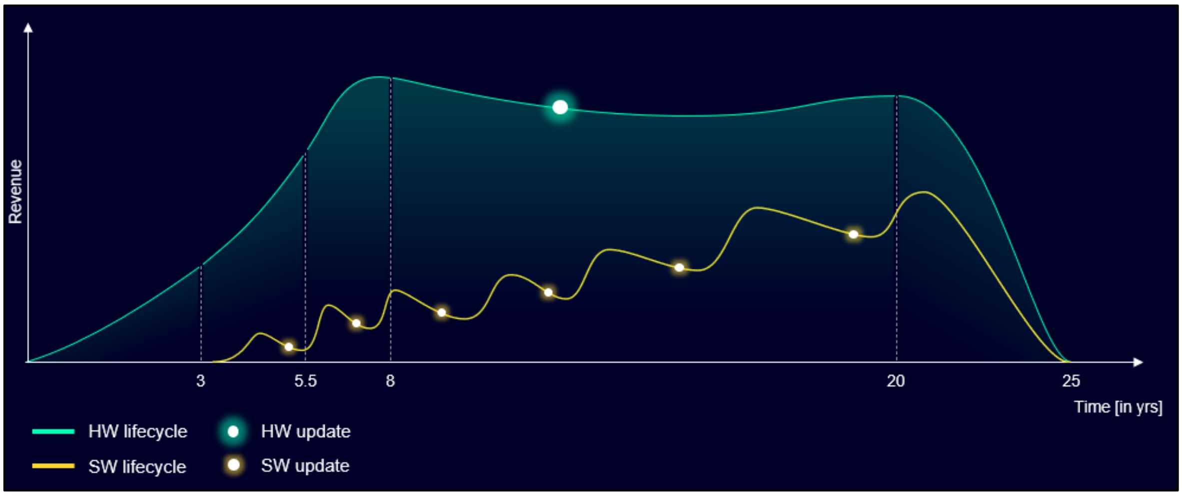

Figure 47: The extension of the product life cycle model to include a second (digital) cycle (Source: Authors own illustration)

First of all, the widely discussed aspect of the change in product lifetime during data collection and literature was not further mapped in the new cycle. Although there is the possibility of improving the product life cycle through optimized maintenance and servicing concepts, the technical limit, i.e., the electronic and mechanical life cycle of the individual components, contrasts with this. Digital-physical products provide the framework for extending the service life and are also advertised in this way. Nevertheless, detailed calculations of components are necessary in order to be able to make a uniform statement about this. It has to be considered product-specifically and depending on the individual components whether the product life can be extended. Furthermore, a comparison must also be made from a sales perspective. According to Novales et al. (2019), continuous sales can be generated over the life cycle, as shown in Figure 40, but this needs to be contrasted with the sale of new developments. The experts from the study conducted by Gentner & Oßwald (2017) were certain that the physical share would still be decisive for product success "*the sale of the purely physical product will nevertheless remain the most important source of revenue in the next 10 years and will therefore never be completely replaced by services*". (Gentner & Oßwald, 2017, p. 120). Although digital-physical products extend the lifetime, this should be contrasted with the sale of a new physical product. For an extension of the product life, both technical and commercial calculations have to be made in order to be able to make a product-specific statement. However, digital-physical products offer more possibilities and greater flexibility throughout the entire product life cycle. To map this, the researcher used a second cycle in his model in dependence with the hardware cycle. The content of the second cycle is based on the software cycle shown and described in Figure 41 on page 138.

Customer and market requirements are in a constant state of change and can be taken into account and implemented as far as possible with the help of digital-physical products. Furthermore, the software cycle also considers the dynamics of competition, because according to FG 1-1, "*the environment will become more dynamic, and we will be able to catch up with competitors or rivals more quickly*". Software cycles are thus much shorter compared to the hardware cycle, as the transitions into the individual phases are shorter. For example, the maturity phase occurs faster because competitors can implement similar features. Although software cycles can be designed to be very short, the non-safety-related requirements should not be implemented individually. On the one hand, the rail operators' top priority is reliable and readily available technology, and individual products should act as effectively as possible without being considered in the overall system: "*Our customers [rail operators] would prefer our infrastructure products not to appear at all, so that smooth and regular operation can always take place*" (FG 2-3). On the other hand, updates should be more targeted and more substantial over time in order to also achieve the probabilities of an increase in sales and visible improvement. The so-called time-pacing strategy, i.e., the time of introduction of innovations, should therefore not be selected too short. "*If the company chooses a fast pace (frequent introduction), it cannibalizes its old generation prematurely and incurs high development costs, while if it chooses a slow pace, it fails to take advantage of customers' willingness to pay for improved technology*" (Druehl et al., 2009, p. 1).

The dependence of the software cycle on the hardware cycle results from the consideration of each other. The software cycle shown here starts later than the hardware cycle, since in the first few years the new product is launched with the product features that are current at that time. After about three years after the product launch, the first suggestions for improvement are made because enough data has been collected about the product itself and about the environment. In addition, from a sales point of view, this is an appropriate time to make suggestions for improvement to the customers: "*The railway world is sluggish, and in my experience, we should give the customers at least three years to see the added value of the update. The industry, and in my opinion the B2B market in general, is not designed for updates every year and would rather make our products look weak*" (FG 2-2). Another characteristic is the software updates of the cycle, which are increasingly spaced out over time. For example, the first updates are around three years apart and the last ones are over five years apart. The reason for this is that after a given time, fewer product features are integrated into the existing product and because the hardware also has to have the capacity to integrate the new software.

Certain features can therefore no longer be integrated due to technical constraints. Moreover, new developments with revised hardware and software are already running in the background. The integration of some product features in new as well as old products leads to additional work and thus costs in the company. The increase in turnover with each update can be explained by several aspects. Primarily, there is a connection with the hardware cycle. If the hardware cycle increases with turnover, then the turnover of the software cycle also increases, as it is also sold. Furthermore, the updates sold so far do not expire and remain valid. Through pay-per-use or pay-per-click models, for example, the revenues remain the same over the life cycle, but increase with the addition of further product features. In addition, more and more data are collected about the product and the environment over time, so that more opportunities for product features arise. Gradually, only those product features that lead to a clear increase in sales are implemented, because otherwise the development costs caused by the development of new products as well as the development of product features in the field would increase excessively. It would no longer be worthwhile to "*integrate features into an old product*" (FG 2-1). Downstream updates will only be implemented if there is more added value.

Like the classic model, the extended model shows sales over time. The software sales were deliberately not integrated into the hardware sales, although they could be added up. The reason is that measures can be derived from the curve of the product life cycle. The product life cycle is an important orientation aid, and its evaluation can be the basis for sales forecasting, planning and strategic decisions (Aumayr, 2019). Knowing the state of the product in the cycle enables companies to take certain measures to continue to be competitive or to achieve the optimal profit on a product. When integrating the sales of the software cycle, the product could be seen as a single entity, but the actions would not be clear. Due to this, the researcher has deliberately chosen to separate the cycles. Especially when managing now two cycles, it becomes clear that this has implications for product management. These impacts are detailed in the next section 5.1.3.

5.1.3 Customization of product management to digital-physical products

The third research question (How do the identified changes within the product life cycle model affect the product management?) involves investigating the effects of digital-physical products and the changed product life cycle on product management. As described in section 2.2, the classification of product management and the role of the product manager strongly depend on the company's philosophy, objective and other subsidiary conditions.

It is therefore even more important to question whether product management and the product manager should be positioned differently in the future management of digital-physical products. The results of the data analysis have shown that a change in the product manager is necessary to be able to manage digital-physical products effectively. The aspect of changing the product manager is supported by various studies in the literature (Gentner & Oßwald, 2017; Baumgartner, 2018; Hoffmann, 2020), which emphasize, for example, that product managers in the future should have knowledge from the field of computer science to be able to understand and drive developments from the software sector (Gentner & Oßwald, 2017). Today, more than ever, a product manager has to create global products, and this requires international market and customer proximity. In addition, there is the digital part of a previously only physical product, where customer requirements change more dynamically. "*Managing additional digital aspects makes our work more complex*" (FG 2-4). In digital-physical products, the product manager has to combine safety-relevant and classical rigid as well as agile thinking and the influencing aspects of globalization in order to be successful.

Overall, these aspects lead to a high burden and complexity for the product manager. Moreover, efficient management of products also means integrating or adapting existing (digital) solutions that were once developed in the company into further products. For example, different diagnostic systems for different products lead to more effort on the part of customers. As indicated by experts in the data analysis, a higher-level authority needs to have an overview of the features to be developed. The change in product management outlined below to be able to optimally manage digital-physical products relates to the boundary conditions of railway industry described in section 2.4. Considering the extended product life cycle model from section 5.1.2, a further cycle is added, so that a second product manager is necessary in order to be able to manage this effectively. The second person, referred to here as the digital product manager (PLM-D) and shown in yellow in Figure 48, works as an interface to the product manager and supports the digital part of the product:

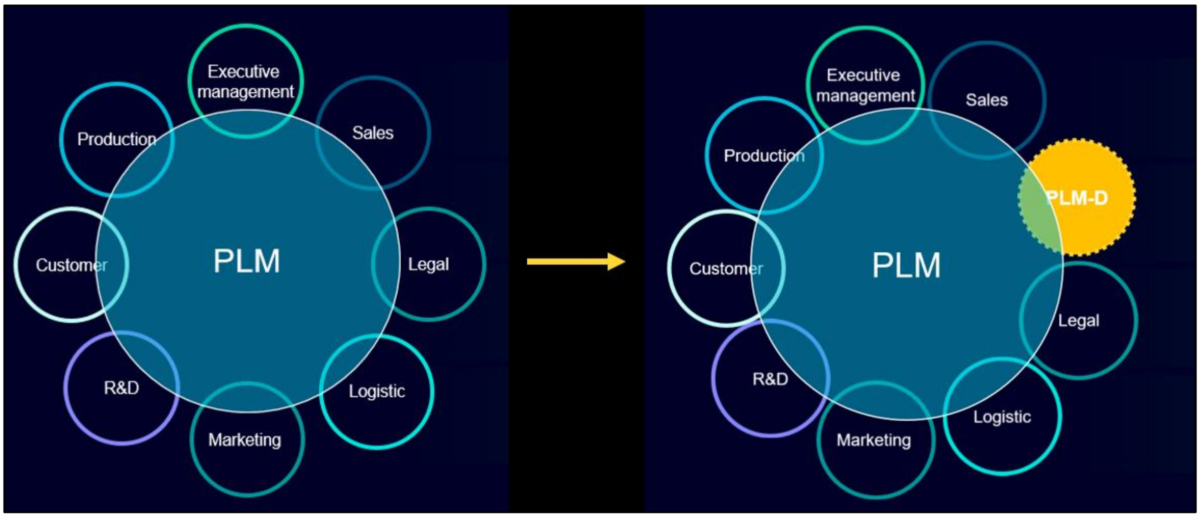

Figure 48:The introduction of a Product Manager Digital (Source: Authors own illustration)

The responsibility of the digital-physical product can be understood as proportional to the size of the circles. The product manager is primarily responsible for his product and continues to act here as the CEO of the product. Here, the researcher refers to the statement of experts that responsibility is indivisible and that the guiding principle of "*one face to the customer*" (FG 1-3) still applies. Nevertheless, the product manager needs to develop in a way that the new interface is understood. Similar to the interface with R&D, where certain forms, rules or concepts are applied, rules must also be established in relation to this interface. The product manager is not a legal expert but knows the basic laws and liabilities related to his product. The interface to PLM-D can be understood in a similar way. An expert in the field of digitalization is not necessarily required, but the basic digital aspects related to the product have to be understood. In contrast, the PLM-D needs to have a new profile compared to the product manager to be able to represent an extension. As a basic requirement, the PLM-D should have comprehensive knowledge of software development and the digital ecosystem. This comprises understanding, summarizing and interpreting data in order to use it successfully as well as domain knowhow on core functionalities of the assets to be digitized.

The last example is proactively finding new use cases or digital services that optimize the core product through data-driven use cases. In addition to these skills, the mindset of the PLM is of great importance, says the expert: "*Our current ship & forget pattern must change through this person. A PLM who deals with the digital world must not adopt the same pattern, but rather drive the others in the direction of seeking new business areas together with him*" (FG 1-1). These previously missing or underdeveloped capabilities should be seen as complementary to the overall organizational set-up. The introduction of a PLM-D is also underpinned by the railway industry itself, which, with its conservative boundary conditions, does not allow for a rapid upheaval.

Expert FG 1-3 mentioned: "*the intermediate phase should not be ignored. It will not work without hardware and for the next few years we must be able to cover the classic and the new*". For the next few years, both the physical and digital world must be covered equally to be successful on the market. Furthermore, the PLM-D was deliberately not presented as a digital expert. In the formulation, the researcher refers to the organizational classification of the PLM-D and rather sees it as anchored in a digital product portfolio within product management. Based on Figure 28, this is expanded as follows (Figure 49):

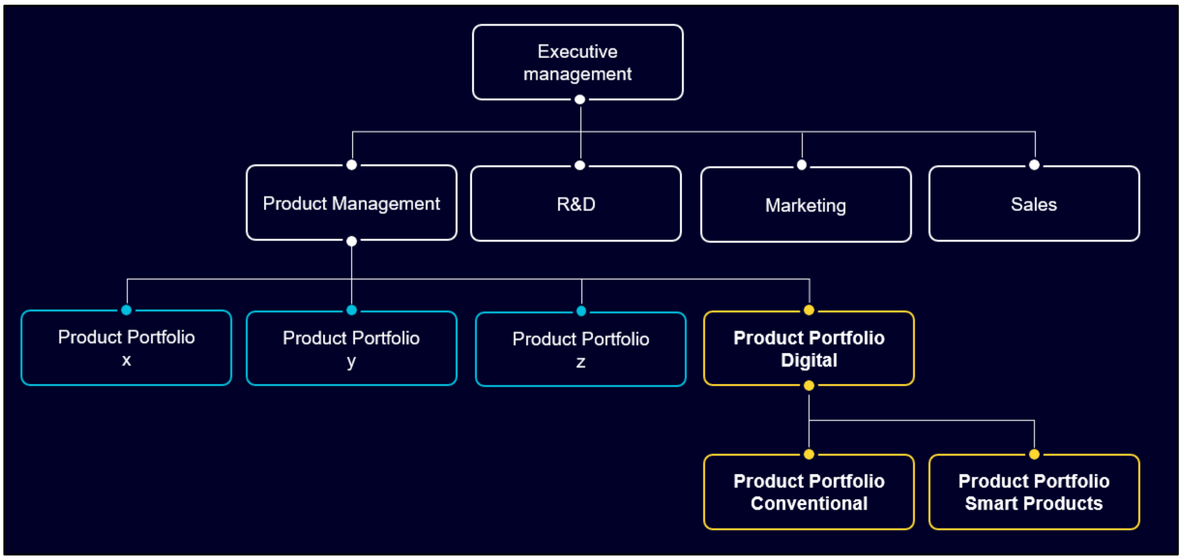

Figure 49: The introduction of a product portfolio for the digital aspects (Source: Authors own illustration)

The product portfolio (here referred to as digital) can be seen as an expert house for digital solutions for other conventional portfolios. Besides using the knowledge and expertise for its own IoT projects, this department corresponds to an interface of conventional product management. The product management is thus expanded by a sub-department to be able to awaken the digital potentials in physical products. The digital product managers are integrated into the portfolio because the introduction of a PLM-D per product would not be economical, as the revenues generated by services would not compensate for this. It therefore makes more sense to implement a PLM-D per product family.

An essential requirement in setting up such an organization is communication between the departments. Gentner & Oßwald (2017) already identified a stronger communication function as an essential characteristic for Industry 4.0 product managers. The communication must also take place not only between the product managers, but also between the respective team and department managers and all other adjacent departments. There is one more reason for integrating the digital product portfolio into product management. As emerged from the data analysis, digital-physical products correspond to an intermediate step.

After time, the physical aspect will move into the background and digital solutions will come to the fore. The ratio of the physical to the digital will continue to shift towards the digital over time. Thus, the PLM-D will increasingly take the lead of the product, exemplified in Figure 50:

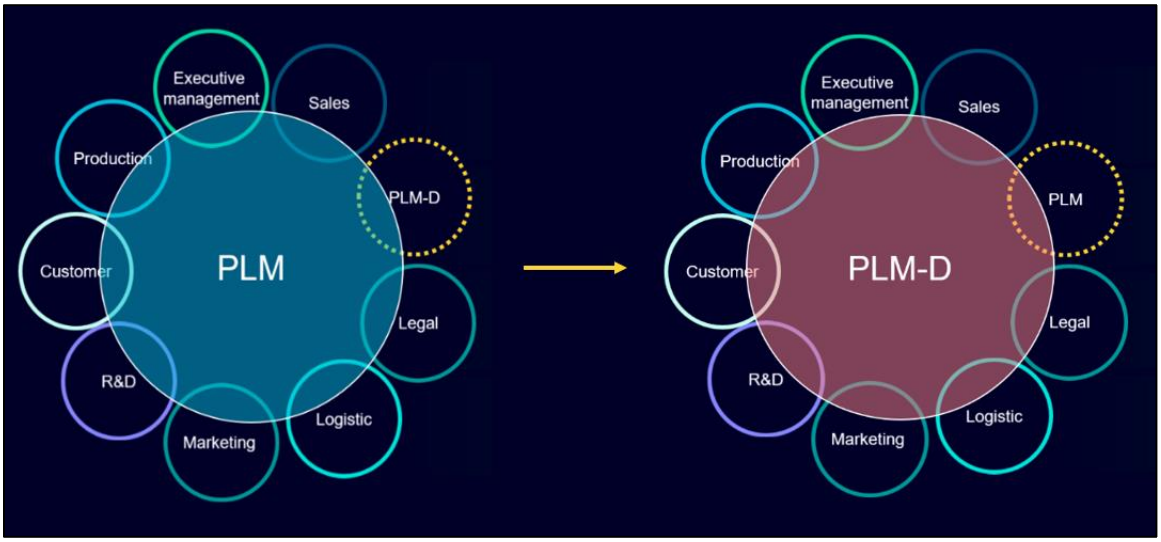

Figure 50: The transition over time between the current PLM and the newly introduced PLM-D (Source: Authors own illustration)

Despite this change, management for soon-to-be purely digital products will also be necessary and will most likely also be subject to the area of product management. In order to suffer as little losses in terms of know-how, market share or product sales in this change, a close linkage and management of both portfolios is indispensable. A division of physical and digital parts in the organization could lead to the aforementioned losses in the transition phase.

5.2 Discussion

The previous section has shown that digital-physical products have an impact on the previous product life cycle. In addition, the product lifecycle is changing in terms of frequency and fluctuation as well as the management of the products themselves. The answer to the first research question has shown that digital-physical products have a great influence on the product life cycle and intervene in every phase of it. The fact that digital-physical products have an impact on previous thought patterns and management systems is already supported by Lerch & Gotsch (2015), who argue that the understanding of companies in this regard must broaden and deepen. "*As digitalized PSS are introduced to markets, new management systems will be needed, powered by new methods and management concepts*" (Lerch & Gotsch, 2015, p. 51).

The results also show that the points of contact between the departments are increasing, and that more attention needs to be paid to phases such as the phase-out phase. With physical products, the previous ship & forget pattern prevailed and after the market launch of a product, development usually only provided technical support - at least in the first few years. Now, if a new software release is to be brought out every few years, development must be carried out in addition to support. Customer surveys or the evaluation of customer wishes are carried out by product management, but the technical discussions about the implementation take place in cooperation with development. A similar picture emerges on the sales side. Discussions about possible business models of the individual features and the associated cost calculation or new product presentations require more coordination effort compared to physical products. In connection with the aspect of increased effort, the active management and administration of data in the field is also highlighted. While in the case of physical products, error messages, malfunctions, etc. are already documented and recycled in the next product development, this type of data collection refers to the active derivation of new possibilities. With the help of structured data management, service models are to be derived or the data resold. The active extraction of data and its structuring requires that the data be analyzed and evaluated manually or automatically in order to build knowledge. This is an activity that has not taken place to this extent before. This aspect is also supported by Genter & Oßwald (2017), who found a similar finding in their research: "*This finding [product management as an essential instance in the introduction of new business models] underlines the importance of product management in the area of initiating new products and business models. This task will be in greater demand in the future, especially with regard to new product requirements in the context of Industry 4.0*" (Gentner & Oßwald, 2017, p. 99). Some of the findings from the first research question are in line with the general literature of, for example, Bauernhansl et al. (2014), Porter & Heppelmann (2015) or Gentner & Oßwald (2017). It was shown that the digitalization of products enables a wide range of opportunities for manufacturers and customers and that the complexity of products is increasing. In comparison to Roecker & Mocker (2018), who examined digital-physical products in the context of the creative industries, however, differences emerge. For example, the economic importance and the general need for these products in the rail industry are already present and are not only considered a strategic goal. What remains the same in this industry, however, is that digital enrichment does not necessarily lead to higher revenues as in the example of data management.

The main difference to previous research, however, is the focus of the characteristics of these products outside of product development. As already called out by Lerch & Gotsch (2015, p. 51), "*Future research should focus on a number of different aspects of this trend, to collect data around companies' experience in delivering new digitalized PSS to market, identify the technical and economic impact of the digitalized PSS, and understand their contribution to industrial change*". After all, with the market introduction of digital-physical products, revised management systems will be needed, and new challenges will arise. Finally, the challenges and solutions will influence strategic management and lead to a new product management framework. (Porter & Heppelmann, 2015; Lerch & Gotsch, 2015). Through the investigation and the results of the first research question, a contribution is made to the aforementioned challenge. It has been shown how these products behave and their intervention in the different phases of the product life cycle. Previous research has focused on the changes and influence on innovation management systems and the development process (Hendler & Boe, 2019). By answering this research question, it can be stated that the focus in dealing with digital-physical products should not only be on product development. This is because it was shown that the complexity of the products, active support, and monitoring of the products as well as the increasing number of actors also take place outside of product development. To be successful, companies need to broaden their understanding of digital-physical products and also pay more attention to this phase. The continuous proliferation of digital-physical products in the market will bring more and more new challenges (Lerch & Gotsch, 2015). Therefore, the understanding of digital-physical products in the market phase is of great importance in order to ultimately be able to optimally design strategic management for it.

The answer to the second research question has shown that the digital aspect of a digital-physical product behaves differently. Similar to the whole principle of product life cycle models, the idealistic representation is to be criticized here as well. As criticized in the literature by Bruhn & Hadwich (2017), even in a modified product life cycle model the phases cannot be clearly delineated and the same arguments apply here. Although the software cycle is much more dynamic, it is only possible to determine in retrospect which phase the product was in by looking at the exact sales figures. Moreover, no generally valid rules can be derived. For one thing, every product behaves differently, and for another, there is a lack of practical experience compared to the traditional model. The model has not yet been tested in practice and may well behave differently. Another point of criticism is that the extended model does not take all influencing factors into account. For example, the macroeconomic environment or environmental influences are neglected. Despite the criticism, it should be borne in mind that the presentation is primarily concerned with grasping the basic features of the model.

The aim of the theoretical product life cycle model and the extended product life cycle model around digital-physical products presented here is to actively control and manage the development and maintenance of managed services (Bruhn & Hadwich, 2017).

Regardless of the criticism of the product life cycle theory itself, this answer to the research question was the first time that digital-physical products were placed in relation to a concept of product management. As already indicated by various researchers, digital-physical products will influence the entire spectrum of strategic management (Aumayr, 2019; Lerch & Gotsch, 2015). This aspect was addressed in answering the second research question, focusing on an essential concept of strategic management. While the study of digitalization of the product life cycle is not new (Fuller et al., 2020), the key difference lies on the approach to the product life cycle. In this study, the behavior of digital-physical products was compared with that of physical products within the product life cycle. The digital twin, on the other hand, aims at an exact mapping of the product life cycle of the physical product. While both approaches lead to a change in the way products are managed, the focus is different. The results have shown that the digital part of a physical product can be separated to manage the digital-physical product more efficiently and follow a different cycle. A digital twin could now digitally represent this adapted life cycle and make further deductions from it. Another difference to the previous literature regarding digitalization of the product life cycle is that no separate tools around the product life cycle were explored for reducing the increased complexity. The focus has been on understanding lifecycle change and not necessarily simplifying it through AI or blockchain-based technologies. While a reduction in complexity and simplification of the management of digital-physical can be interpreted by the introduction of separation into two cycles, the focus here is also interpreted differently.

Thus, it can be stated that the contribution of the present research question focuses on the lack of understanding about the nature of digital-physical products within the product life cycle model. With the help of the knowledge about this, various derivations can be made in the next step. From the researcher's point of view, the aspects are therefore all interrelated, whereby here primarily the understanding of digital-physical products was set in relation to the product life cycle theory. This aspect is shown schematically in Figure 51:

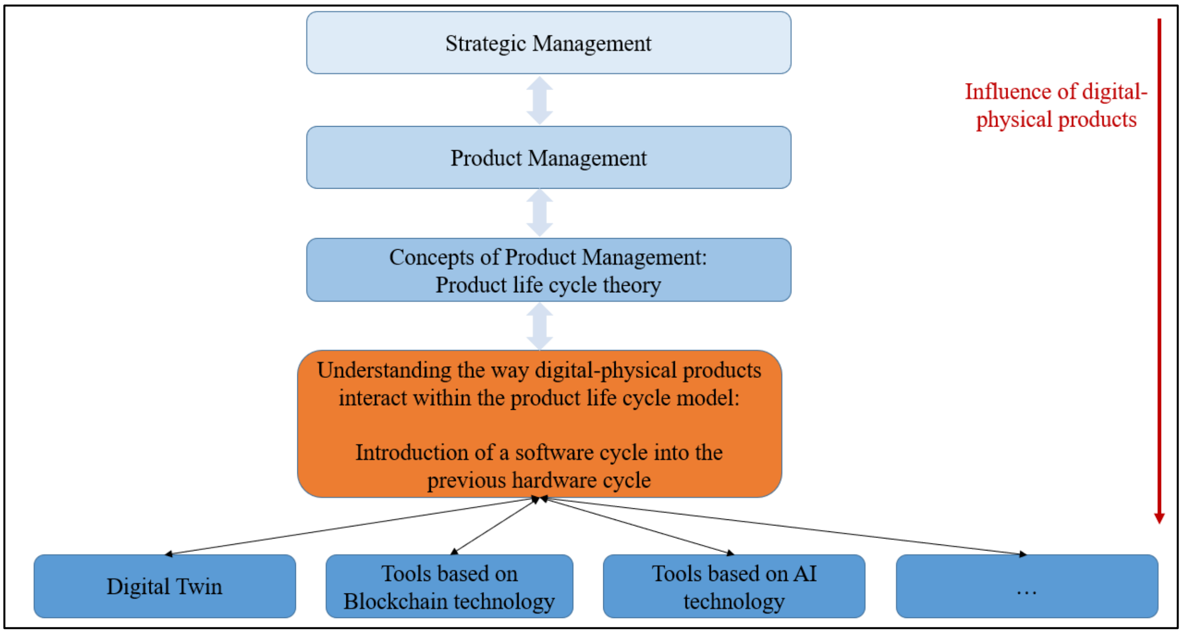

Figure 51: Classification of the conducted study in the literature (Source: Authors own illustration)

Digital-physical products affect all areas of the company and lead to a change in strategic management (Lerch & Gotsch, 2015). For the derivation of suitable measures, a fundamental understanding within the framework of the product life cycle model is indispensable, which is used as the basis for answering the research question. The study also makes a contribution with regard to the much-discussed length of the product life cycle. Many publications such as those by Keller & Lasch (2020) and Schork (2020) are of the opinion that the shortening of the product life cycle is necessary in order to remain successful in the market. Often the shortening of the product life cycle is seen as a solution to the advancing digitalization (Schork, 2020). As mentioned in this study, this is not always possible due to various constraints. The integration of a second cycle therefore shows an alternative in dealing with the influence of digitalization. The statement by Drechsler et al. (2019) that a shortening of the product is not necessary for the extensions of services in a product is thus supported, because services can be managed proactively through a second cycle.

In the context of the third research question, one of the results was the so-called PLM-D and the product portfolio digital as an expert house for digital solutions. Here, the previous approaches regarding the change of product management were further concretized and, in comparison to previous research, derived from the change of the product life cycle concept. As already mentioned in the literature review, the change of product management is already being investigated, but mostly conclusions are drawn from the corporate strategy (Porter & Heppelmann, 2015).

By deriving a change from the perspective of the product life cycle concept, it becomes noticeable that active management of products along the entire life cycle is necessary in order to be able to derive the greatest possible benefit from digital-physical products. This has also been mentioned by other researchers such as Gentner & Oßwald (2017), who determined that product management is expanding to include new tasks and that the product manager is still considered to be the appropriate person responsible. However, the findings shown here go a step further and translate the changes into concrete approaches and introduce a new product manager in the process. In particular, the introduction of the second, digital product manager introduces a new perspective to the discussion. Compared to other research, this study has shown the extension of product management and product managers to play an essential role in managing digital-physical products and can be seen as a suitable step for the digital business transformation of companies. The introduction of a new role, how it should be aligned and how the expanded tasks can be distributed and processed, has not yet been specifically examined. Through this research, the question of implementation is answered in more depth, rather than just answering the call for change. However, these approaches can also be criticized. After all, when a new product portfolio digital is introduced, it has to be accepted by the whole organization so that its benefits become visible. This also entails a criticism of the concept. The introduction of a new department and new employees can be rejected for a wide variety of reasons (including personal ones). The change of work task or place of work or other cuts in the comfort zone are only some of the reasons to be mentioned. In addition to the acceptance of such a department, it is often a question of effort and cost. The corporate philosophy and goals must be able to identify with digital-physical products so that investments of any kind can be made and accepted.

Furthermore, it needs to be considered whether the introduction of a PLM-D is resource or dedicated personnel in order to realize the full potential of a digital-physical product. This is because the experts from the study agree that the complexity in dealing with digital-physical products is increasing and therefore a separate person who deals with the digital aspects in greater depth is needed. From the results of the focus groups, it emerged that in addition to the traditional tasks, there are also other tasks (cf. Table 2) that now need to be managed in the same way when dealing with digital-physical products. As described above, these tasks require a good understanding of the digital ecosystem as well as an affinity for data. The skills needed to effectively and efficiently manage digital-physical products span the entire conventional product life cycle, but with different emphases in each phase. Thus, as early as in the development phase of a product, the derived functions that have resulted from the already collected data have to be integrated.

Therefore, extensive expertise on the core functions of the assets to be digitized and the product is necessary at the beginning. This goes hand in hand with the overarching product strategy and the strategy of the conventional system. The competition and market analyses with regard to digital assets in the rail industry complete the product development phase. In principle, the focus here is less on data analysis or sales capabilities, but rather on integrating the idea of innovation now for future services so that they can be accessed during operation. During the launch of the product, the goal is to put the sales force in a position to market successfully, to set the refined pricing strategy of the digital features and to define target groups. As described by participant FG 2-1, the two parties of both interests always have to be served. After the launch phase, the proactive search and finding of new use cases or digital services that optimize the core product through data-driven use cases takes place. Over this time, the data needs to be understood, summarized, and interpreted to be used successfully in the next update or product development. The skills required in this phase mainly relate to the tasks as shown in table 6. So, in order to realize the full potential of digital-physical products, an understanding of the digital aspects is indispensable and throughout the product life cycle it requires business-oriented thinking in relation to the digital aspect in order to be able to offer ever new services. Increasing staff alone without reference to the required skills could also reduce the workload but would still not utilize the full potential of the products. Although the results shown here are reflected by the establishment of a person, the missing skills can nevertheless be learned with reference to the digital ecosystem within the organization. At the same time, the redistribution of the previous tasks of the product manager could also create freedom to expand the skills. Because of this, the results mainly relate to a resource, rather than an increase in staff per se. In the course of this, human resource management takes on a significant role. Human Resource Management (HRM) describes the optimal use of resources with the aim of contributing to the company's success (Rowold, 2015). The focus is on the skills, knowledge, or motivation of the individual employee (Rowold, 2015). In the practical application of the results, the reference to HRM is an essential point of reference. Together with strategic HRM, the results shown are to be transferred to the respective company and reflected in its boundary conditions. This, in turn, allows conclusions to be drawn on how the required skills and organizational change can be implemented. This aspect is also underpinned and driven by the overarching (rail) infrastructure management, which has the ambition to continuously enhance planning, execution, and operations.

A study conducted by BearingPoint in 2019 shows that rail infrastructure companies are far behind the industry average in terms of planning and technology trends, and a new digital culture in the organization and processes is a key lever for improvement. Participants in the study see digitalization in this sector as only in its early stages, with a major impact on business processes and collaboration, "*because digitalization will change ways of working*" (Bahrenburg et al., 2019, p. 24). Rail infrastructure management sees digitalization as a game changer and therefore works on standards for the mandatory use of digital aspects and demands (digital) solutions as well as new technologies. These aspects within infrastructure management interact with the changes in the company. This means that the potential introduction of a PLM-D or the digital product portfolio could have an influence on the internal transformation of infrastructure management and vice versa. Establishing the insights shown here at an early stage therefore allows for the co-creation of change in infrastructure management and prepares them for the upcoming standards. Nevertheless, in addition to the interfaces to strategic HRM and rail infrastructure management, further dependencies and company-specific boundary conditions need to be taken into account in order to be able to achieve optimal applicability of the results.

Moreover, it needs to be discussed to what extent the results can also be projected onto other digital-physical products. At first, the infrastructure products of the railway industry are subject to the same contractual framework conditions, so that they are also subject to a long-life cycle and the same safety-critical standard. The same applies to the structural changes of the railway operators often mentioned by the experts. Due to demographic change and by serving different interest groups, the need for digital solutions in physical products is increasingly coming to the fore. It can thus be deduced that customer and market requirements will also continue to spread in this direction for other products (IntExpert-3). For example, the need for fast and uncomplicated updates or the integration of cybersecurity solutions without directly changing the physical product and thus the entire system will also apply to other products. It is therefore entirely justified to transfer the considerations of the integrated software cycle shown here to other products as well. Another commonality arises from the general characteristics of the product life cycle model in the railway industry. As described in the previous section, for example, the first improvement proposals follow after about three years or the interval between software updates is also extended over time due to technical performance. The separation of the cycle is also argued here through the derivation of product-specific measures.

Nevertheless, there are also some aspects to consider when transferring the results to other products. First, it depends on the digital capabilities of a product. Even if customer and market requirements push in a certain direction, some products can hardly be enriched with digital possibilities, so that here the behavior within the life cycle model hardly differs from the previous one. Establishing a dedicated person to look at the digital part would also not be worthwhile here. Furthermore, it may be possible to enrich technical-digital possibilities in products, but the focus within the life cycle could be distributed differently. For example, in the case of level crossing systems, the focus could be on the initial phase, as these are subject to special approval processes and complex overall system integration. At the same time, the focus could be more on the follow-up phase for onboard products, as these are now subject to recycling requirements in connection with trains. Depending on this, the focus on certain phases would then have to be placed differently, or specific phases could remain completely unaffected by previous activities. This would then also allow other measures and responsibilities to be derived. Therefore, it can be stated that the results can generally also be transferred to other products, but in particular the respective products need to be examined in more detail and analyzed to see whether the results shown here are effective.

Furthermore, the question remains to be clarified to what extent the results can be implemented in practice. In the final stages of the thesis, the findings were also discussed in the author's organization with regard to practical implementation. At first, the topic itself and its findings were in line with the current boundary conditions of the company. Among other things, the corporate strategy includes strengthening the product business with the requirement to invest primarily in software solutions. In addition, the enrichment of digital aspects in physical products is firmly planned within the framework of the product policy in order to be able to serve and develop further segments, which in turn are reflected in profitability and higher margins. Furthermore, the product portfolio has a heterogeneous structure, which leads to a considerable complexity. Due to the demand for more and more customer-specific solutions, the product portfolio has been expanded both vertically and horizontally. The now increasingly demanded aspect of investment and integration in software solutions leads to an increase in complexity and moves product management to the forefront of various discussions across the organization. The results were well received by the company, as they fit into the general discussions of rail infrastructure management, take into account the corporate strategy and ultimately contribute to an improved product business. Based on a specific product portfolio, which includes digital-physical products, the integration of the results should be planned. A dedicated team outlined a requirement profile of a PLM-D together with the strategic HRM and presented a draft for the revision of the internal guide process.

This describes the dependencies, responsibilities, and activities of a product manager across the product life cycle. The results determined in this thesis with the modified product life cycle model were integrated into the guide process in a next step. Furthermore, the technical possibilities for the digital-physical product over the life cycle were analyzed and potential technical measures were assessed and evaluated. After these activities, positive feedback was received, so that the next step will be to pilot a digital-physical product with the new guide process and PLM-D.

Even though the full integration of the results has not yet been completed, the first steps showed promising results for applying the findings in practice. Nevertheless, the findings shown here relate to the boundary conditions of Siemens Mobility GmbH and may well be realized differently in other companies. The behavior of digital-physical products in the product life cycle model shown here and the resulting conclusions regarding its management rather show a potential possibility of organizational change in product management in order to be able to map and manage digital-physical products in it. This is because "*change enables a company to better position itself vis-à-vis its competitors and to remain in a certain dynamic and learn new things*" (Santiago et al., 2015, p. 243).

6 Conclusion

The use of digital-physical products is becoming increasingly important in practice. With the help of these products, potentials are opening up for both manufacturers and customers along the product life cycle. The increasing use of digital-physical products in the railway industry forces manufacturers to move away from traditional patterns and to go more innovative ways, especially with regard to services. To ensure this, the management of these products is essential. The aim of the research was to investigate in an exploratory study the way digital-physical products interact within the framework of the classical product life cycle model. The research was conducted using a constructivist philosophy and a qualitative, inductive approach. Conducting a qualitative research study with a constructivist guiding principle, assumes that knowledge emerges in a specific context and does not claim that its research findings are commonly generalizable. Rather, this framework aims at a better understanding of complex contexts, especially when little prior knowledge exists or when deeper insights about a research object are to be gained. The expert interviews as well as the focus groups within the embedded case study ensured different insights and ensured sufficient good data. The structuring, clustering, and processing of the data was carried out with the help of the thematic analysis. In addition, throughout the research process, the researcher considered the ethical guidelines regarding the participants and the research.

The findings of this study have helped to gain a deeper understanding about digital-physical products and its impact on the product life cycle as well as product management in the railway industry environment. It was shown in **section 5.1.1** that the characteristics of digital-physical products find their way into every phase of the product life cycle. In addition to the increasing economic importance and relevance of digital-physical products within the next few years, it is above all the requirements of the products that are pushing for a rethink. Through these, new possibilities can be derived in the individual phases of the product life cycle, which leads to a change in the way products are managed. The product life cycle model is a model for strategically managing products throughout their life cycle. It can help to ensure market success in the future and help to implement targeted measures to increase sales. **Section 5.1.2** answered the question about the behavior of digital-physical products in the context of the product life cycle model. This showed that for ideal product management, the digital and physical aspects of a product can be listed separately within the framework of the product life cycle model. In this way, targeted measures can be derived over the product life cycle for the digital aspects of a product, embedded in the still leading hardware.

Ultimately, this leads to active governance and management of new business models. The answer to how these changes affects product management was given in **section 5.1.3** Based on the data collected, it emerged that a product manager digital (PLM-D) can increase efficiency in dealing with digital-physical products. In this context, a people profile with a basic understanding of the digital ecosystem should be mentioned, rather than a simple increase in staff. In addition, a change in organizational product management is needed to close the efficiency gaps in the long term. It has been found that an adaptation of the product life cycle model and product management is needed to manage the resulting benefits and complexity of digital-physical products. The results were mirrored on the boundary conditions of Siemens Mobility GmbH. The newly established product lifecycle model for deriving strategic measures for digital-physical products and the proposed changes in product management open up a structured transformation for the company to manage these products more effectively and efficiently in order to ultimately create a competitive advantage in the industry. Based on the findings identified here, this chapter will present the main contributions to knowledge and practice. In addition, recommendations for practice and for future research are also given on the part of the researcher. The end of the paper includes concluding comments and personal reflections by the researcher.

6.1 Contribution to knowledge

The study has helped to fill the research gap and contribute to current management research. In doing so, this study contributes to science on several levels, which are described below.

New insights by focusing on the user phase of digital-physical products

The phenomenon of digital-physical products has already been studied from different perspectives. For example, many scholars have discussed the definition of these products (Novales et al, 2016), how product development is changing or needs to change because of these products (Hendler, 2019), and the complexity brought about by the products (Bahrenburg, 2019). This study has made a more in-depth contribution to the impact of digital-physical products in the user phase. The much-discussed aspect of increasing complexity mostly referred to product development, while the use phase of these products was hardly considered. In this study, the focus was placed on the market phase, and it has been shown that digital-physical products also intervene in this phase and push for a change of previous patterns. The prior type of product maintenance, data management and the increased coordination effort between customers and manufacturers, but also within a company along the market phase, are influenced by digital-physical products and require an adjustment.

The relation between the product life cycle model and digital-physical products

Another contribution to the research was the discussion on the relation of digital-physical products to the classic concept of the product life cycle model. For the first time, the approach was to divide the model into a physical and a digital part, even though it is a product. The model itself is criticized because the ideal-typical course does not exist, or a clear demarcation of the phases is not possible. However, the model basically helps to think about strategic measures. The study has shown that there are different measures between the digital and physical parts of a product as well as different approaches with regard to the business models. In order to be able to derive these measures transparently and optimally with the help of the product life cycle model, a second cycle was therefore integrated. This aspect provides a new contribution to the discussion about the model, integrating the characteristics of digital-physical products. The shortening of the product life cycle, which is repeatedly mentioned in connection with digitalization, was also discussed and shown that this is not always possible due to legal and industry-specific framework conditions, so that the introduction of a second cycle offers a new perspective on the previous literature.

A new contribution to digital product management

Furthermore, a scientific contribution to product management has been made. Section 2.2 has shown the different facets of product management, which result from various internal and external factors. These factors influence the orientation and organizational structure of product management in an organization. The discussion about the influencing factors of product management was expanded to include digital-physical products. It has been shown that a change in product management is necessary in order to be able to manage digital-physical products efficiently and effectively. The much-discussed question of the extent to which the product manager must change in order to master the complexity of products was expanded to include the change in product management. For this purpose, digital-physical products were placed in relation to the prominent concept of the product life cycle. The existing literature derives the consequences for product management and its models as well as the product manager from the corporate strategy with regard to digitalization. This paper has derived the changes via the concepts of product management. This view complements previous academic research as it takes a different perspective.

In summary, management research benefits from this study by establishing a suitable product life cycle model for digital-physical products. Furthermore, a contribution has also been made to the still young field of digital product management. Previous literature focused on the optimization and positioning of product management for classic products or for digital products. With this study, a contribution was made and potential possibilities for positioning product management between both worlds were identified.

6.2 Contribution to practice

This study contributes to practice on three levels. The contributions provide practical orientation on how product management can be restructured, and the product life cycle modified. In addition, it takes into account the special boundary conditions of the railway industry. Firstly, a product life cycle model adapted to digital-physical products was designed. The previously reactive behaviour of a product manager with regard to these products can be structured in the next step. The orientation towards a second cycle, which focuses on the digital part of a product, helps with strategic decision-making and roadmap planning in practice.

Secondly, a new product manager role was introduced through the investigation. This aspect introduces a new perspective to the discussion on expanding the skillset of a product manager. The establishment of a digital product manager and a new portfolio show a new structure of product management. This organizational set-up also provides food for thought and hints for the changes in practice. Digitalization will continue to intervene in the individual areas of a company, so that the adaptation of processes, departments and people will be necessary. The results shown here provide direction in the adaptation of these functions.

Thirdly, this study makes a significant contribution to practice with regard to the railway industry. The discussion about product management within the railway industry is still quite new and often concepts, models or recommendations for action are implemented from other industries, especially the automotive industry. The reason for this is that the industry is defined by some peculiarities and specific boundary conditions and was hardly in the focus before the discussion about climate change. With its findings, this study has contributed to the industry from within the industry. The essential boundary conditions, such as the long-life cycles and the high safety standard, were taken into account and digital-physical products were mirrored against them. The results provide a basis for deriving recommendations for action for the industry. The main advantage is that the basics do not have to be transferred to the industry first, as is often the case otherwise. The results are therefore directly related to the boundary conditions of the sector and can be implemented directly.

6.3 Implications for practice

This section contains a call to action for the challenges described in the first section of this thesis. In a digitalized world that has become more dynamic and agile in recent decades, adapting previous structures and processes will become increasingly important. Mastering the increasing complexity in product management in order to ultimately generate more revenue over the life cycle, to react more dynamically as well as to remain competitive requires new guidelines and supports. The belief that digital-physical products can be managed in the same way as before will, in the researcher's view, lead to revenue losses in the medium term. Many studies have substantiated that a lack of or poor management of products leads to unsatisfactory results. Therefore, the author recommends that companies should invest time and money in adapting the product management and its concepts as well as people to digital-physical products. Above all, the focus should be on an evolutionary approach rather than an immediate rebuild for the digital world. The research results presented here with the implementation of a portfolio and product managers for the digital aspects of a product family provide practical orientation. It has to be decided on a company-specific basis how exactly the adjustment can be made, but it is recommended to make a division. This recommendation comes not only from a business perspective, but also from the perspective of modern leadership. Ever-increasing complexity, increasingly dynamic markets and globalization lead to great expectations of the product manager. Matys (2018, p. 1) claims: "*Stress is a constant companion for many product managers*". Therefore, the stress level that affects product managers should also be included in the considerations and physical health should be taken into account. Based on the adapted product life cycle model, the researcher recommends deriving recommendations for action for product managers.

The developed conceptual model for practice can help the product manager to orient himself or herself about the current situation and to classify strategic measures from it. Nevertheless, clear company-specific guidelines must be derived from this model so that the product manager can use it as a pattern for active action and is not subject to reaction. In this context, the researcher recommends taking a deeper look at the market phase. The focus of digitalization and its influence on products is currently on product development, but sales are only generated in the market phase. It has been shown that new business models are possible with the help of digital-physical products and potentials can also be used during the market phase. In order to derive the maximum benefit from this, previous activities must be integrated, expanded or adapted in certain phases of the cycle. This will inevitably lead to changes in other departments, which must be taken into account by the company in an evolutionary way.

Finally, it is important to be persistent in the implementation of the developed strategy and to allow enough flexibility to adapt it as needed. Regular meetings should be held to ensure that all stakeholders are aware of the strategy's progress and that help and support can be offered when needed. The adapted models should serve as the main guidance for the current strategy period.

6.4 Limitations of the study

During the research process, certain limitations were identified. One of the limitations is related to the research design, for example, or even the limited literature from the railway industry. The limitations that resulted for this study are described below.

The lack of real-life implementation

A first limitation arises from the lack of implementation of the findings in reality. The results of this study are based on theory and have not yet been tested in practice. The researcher, from his position, did not have the power in the company nor the accountability over the necessary budget to introduce a new digital portfolio or a product manager digital. Although the results are based on expert knowledge and the research was conducted in a practical way, the present research is limited by the fact that the results have not been tested in reality.

Limitation of the results by the defined case

Another limitation of the research is the applied research design. Based on the case study used, the research does not claim to be universally applicable to the entire industry or other industries. A researcher uses the case study when the researcher wants to understand or explain "how" or "why" a phenomenon occurs in a particular context (Warren & Bell, 2022). "*Case study research has the advantage of investigating problems that are embedded in a particular real-world context*" (Warren & Bell, 2022, p.8) Therefore, the researcher can only refer to his or her specified case when making findings. Nevertheless, the findings serve as a basis for questioning and changing the existing product life cycle model and the previous management of products. Concrete measures and changes were derived that can be implemented in this way, mirrored in the specific boundary conditions of the industry. Especially in sectors where digitalization is becoming more and more influential and products have similar long-life cycles, the same challenges will arise so that the results can be easily implemented.

Admittedly, the literature research has shown how diverse product management and the role of the product manager can be. Depending on the company philosophy and sector-specific basic conditions, a different interpretation can result, so that the influence of digital-physical products may have a different effect. Regardless of the diversity of product management, the results provide concrete food for thought on how to increase the efficiency of product management.

Content in the literature for the rail industry

It has already become apparent in the literature review that there is only a manageable number of scientific studies dealing with product management in the rail industry. Moreover, the railway industry corresponds to a closed and specific environment, which makes it difficult for researchers to access the industry. As a result, the literature contains few aspects, examples or focal points related to the rail industry and the impact of digitalization. Due to this, the researcher transferred many aspects and discussion from other industries to this environment. Further debates regarding the digital transformation in this environment are needed in order to understand the transformation holistically.

The derivation of recommendations for action

The last limitation is the derivation of recommendations for product managers. The development of a solid and practical management guide for product managers, based on the adapted product life cycle model, is another challenge to complete the overall picture of the impact of digital-physical products on product management.

This research was not able to investigate this aspect further because of a lack of basic knowledge on the topic and because the inclusion of this aspect would have exceeded the time frame of the research.

6.5 Recommendation for future research

The discussions on the influences of digital-physical products on the product life cycle model and product management, as well as the models proposed here form a first basis, but are not yet sufficient to address all future challenges between product management and digitalization. With the starting point shown here, there is a need for new and comprehensive research to bring about an expanded redesign of life cycle management. In doing so, the following questions are to be encouraged for further research:

- An expansion and application of the approaches to other sectors and companies lends itself to research. The changes shown apply to the railway industry with a focus on company-specific boundary conditions of Siemens Mobility GmbH. An adaptation to similar industries and areas also promises potential changes there with regard to product management and its models and concepts.
- A further question could be the examination of the results shown in reality. As already mentioned, these results are theoretical concepts despite the practice-oriented research. The implementation of the findings shown here in reality will lead to diverse questions in research and thus sustainably optimize the management of digital-physical products.
- The acceptance and confirmation of the findings shown here can be tested by further scientific research in the field of digital-physical products. Thus, the approaches and results can be applied to other life cycle models, such as the customer life cycle, or even other concepts within the product management. The more that is known and researched about these types of products, the more conclusions can be drawn about product management and its concepts. The limitations of the model presented here can thus be recognized, improved or criticized.
- The considerations presented here serve as a basis for a detailed investigation of the product manager and its environment in relation to digitalization. Future research could focus on practical recommendations for product managers in dealing with digital-physical products.

These topics go beyond the issues addressed in this research paper and offer further opportunities for new research approaches.

6.6 Research journey

As a conclusion to this thesis, the last few years should be reflected upon again, both professionally and privately, with reference to the doctorate. Finally, the main insights of the DBA journey are summarized once again.

The starting phase

At the beginning of my studies, both my thoughts and my way of working were strongly influenced by my engineering background. I believed in a single solution to the problem and a straightforward and rigorous process. However, when the DBA modules dealt with issues such as philosophical stance and the "being", I realized that I did not always agree with my engineering mindset. The typical black and white pattern could not fully take hold here, and I was forced to adapt my previous way of thinking. In the process, I began to reflect on myself by questioning my thoughts, but also, after a while, the thoughts of others. I noticed this especially during my daily work, where I started to question comments and statements and to react differently to problems. Especially as a newly appointed manager, this way of thinking benefited me, as I often took a different position when faced with a problem. This attitude, which was unfamiliar at the beginning, led to the repetition of various thoughts even after working or learning time, but in retrospect it is one of the most formative insights of the trip.

The challenges in the middle

In retrospect, this phase corresponded to the most challenging time of the whole journey. Firstly, the Covid crisis hit me in the middle of my studies and forced me to rethink my subject, as many things that were valid before February 2020 changed from one month to the next. My personal life was also greatly affected, as the Covid crisis led to a change in previous habits and increased involvement on my part in the family business. Writing a DBA thesis alongside daily work and additional support in the family business led to a level of stress never felt before. At the same time, it also strengthened the relationship with my family and optimized my personal time management. Secondly, the phase was characterized by various iterative processes. The constant rethinking of the research questions, research design and methods led me to several repetitions. Although progress was evident after each loop, it tested my motivation time again and again. In retrospect, the process of constant reflection has had a positive effect on my perseverance and discipline.

After the basics had become more stable, the following time turned out to be very enjoyable. I found conducting the interviews and focus groups very stimulating, and it was fun to listen to and discuss the views of colleagues.

The final phase

Despite the increased workload in the final phase and the sprint at the end, I have to admit that I liked this phase the most. There was a light at the end of the tunnel, and the results of the research started to emerge. Although it was challenging to sort out one's own thoughts and to formulate them clearly so that third parties could understand them, I found this challenge pleasant. In addition, the regular meetings with my supervisors also changed. The question-and-answer aspect increasingly moved into the background and the discussions about the topic or certain decisions were now in the foreground.

Final words

Writing this DBA thesis has been an enjoyable, challenging but also intense journey. Researching and writing the dissertation in a foreign language and discussing the topic with my supervisors in English helped me develop my language skills and analytical thinking and forced me to step out of my comfort zone several times. Applying various tools for better time management, had helped me to manage my business, academic and family tasks according to urgency and importance so as not to neglect any of the three issues and maintain a good work-life balance with quality business and academic outcomes. Above all, the DBA gave me a sanctuary to do my own thinking on a topic adjacent to the work. Often, this made working on the DBA does not feel like pressure, but a bubble to reflect on my own thoughts. Also worth highlighting is that the interaction with the other students and discussing their ideas and being challenged by them was refreshing and interesting. The DBA journey gave me the opportunity to talk to very experienced leaders, experts and colleagues and expanded my business and academic network. I would like to conclude this thesis with a quote from Dietrich Bonhöffer, which served as a guiding principle for me throughout the entire DBA journey: "*If you're on the wrong train, it doesn't help to go in the right direction in the corridor*".

7 References

Anderson, C. (2010). Presenting and evaluating qualitative research. *American journal of pharmaceutical education*, *74*(8).

Antoni, M. (2011). Complementarity between Axle Counters and Tracks Circuits. *Forms/Format 2010* (pp. 65-76). Springer, Berlin, Heidelberg.

Ansell, A., Froyland, T., & Rovida, F. (2019). Asset Management: A Key Enabler for Railway Infrastructure. *Proceedings of the Institution of Civil Engineers - Transport, 172*(3).

Appelfeller, W., & Feldmann, C. (2018). *Die digitale Transformation des Unternehmens: Systematischer Leitfaden mit zehn Elementen zur Strukturierung und Reifegradmessung*. Springer Gabler. https://doi.org/10.1007/978-3-662-54061-9

Appius, D., Probst, R. A., & Tokarski, K. O. (2021). Edge Computing und Industrie 4.0. *Digital Business* (pp. 305–334). Springer Nature. https://doi.org/10.1007/978-3-658-32323-3_13

Aumayr, K. J. (2019). *Erfolgreiches Produktmanagement: Tool-Box für das professionelle Produktmanagement und Produktmarketing* (5th ed.). Springer Fachmedien Wiesbaden. https://ebookcentral.proquest.com/lib/kxp/detail.action?docID=5754967

Babbie, E. R. (2021). *The practice of social research* (15th edition). Cengage.

Babüroglu, O. N. & Ravn, I. (1992). Normative Action Research. *Organization Studies*, *13*(1), 19–34. https://doi.org/10.1177/017084069201300104

Bahrenburg, S., Munk, S., Fischer, J., Rützel, H., Fuchs, B. (2019). Studie „Future PLM". Product Lifecycle Management in der digitalen Zukunft – Wegbereiter für IoT, Industrie 4.0 und Digital Twin. BearingPoint. https://www.bearingpoint.com/files/PLM_BearingPoint_Studie.pdf? download=0&itemId=564780.

Baldacchino, D. & Draper, P. (2001). Spiritual coping strategies: a review of the nursing research literature. *Journal of Advanced Nursing*, *34*(6), 833–841. https://doi.org/10.1046/j.1365-2648.2001.01814.x

Barney, J. (1991). Firm Resources and Sustained Competitive Advantage. *Journal of Management*, *17*(1), 99–120. https://doi.org/10.1177/014920639101700108

Bauer, W., & Horváth, P. (2015). Industrie 4.0 - Volkswirtschaftliches Potenzial für Deutschland. *Controlling*, *27*(8-9), 515–517. https://doi.org/10.15358/0935-0381-2015-8-9-515

Bauernhansl, T., Hompel, M. ten, & Vogel-Heuser, B. (2014). *Industrie 4.0 in Produktion, Automatisierung und Logistik: Anwendung· Technologien· Migration*. https://link.springer.com/978-3-658-04682-8

Baumbusch, J. (2010). Semi-structured interviewing in practice-close research. *Journal for specialists in pediatric nursing*, *15*(3), 255.

Baumers, M., Koleva, B., Tóth, Z., Winklhofer, H., Ashcroft, I., Flintham, M., & Benford, S. (2020). A framework for differentiation in composed digital-physical products. *International Journal of Mechatronics and Manufacturing Systems, 13*(4), Article 10034618, 286. https://doi.org/10.1504/IJMMS.2020.10034618

Baumgartner, R. J. (2018). Nachhaltiges Produktmanagement durch die Kombination physischer und digitaler Produktlebenszyklen als Treiber für eine Kreislaufwirtschaft. In: *Interdisziplinäre Perspektiven zur Zukunft der Wertschöpfung* (pp. 347–360). Springer Gabler, Wiesbaden. https://doi.org/10.1007/978-3-658-20265-1_26

Baur, N. & Blasius, J. (2019). Methoden der empirischen Sozialforschung – Ein Überblick. In: *Handbuch Methoden der empirischen Sozialforschung* (S. 1–28). Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-21308-4_1

Berndt, R., Fantapié Altobelli, C., Sander, M., Berndt, R., Fantapié Altobelli, C., & Sander, M. (2020). Internationalisierung und internationales Marketingmanagement. *Internationales Marketingmanagement*, 3-17.

Bertrand, B., Williams, M. R. M. & Bochmann, M. (2018). Complexes for Antitumor Applications: An Overview. *Chemistry – A European Journal*, *24*(46), 11840–11851. https://doi.org/10.1002/chem.201800981

Bhatta, T. P. (2018). Case Study Research, Philosophical Position and Theory Building: A Methodological Discussion. *Dhaulagiri Journal of Sociology and Anthropology*, *12*, 72–79. https://doi.org/10.3126/dsaj.v12i0.22182

Biermann, B., & Erne, R. (2020). *Nachhaltiges Produktmanagement*. Springer Books.

Bisman, J. E. & Highfield, C. (2012). The road less travelled: An overview and example of constructivist research in accounting. *Business and Finance Journal*. https://ro.uow.edu.au/aabfj/vol6/iss5/2/

Bohnsack, R. & Nentwig-Gesemann, I. (2010). *Dokumentarische Evaluationsforschung: Theoretische Grundlagen und Beispiele aus der Praxis*. Verlag Barbara Budrich.

Bonoma, T. V. (1985). Case Research in Marketing: Opportunities, Problems, and a Process. *Journal of Marketing Research*, *22*(2), 199–208. https://doi.org/10.1177/002224378502200209

Borchardt, A. & Göthlich, S. E. (2007). Erkenntnisgewinnung durch Fallstudien. In: *Methodik der empirischen Forschung* (2nd ed.). Springer, Wiesbaden.

Borgia, E. (2014). The Internet of Things vision: Key features, applications and open issues. *Computer Communications*, *54*, 1–31. https://doi.org/10.1016/j.comcom.2014.09.008

Bortz, J. & Döring, N. (1995). Hypothesengewinnung und Theoriebildung. *Forschungsmethoden und Evaluation* (S. 327–367). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-07301-8_7

Bracken, I., & Scholten, N. (2017). Designing Railway Innovations: How to Align Stakeholders in the Early Stages of the Innovation Process. *Transportation Research Procedia, 22,* 253-262.

Brauckmann, O. (2019). *Digitale Revolution in der industriellen Fertigung - Denkansätze* (1st ed.). *Springer eBook Collection*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-58037-0

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*.

Braun, V. & Clarke, V. (2013). Teaching thematic analysis: Overcoming challenges and developing strategies for effective learning. *The Psychologist* (26/2). https://uwe-repository.worktribe.com/preview/937606/teaching

Bravo, A. & Lüddecke, K. (2021). Sichere, cloudbasierte Lösungen für das Asset Performance Management. *Signal + Draht*. 06/ 2021. pp. 40-66.

Braess, H. H., & Seiffert, U. (2012). *Produktentstehungsprozess.* Vieweg Handbuch Kraftfahrzeugtechnik. Springer Verlag.

Breitenfelder, U., Hofinger, C., Kaupa, I. & Picker, R. (2004). Fokusgruppen im politischen Forschungs- und Beratungsprozess. *Forum: Qualitative Social Research*, *5*(2). https://doi.org/10.17169/fqs-5.2.591

Breuer, F. & Schreier, M. (2010). Lehren und Lernen qualitativer Forschungsmethoden. In: *Handbuch Qualitative Forschung in der Psychologie (S. 408–420)*. VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-92052-8_29

Breuer, P., & Perrey, J. (2011). Kapital Kunde – mehr Markterfolg durch Customer Lifecycle Management. *Marketing Review St. Gallen, 28*(1), 20–25. https://doi.org/10.1007/s11621-011-0003-7

Brockhoff, K. (1999). *Produktpolitik*. (4th ed.) Stuttgart. Lucius und Lucius

Bruhn, M. (2009). Das Konzept der kundenorientierten Unternehmensführung. *Kundenorientierte Unternehmensführung* (pp. 33–68). Gabler. https://doi.org/10.1007/978-3-8349-8051-9_2

Bruhn, M., & Hadwich, K. (2017). *Produkt-und Servicemanagement: Konzepte, Prozesse, Methoden*. Vahlen.

Buerki, R. (2000). *Klimaänderung und Anpassungsprozesse im Wintertourismus*. (6th ed.). Ostschweizerische Geographische Gesellschaft. St. Gallen.

Bunduchi, R., & Candi, M. (2021). Technology Legitimation: A Product-Level Examination Across the Technology Lifecycle. *British Journal of Management*, Article 1467-8551.12562. Advance online publication. https://doi.org/10.1111/1467-8551.12562

Cagan, M. (2017). *Inspired: How to create tech products customers love*. John Wiley & Sons.

Cano, E. L., García-Camús, J. M., Garzás, J., Moguerza, J. M., & Sánchez, N. N. (2021). A Scrum-based framework for new product development in the non-software industry. *Journal of engineering and technology management, 61.*

Cao, H., & Folan, P. (2012). Product life cycle: the evolution of a paradigm and literature review from 1950–2009. *Production Planning & Control*, *23*(8), 641–662. https://doi.org/10.1080/09537287.2011.577460

Chandra, S. (2019). *Railway Engineering: The Ultimate Guide for Beginners*. Oxford University Press

Chandy, R. K., Tellis, G. J., Macinnis, D. J., & Thaivanich, P. (2001). What to Say When: Advertising Appeals in Evolving Markets. *Journal of Marketing Research*, *38*(4), 399–414. https://doi.org/10.1509/jmkr.38.4.399.18908

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. *Introducing qualitative methods*. SAGE.

Ciszewski, T., & Nowakowski, W. (2018). Economic Analysis of the life-cycle cost structure for railway traffic control systems. *Ekonomicko-Manazerske Spektrum*, *12*(1), 30–43. https://doi.org/10.26552/ems.2018.1.30-43

Cloutier, M. S., & Paré, G. (2013). The Role of the Chief Product Officer in the Software Industry: An Exploratory Study. *Journal of Product Innovation Management, 30*(2).

Cole, J., & Gardner, K. (1979). Topic work with first-year secondary pupils. *The Effective Use of Reading*, 167–192.

Conforto, E. C., Amaral, D. C., da Silva, S. L., Di Felippo, A., & Kamikawachi, D. S. L. (2016). The agility construct on project management theory. *International Journal of Project Management, 34*(4), 660-674.

Côté-Arsenault, D. & Morrison-Beedy, D. (2005). Maintaining your focus in focus groups: avoiding common mistakes. *Research in Nursing & Health*, *28*(2), 172–179. https://doi.org/10.1002/nur.20063

Creswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches*. (2nd ed.). Sage Publications.

Creswell, J. W. (2013). Steps in conducting a scholarly mixed methods study.

Crossan, F. (2003). Research philosophy: towards an understanding. *Nurse Researcher (through 2013)*, *11*(1), 46.

Crotty, M. J. (1998). The foundations of social research: Meaning and perspective in the research process. *The foundations of social research*, 1-256.

Dean, J. (1950). Pricing Policies for New Products. *Harvard Business Review* (Nov.-Dec.).

Deneux, F., Kane R., Lundh R., Schaper, A., & Thomas, F. (2004). Mid-Life Crisis: New Challenges in Pharmaceutical Life-Cycle Management. *Prism* (1), 77–91.

Denzin, N. K. & Lincoln, Y. S. (2011). *The Sage handbook of qualitative research* (4th ed.). Sage Publications.

Dervin, B. (1997). Given a context by any other name: Methodological tools for taming the unruly beast. *Information seeking in context*, *13*, 38.

Dhalla, N. K., & Yuspeh, S. (1980). Forget the Product Life Cycle Concept. *Harvard Business Review* (Jan.-Feb.).

Dietterich, T. G. (1990). Machine Learning. *Annual Review of Computer Science*, *4*(1), 255–306. https://doi.org/10.1146/annurev.cs.04.060190.001351

Drechsler, S., Knieps, L., & Lasch, R. (2019). Framework zur Umsetzung von Performance-Based-Contracting auf dem Industriegütermarkt. In: *Logistik im Wandel der Zeit – Von der Produktionssteuerung zu vernetzten Supply Chains* (pp. 323–344). Springer Gabler, Wiesbaden. https://doi.org/10.1007/978-3-658-25412-4_15

Druehl, C. T., Schmidt, G. M., & Souza, G. C. (2009). The optimal pace of product updates. *European Journal of Operational Research*, *192*(2), 621–633. https://doi.org/10.1016/j.ejor.2007.09.043

Dürrenberger, G., Kastenholz, H. & Behringer, J. (1999). Integrated assessment focus groups: bridging the gap between science and policy? *Science and Public Policy*, *26*(5), 341–349. https://doi.org/10.3152/147154399781782257

Duffy, T. M. & Jonassen, D. H. (2013). *Constructivism and the technology of instruction: A conversation*. https://www.taylorfrancis.com/books/mono/10.4324/9780203461976/constructivism-technology-instruction-thomas-duffy-david-jonassen

Dwivedi, Y. K., Rana, N. P., Jeyaraj, A., Clement, M., & Williams, M. D. (2019). Social Media Marketing: A Literature Review and Implications. *Decision Support Systems,* 117, 27-54.

Easterby-Smith, M., Thorpe, R. & Lowe, A. (2002). *Management research: An introduction* (2nd ed.). *SAGE series in management research*. SAGE.

Ebert, C. (2014). Software Product Management. *IEEE Software*, *31*(3), 21–24. https://doi.org/10.1109/ms.2014.72

Eckhart, M., & Ekelhart, A. (2019). Digital twins for cyber-physical systems security: State of the art and outlook. *Security and Quality in Cyber-Physical Systems Engineering: With Forewords by Robert M. Lee and Tom Gilb*, 383-412.

Egbert, L., Quandt, M., Thoben, K.-D., & Freitag, M. (2020). *Mobile AR-Based Assistance Systems for Order Picking – Methodical Decision Support in the Early Phases of the Product Life Cycle.* In: International Conference on Subject-Oriented Business Process Management (pp. 74–87). Springer, Cham. https://doi.org/10.1007/978-3-030-64351-5_6

Eisenhardt, K. M. (1989). Building Theories from Case Study Research. *Academy of Management Review*, *14*(4), 532–550. https://doi.org/10.5465/amr.1989.4308385

El-Gayar, O. F., Moran, M., & Hawkes, M. (2020). Challenging the notion of smart products: Key areas for exploration and research. *International Journal of Information Management, 52,* 102068.

Elam, G., Ritchie, J. & Lewis, J. (2013). *Qualitative Research Methods*. SAGE.

European Commission. (2019). Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs, Study on the competitiveness of the rail supply industry – Final report, Publications Office, 2019, https://data.europa.eu/doi/10.2873/592269

Federal Ministry of Transport and Digital Infrastructure. (2020). *Masterplan Schienenverkehr*. https://www.bmvi.de/SharedDocs/DE/Anlage/E/masterplan-schienenverkehr.pdf?__blob=publicationFile

Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway. (2017). *Marktuntersuchung Eisenbahn*. https://www.bundesnetzagentur.de/SharedDocs/Downloads/DE/Sachgebiete/Eisenbahn/Unternehmen_Institutionen/Veroeffentlichungen/Marktuntersuchungen/MarktuntersuchungEisenbahnen/MarktuntersuchungEisenbahn2017.pdf?__blob=publicationFile&v=2

Firestone, W. A. (1993). Alternative Arguments for Generalizing From Data as Applied to Qualitative Research. *Educational Researcher*, *22*(4), 16–23. https://doi.org/10.3102/0013189X022004016

Fischer, M. (2001). *Produktlebenszyklus und Wettbewerbsdynamik: Grundlagen für die ökonomische Bewertung von Markteintrittsstrategien* (1st ed.). *Gabler Edition Wissenschaft: Schriftenreihe des Instituts für marktorientierte Unternehmensführung (IMU), Universität Mannheim*. Dt. Univ.-Verl.; Gabler.

Flick, U., Kardoff, E.v., Keupp, H., Rosenthiel, L.v., Wolff, S. (1995). *Handbuch qualitative Sozialforschung*. Beltz. https://katalog.ub.uni-heidelberg.de/titel/67133511

Flick, U. (2006). *Qualitative Evaluationsforschung. Konzepte, Methoden, Umsetzungen.* Hamburg. Rowohlt.

Flick, U. (2008). *Triangulation – Eine Einführung* (2nd ed.). Wiesbaden. Verlag für Sozialwissenschaft.

Flick, U. (2019). Gütekriterien qualitativer Sozialforschung. In: *Handbuch Methoden der empirischen Sozialforschung* (S. 473–488). Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-21308-4_33

Flower, L. (2009). *Interpretative Phenomenological Analysis: Theory, Method and Research*. Sage Publication.

Flyvbjerg, B. (2011). Case study. *The Sage handbook of qualitative research*, *4*, 301-316.

Fosnot, C. T. (2013). *Constructivism: Theory, Perspectives, and Practice* (2nd ed.). Teachers College Press. http://gbv.eblib.com/patron/FullRecord.aspx?p=3545062

Fraunhofer IPT. (2022). *Agile Produktentwicklung als Befähiger für die Entwicklung disruptiver Innovationen.* Fraunhofer-Institut für Produktionstechnologie IPT. https://www.ipt.fraunhofer.de/de/kompetenzen/Technologiemanagement/agile-produktentwicklung-disruptive-innovationen.html

Frick, J.E., Fremont, V.H.J., Åge, L.-J. and Osarenkhoe, A. (2020). Digitalization efforts in liminal space–inter-organizational challenges. *Journal of Business & Industrial Marketing*, Vol. 35 No. 1

Fricker, S. A. (2012). Software Product Management. In: *Software for People* (pp. 53–81). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-31371-4_4

Fuller, A., Fan, Z., Day, C., & Barlow, C. (2020). Digital twin: Enabling technologies, challenges and open research. *IEEE access*, *8*, 108952-108971.

Gaubinger, K. (2015). *Innovation and product management: A holistic and practical approach to uncertainty reduction*. *Springer Texts in Business and Economics*. Springer. https://doi.org/10.1007/978-3-642-54376-0

Gemünden, H. G., Dammer, H., & Jonas, D. (2008). Die Zusammenarbeit der Akteure im Multiprojektmanagement: Empirische Untersuchungsergebnisse. *Handbuch Multiprojektmanagement und-controlling: Projekte erfolgreich strukturieren und steuern.* Berlin: Erich Schmidt.

Gentner, D., & Oßwald, M. (2017). *Industrie 4.0 und resultierende Anforderungen an das Produktmanagement: Theorie und Empirie.* https://doi.org/10.18725/OPARU-4207

Geracie, G., & Eppinger, S. D. (2013). *The Guide to the Product Management and Marketing Body of Knowledge: ProdBOK*. Product Management Educational Institute.

Gericke, K., et al. (2020). Product development for digital-physical products: An exploratory study. *Procedia CIRP, 93,* 1102-1107.

German Bundestag. (2016). *Zur Diskussion um die Verkürzung von Produktlebenszyklen.* WD 5: Economy and Technology, Food, Agriculture. https://www.bundestag.de/resource/blob/438002/42b9bf2ae2369fd4b8dd119d968a1380/wd-5-053-16-pdf-data.pdf

Gerson, K. & Horowitz, R. (2002). Observation and Interviewing: Options and Choices in Qualitative Research. *Qualitative Research: An International Guide to Issues in Practice*. https://nyuscholars.nyu.edu/en/publications/observation-and-interviewing-options-and-choices-in-qualitative-r

Ghasemzadeh, F., & Archer, N. (2019). Managing Agile Open-Innovation Ecosystems: Roles of Project Managers and Core Team Leaders in Digital Transformation. *Project Management Journal, 50*(6), 665-680.

Ghauri, P. G., & Gronhaug, K. (2002). Research methods in business studies: A practical guide. *Essex: Pearson education limited*.

Gläser, J., & Laudel, G. (2010). *Experteninterviews und qualitative Inhaltsanalyse*. Springer-Verlag.

Gmelin, H., & Seuring, S. (2014). Achieving sustainable new product development by integrating product life-cycle management capabilities. *International Journal of Production Economics*, *154*, 166–177. https://doi.org/10.1016/j.ijpe.2014.04.023

Göll, E. (2009). Zukunftsforschung und -gestaltung. In: *Zukunftsforschung und Zukunftsgestaltung* (S. 343–355). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-78564-4_26

Gopinath, S., & Kishore, S. (2017). Organizing for Product Management Excellence. *Journal of Product Innovation Management*, *34*(6), 744-763.

Grant, M. J., & Booth, A. (2009). A typology of reviews: an analysis of 14 review types and associated methodologies. *Health information & libraries journal*, *26*(2), 91-108.

Gray, C. (2010). Analysing cultural policy: incorrigibly plural or ontologically incompatible? *International journal of cultural policy*, *16*(2), 215-230.

Greitemann, J., Zaggl, M. A., Hehl, M., Raasch, C., & Reinhart, G. (2017). Technology lifecycle-oriented search for production technologies. *CIRP Journal of Manufacturing Science and Technology*, *16*, 21–33. https://doi.org/10.1016/j.cirpj.2016.08.001

Grix, J. (2004). *The foundations of research*. Palgrave Macmillan, New York.

Großklaus, R.H.G. (2009). *Praxisbuch Produktmanagement*. (1st ed.). Mi-Wirtschaftsbuch, München

Grzechca, D., & Szczeponik, A. (2020). Comparison of filtering methods for enhanced reliability of a train axle counter system. *Sensors*, *20*(10), 2754.

Guiltinan, J. P., & Paul, G. W. (1995). A Differentiated Look at Product Life Cycles. *Journal of Product Innovation Management*, 12(4), 322-335.

Guo, H., & Yang, S. (2017). Product Lifecycle Management of Railway Infrastructure. *Journal of Traffic and Transportation Engineering*, *4*(5), 547-558.

Gutenberg E. (1951) *Grundlagen der Betriebswirtschaftslehre*. (1st ed.). Springer, Berlin.

Harms, C. (2017). *Digitalisierung: „Intelligente, innovative, vernetzte Systeme sind gefragt“*. https://www.allianz-pro-schiene.de/themen/aktuell/digitalisierung-interview-manfred-fuhg/

Harrison, A. G., & Treagust, D. F. (2000). Learning about atoms, molecules, and chemical bonds: A case study of multiple model use in grade 11 chemistry. *Science Education*, *84*(3), 352–381. https://doi.org/10.1002/(SICI)1098-237X(200005)84:3<352::AID-SCE3>3.0.CO;2-J

Hecker, F. (2012). *Management-Philosophie: Strategien für die Unternehmensführung - Grundregeln für ein erfolgreiches Management*. Gabler Verlag. https://ebookcentral.proquest.com/lib/kxp/detail.action?docID=885743

Helfferich, C. (2022). Leitfaden- und Experteninterviews. In: *Handbuch Methoden der empirischen Sozialforschung* (S. 875–892). Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-37985-8_55

Hendler, S., & Boer, H. (2019). Digital-physical product development: a review and research agenda. *International Journal of Technology Management*, *80*(1-2), 12-35.

Hendler, S. (2019). Digital-physical product development: A qualitative analysis. *European Journal of Innovation Management*, *22*(2), 315–334. https://doi.org/10.1108/EJIM-01-2018-0026

Henseling, C., T. Hahn and K. Nolting. (2006). *Die Fokusgruppentechnik als Instrument in der Umwelt- und Nachhaltigkeitsforschung.* Berlin: IZT. http://www.izt.de/fileadmin/downloads/pdf/IZT_WB82.pdf

Herrmann, A., & Huber, F. (2013). *Produktmanagement: Grundlagen - Methoden - Beispiele* (3rd ed.). *Springer eBook Collection*. Springer Fachmedien Wiesbaden; Imprint; Springer Gabler. https://doi.org/10.1007/978-3-658-00004-2

Herterich, M., & Mikusz, M. (2016). Looking for a Few Good Concepts and Theorie for Digitized Artifacts and Digital Innovation in a Material World. *Thirty Seventh International Conference, 2016.*

Hesse-Biber, S. N. & Leavy, P. (2011). *The practice of qualitative research* (2nd ed.). Sage Publication.

Heyde, W., Laudel, G., Pleschak, F., & Sabisch, H. (1991). Prozesse der Produkt- und Technologieinnovation. In: *Innovationen in Industrieunternehmen* (pp. 29–81). Gabler Verlag. https://doi.org/10.1007/978-3-322-87041-4_3

Hoffmann, S. (2020). *Digitales Produktmanagement*. Springer Fachmedien, Wiesbaden. https://doi.org/10.1007/978-3-658-30629-8

Holden, M. T., & Lynch, P. (2004). Choosing the appropriate methodology: Understanding research philosophy. *The marketing review*, *4*(4), 397-409.

Holler, M., Barth, L., & Fuchs, R. (2019). Trustworthy Product Lifecycle Management Using Blockchain Technology—Experience from the Automotive Ecosystem. In: *Product Lifecycle Management (Volume 4): The Case Studies* (pp. 13–19). Springer, Cham. https://doi.org/10.1007/978-3-030-16134-7_2

Hopf, C. (2016). Soziologie und qualitative Sozialforschung. In: *Schriften zu Methodologie und Methoden qualitativer Sozialforschung* (S. 13–45). Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-11482-4_2

Horowitz, B., & Weiden, D. (2010). Good product manager/bad product manager. *Adv. Res. Econ. Manage. Sci.*, *15*, 627-633.

Horváth, P., & Michel, U. (2016). *Digital Controlling & Simple Finance: Die Zukunft der Unternehmenssteuerung*. Schäffer-Poeschel.

Huber, F., & Kopsch, A. (2007). Produktbündelung. In: *Handbuch Produktmanagement* (pp. 617–648). Gabler Verlag, Wiesbaden. https://doi.org/10.1007/978-3-8349-9517-9_27

Hünerberg, R., Mann, A., & Töpfer, A. (2009). *Ganzheitliche Unternehmensführung in dynamischen Märkten: Festschrift für Armin Töpfer*. *Gabler Research*. Wiesbaden. Gabler Verlag.

Huh, J. H., Lee, S., & Seo, K. (2018). Conceptual design framework for hybrid products: A combination of digital and physical artifacts. *Design Science, 4,* e3.

Hunt, S. D. (1991). Positivism and Paradigm Dominance in Consumer Research: Toward Critical Pluralism and Rapprochement. *Journal of Consumer Research*, *18*(1), 32. https://doi.org/10.1086/209238

Iansiti, M., & Lakhani, K.R. (2014). Digital ubiquity: How connections, sensors, and data are revolutionizing business. *Harvard Business Review*, *92*(11), 19. https://dialnet.unirioja.es/servlet/articulo?codigo=5544176

Jacobs, J. (2019). *Produktlebenszyklusorientiertes Controlling am Beispiel des produktbezogenen Businessplans*. Gabler. https://doi.org/10.1007/978-3-658-24330-2

Jäger, U. & Reinecke, S. (2009). Expertengespräch. In: *Empirische Mastertechniken* (S. 29–76). Gabler Verlag, Wiesbaden. https://doi.org/10.1007/978-3-8349-8278-0_2

Jesson, J., Matheson, L., & Lacey, F. M. (2011). Doing your literature review: Traditional and systematic techniques.

Johnson, P., & Gill, J. (2010). Research methods for managers. *Research Methods for Managers*, 1-288.

Johnson, R. B. & Onwuegbuzie, A. J. (2004). Mixed Methods Research: A Research Paradigm Whose Time Has Come. *Educational Researcher*, *33*(7), 14–26. https://doi.org/10.3102/0013189X033007014

Kagermann, H. (2014). Theseus: A Successful First Step. In *Towards the Internet of Services: The THESEUS Research Program* (pp. 51–56). Springer, Cham. https://doi.org/10.1007/978-3-319-06755-1_5

Kaiser, R. (2014). *Qualitative Experteninterviews: Konzeptionelle Grundlagen und praktische Durchführung*. *Elemente der Politik*. Springer VS. https://doi.org/10.1007/978-3-658-02479-6

Keite, L. (2022). Zentrale Zielsetzung und Rahmenbedingungen im Produktmanagement. In: *Produktmanagement im digitalen Zeitalter (pp. 69-152).* Haufe, München.

Kelemen, M. & Rumens, N. (2008). *An introduction to critical management research*. SAGE.

Keller, J., & Lasch, R. (2020). Governance-Mechanismen zur Reduzierung der Time-to-Market. *Supply Management Research* (pp. 199–219). Springer Gabler, Wiesbaden. https://doi.org/10.1007/978-3-658-31898-7_10

Keskin, D., Wever, R., & Brezet, H. (2020). Product innovation processes in sustainability-oriented ventures: A study of effectuation and causation. *Journal of Cleaner Production*, *263*, 121210.

Khan, F. U., & Hafeez, S. (2020). Supply Chain Management of Digital-Physical Products: Challenges, Opportunities, and Research Directions. *International Journal of Information Management, 52*, 102087.

King, G., Murray, C. J. L., Salomon, J. A. & Tandon, A. (2004). Enhancing the Validity and Cross-Cultural Comparability of Measurement in Survey Research. *American Political Science Review*, *98*(1), 191–207. https://doi.org/10.1017/s000305540400108x

King, N., Horrocks, C., & Brooks, J. (2018). *Interviews in Qualitative Research*. SAGE Publications.

Kinkel, S. (2005). *Anforderungen an die Fertigungstechnik von morgen: wie verändern sich Variantenzahlen, Losgrößen, Materialeinsatz, Genauigkeitsanforderungen und Produktlebenszyklen tatsächlich?* Karlsruhe: Fraunhofer-Institut für System- und Innovationsforschung ISI. https://www.econstor.eu/handle/10419/29499

Kirchner, K., Lemke, C., & Brenner, W. (2018). Neue Formen der Wertschöpfung im digitalen Zeitalter. *Digitalisierung in Unternehmen* (pp. 27–45). Springer Vieweg, Wiesbaden. https://doi.org/10.1007/978-3-658-22773-9_3

Kleinaltenkamp, M., & Jacob, F. (2013). Grundlagen der Gestaltung des Leistungsprogramms. In: M. Kleinaltenkamp & W. Plinke (Eds.), *Technischer Vertrieb. Markt- und Produktmanagement: Die Instrumente des technischen Vertriebs* (1st ed.). Springer. https://doi.org/10.1007/978-3-642-58256-1_1

Kocak, S., & Pawlowski, J. (2021). A Qualitative Study on the Categorisation and Prioritisation of Digital Competencies and Attitudes for Managers and Employees. *International joint conference on knowledge discovery, knowledge engineering and knowledge management*. SCITEPRESS-Science and Technology Publications.

Köhler, R. (2000). Organisation des Produktmanagement. In: *Handbuch Produktmanagement* (pp. 683–704). Gabler Verlag, Wiesbaden.

Koppelmann, U. (2013). *Produktmarketing: Entscheidungsgrundlage für Produktmanager* (6th ed.). Springer.

Kotler, P. (1992). Marketing's new paradigms: What's really happening out there. *Planning review.*

Kotler, P., & Keller, K. L. (2016). Marketing Management. (3rd. ed.). Pearson

Kotler, P., Armstrong, G., Harris, L. C., & Piercy, N. (2019). *Grundlagen des Marketings* (7th ed.). Pearson.
https://elibrary.pearson.de/book/99.150005/9783863268503

Krüger, R. A. & Casey, M. A. (2015). *Focus groups: A practical guide for applied research* (5th edition). SAGE.

Krüger, W. (1994). Transformations-Management. In: *Unternehmerischer Wandel* (S. 199–228). Gabler Verlag. https://doi.org/10.1007/978-3-322-82548-3_8

Kuhn, T.S. (1962). *Historical Structure of Scientific Discovery: To the historian discovery is seldom a unit event attributable to some particular man, time, and place*.
https://www.science.org/doi/pdf/10.1126/science.136.3518.760?casa_token=hc6swarkf6eaaaaa:r_lzs2msmcszjv_dq8jmabtmglvjvcpvlnbs1relxaaksi9k5y2u_-qsw_gloqy71xlhxc4zhxszkhcc

Lambert, S. D. & Loiselle, C. G. (2008). Combining individual interviews and focus groups to enhance data richness. *Journal of Advanced Nursing*, *62*(2), 228–237. https://doi.org/10.1111/j.1365-2648.2007.04559.x

Lamnek, S. (2000). Sozialforschung in Theorie und Praxis. Zum Verhältnis von qualitativer und quantitativer Forschung. In: *Empirische Sozialforschung und gesellschaftliche Praxis* (S. 23–46). VS Verlag für Sozialwissenschaften, Wiesbaden. https://doi.org/10.1007/978-3-322-97475-4_2

Langley, A., & Royer, I. (2006). Perspectives on Doing Case Study Research in Organizations. *M@n@gement*, *9*(3), 81–94. https://www.cairn.info/revue-management-2006-3-page-81.htm

Le, H. V. (2020). *Valuing Teachers' Flexibility, Resourcefulness and Proactivity in Processes of Educational Change: Investigating Teachers' Use of Information and Communication Technology in English Language Teaching in Secondary Schools in Ben Tre Province, Vietnam* (Doctoral dissertation, University of Gloucestershire).

Lehtonen, T., et al. (2018). Complexity in the development of digital-physical systems. *IEEE Access, 6.* 34414-34426.

Leng, J., Ruan, G., Jiang, P., Xu, K., Liu, Q., Zhou, X., & Liu, C. (2020). Blockchain-empowered sustainable manufacturing and product lifecycle management in industry 4.0: A survey. *Renewable and sustainable energy reviews*, *132*, 110112.

Lerch, C., & Gotsch, M. (2015). Digitalized Product-Service Systems in Manufacturing Firms: A Case Study Analysis. *Research-Technology Management*, *58*(5), 45–52. https://doi.org/10.5437/08956308X5805357

Levac, D., Colquhoun, H., & O'Brien, K. K. (2010). Scoping studies: advancing the methodology. *Implementation science*, *5*, 1-9.

Lincoln, Y. S. & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publication.

Littig, B., & Wallace, C. (1997). *Möglichkeiten und Grenzen von Fokus-Gruppendiskussionen für die sozialwissenschaftliche Forschung*. https://www.ssoar.info/ssoar/handle/document/22202

Little, A. D. (1986). *Management im Zeitalter der strategischen Führung* (2nd edition). Gabler Verlag, Wiesbaden.

Liu, C., & Yan, X. (2018). Digital-Physical Convergence in Railway Systems: Current Trends and Future Directions. In: *Transportation Research Part C: Emerging Technologies*, *89*, 221-240

Lühring, N. (2007). Innovationsfördernde Organisationsstrukturen unter Berücksichtigung früher Innovationsphasen. In: *Management der frühen Innovationsphasen* (pp. 135–164). Gabler. https://doi.org/10.1007/978-3-8349-9293-2_7

Majumdar, R. (2008). *Product management in India* (3rd. ed.). Prentice-Hall of India.

Malterud, K. (2001). The art and science of clinical knowledge: evidence beyond measures and numbers. *The Lancet*, *358*(9279), 397–400. https://doi.org/10.1016/s0140-6736(01)05548-9

Mangram, M. E. (2012). The globalization of Tesla Motors: a strategic marketing plan analysis. *Journal of Strategic Marketing*, *20*(4), 289-312.

Mason, J. (2002). *Researching your own practice: The discipline of noticing*. RoutledgeFalmer. https://www.taylorfrancis.com/books/mono/10.4324/9780203471876/researching-practice-john-mason https://doi.org/10.4324/9780203471876

Matys, E. (2018). *Praxishandbuch Produktmanagement: Grundlagen und Instrumente* (7th. ed.). *Business 2018*. Campus Verlag. http://www.content-select.com/index.php?id=bib_view&ean=9783593438115

Mayring, P. (2015). Qualitative content analysis: Theoretical background and procedures. *Approaches to qualitative research in mathematics education: Examples of methodology and methods*, 365-380.

McAllister, M., Withyman, C., & Knight, B. A. (2018). Facilitation as a vital skill in mental health promotion: Findings from a mixed methods evaluation. *The Journal of Mental Health Training, Education and Practice*, *13*(4), 238–247. https://doi.org/10.1108/JMHTEP-05-2017-0036

Meffert, H. (1999). Globalisierungsstrategien und ihre Umsetzung im internationalen Wettbewerb. In: *Marktorientierte Unternehmensführung im Wandel* (pp. 383-410). Gabler Verlag.

Mertens, P. & Benlian A. (2016). Digital Transformation in the Automotive Industry: A Case Study of BMW**.** *Journal of Information Technology Case and Application Research.*

Meserve, W. (1989). The Changing Role of Product Management. In: *Electronic Business* (1989; Vol. 15, No.1, pp. 143-145.).

Meuser, M. & Nagel, U. (2009). Das Experteninterview — konzeptionelle Grundlagen und methodische Anlage. In: *Methoden der vergleichenden Politik- und Sozialwissenschaft* (S. 465–479). VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-91826-6_23

Mey, G. & Mruck, K. (2010). *Handbuch Qualitative Forschung in der Psychologie.* (2010). VS Verlag für Sozialwissenschaften.

Meyer, D. L. (2009). The Poverty of Constructivism. *Educational Philosophy and Theory*, *41*(3), 332–341. https://doi.org/10.1111/j.1469-5812.2008.00457.x

Miles, M.B. & Huberman, A. (1994). *An expanded sourcebook: Qualitative data analysis.* (2nd ed.). London. Sage Publications Ltd.

Moon, K. & Blackman, D. (2014). A guide to understanding social science research for natural scientists. *Conservation biology: the journal of the Society for Conservation Biology*, *28*(5), 1167–1177. https://doi.org/10.1111/cobi.12326

Moreno-Mendoza, H., Santana-Talavera, A., & J. León, C. (2019). Stakeholders of Cultural Heritage as Responsible Institutional Tourism Product Management Agents. *Sustainability*, *11*(19), 5192. https://doi.org/10.3390/su11195192

Morgan, D. (1997). *Focus Groups as Qualitative Research*. London. Sage Publication.

Morse, J. M. (2003). A review committee's guide for evaluating qualitative proposals. *Qualitative Health Research*, *13*(6), 833–851. https://doi.org/10.1177/1049732303013006005

Mühlhäuser, M. (2008). Smart products: An introduction. In *Constructing Ambient Intelligence: AmI 2007 Workshops Darmstadt, Germany, November 7-10, 2007 Revised Papers* (pp. 158-164). Springer Berlin Heidelberg.

Müller, D. (2013). *Betriebswirtschaftslehre für Ingenieure*. Berlin: Springer Gabler.

Müller, D., & Müller, D. (2020). Merkmale von Unternehmen, Akteuren und Produkten. *Betriebswirtschaftslehre für Ingenieure, 1*(57).

Multerer, N. (2019). *Change-Management zur Digitalisierung der Unternehmens-funktion Beschaffung* [University of Graz, Graz]. RIS. https://unipub.uni-graz.at/obvugrhs/content/titleinfo/4515634/full.pdf

Nair, H. S. (2019). Diffusion and pricing over the product life cycle. *Handbook of the Economics of Marketing*, *1*, 359–439. https://doi.org/10.1016/bs.hem.2019.05.001

Namatherdhala, B., Mazher, N., & Sriram, G. K. (2022). Artificial Intelligence in Product Management: Systematic review. *International Research Journal of Modernization in Engineering Technology and Science*, *4*(7).

Nascimento, D. L. M., Alencastro, V., Quelhas, O. L. G., Caiado, R. G. G., Garza-Reyes, J. A., Rocha-Lona, L., & Tortorella, G. (2019). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of Manufacturing Technology Management*, *30*(3), 607-627.

Neumann, L., & Krippendorf, W. (2016). *Branchenanalyse Bahnindustrie: Industrielle und betriebliche Herausforderungen und Entwicklungskorridore* (Study der Hans-Böckler-Stiftung No. 331). Düsseldorf: Hans-Böckler-Stiftung. https://www.econstor.eu/handle/10419/146408

Novales, A., Mocker, M., & Simonovich, D. (2016). IT-enriched" digitized" products: building blocks and challenges. In: *Proceedings of the 22nd Americas.* https://scholar.archive.org/work/cdnnovqc5jhblgw7z42cx3zcbu/access/wayback/https://aisel.aisnet.org/cgi/viewcontent.cgi?referer=&httpsredir=1&article=1540&context=amcis2016

Novales, A., Mocker, M., & van Heck, E. (2019). *Producer-side Use Cases of Digitized Products: What's Best for Your Company?* https://repub.eur.nl/pub/124949/

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International journal of qualitative methods*, *16*(1), 1609406917733847.

Olsen, D. (2015). *The lean product playbook: How to innovate with minimum viable products and rapid customer feedback*. John Wiley & Sons.

Onwuegbuzie, A. J., Johnson, R. B. & Collins, K. M. (2009). Call for mixed analysis: A philosophical framework for combining qualitative and quantitative approaches. *International Journal of Multiple Research Approaches*, *3*(2), 114–139. https://doi.org/10.5172/mra.3.2.114

Osterwalder, A., Pigneur, Y., Bernarda, G., & Smith, A. (2014). *Value Proposition Design: How to Create Products and Services Customers Want.* Wiley.

Pant, S. (2022). *Home is where the Heart is? Experiences, Expectations and Struggles of Highly Qualified Female Love Migrants* (Doctoral dissertation).

Patton, A. J. (2001). *Modelling Time-Varying Exchange Rate Dependence using the Conditional Copula.* https://doi.org/10.2139/ssrn.275591

Patton, D., & Deshler, W. (1959). International Fellowships and Research Grants. *The Professional Geographer*, *11*(6), 21. https://doi.org/10.1111/j.0033-0124.1959.116_21.x

Patton, M. Q. (2002). Two decades of developments in qualitative inquiry: A personal, experiential perspective. *Qualitative social work*, *1*(3), 261-283.

Pfäfflin, H., Biehler, H., Schwarz-Kocher, M., & Krzywdzinski, M. (2019). Zentrale Entwicklungstrends in der Automobilindustrie. In *Standortperspektiven in der Automobilzulieferindustrie: Die Situation in Deutschland und Mittelosteuropa unter dem Druck veränderter globaler Wertschöpfungsstrukturen* (pp. 21-39). Düsseldorf: Hans-Böckler-Stiftung.

Pichler, R. (2014). *Agile Produktmanagement mit Scrum: Erfolgreich als Product Owner arbeiten* (2nd. ed.). dpunkt.verlag.

Pichler, R. (2022). *Strategize: Product Strategy and Product Roadmap Practices for the Digital Age*. Pichler Consulting.

Pieriegud, J. (2018). Digital Transformation of Railways. *Siemens Sp. z o.o., Poland.* https://rail-research.europa.eu/wp-content/uploads/2018/04/DIGITAL_TRANSFORMATION_RAILWAYS_2018_web.pdf

Piller, F. T. (2000). Mass Customization. In: *Handbuch Produktmanagement* (pp. 883–907). Gabler Verlag. https://doi.org/10.1007/978-3-663-05717-8_37

Pine, G. J. (2008). *Teacher action research: Building knowledge democracies*. Sage.

Plass, C. (2020). Wie digitale Geschäftsprozesse und Geschäftsmodelle die Arbeitswelt verändern. In: *Handbuch Gestaltung digitaler und vernetzter Arbeitswelten (pp. 59-85).* Springer Berlin Heidelberg.

Polkinghorne, D. E. (1988). *Narrative knowing and the human sciences*. *SUNY series in philosophy of the social sciences*. State Univ. of New York Press.

Porter, M. E. (2013). *Wettbewerbsstrategie: Methoden zur Analyse von Branchen und Konkurrenten = Competitive strategy* (12th ed.). Campus-Verlag.

Porter, M., & Heppelmann, J. (2014). How smart, connected products are transforming competition. *Harvard Business Review* 92(11), 64–88.

Porter, M. E., & Heppelmann, J. E. (2015). How smart, connected products are transforming companies. *Harvard business review*, *93*(10), 96-114.

Pratt, M. G. (2009). From the editors: For the lack of a boilerplate: Tips on writing up (and reviewing) qualitative research. *Academy of management journal*, *52*(5), 856-862.

Prickarz, H., & Urbahn, J. (2002). Qualitative Datenerhebung mit Online-Fokusgruppen. *Planung & Analyse*, *28*(1), 63-70.

Przyborski, A. & Riegler, J. (2010). Gruppendiskussion und Fokusgruppe. In: *Handbuch Qualitative Forschung in der Psychologie* (S. 436–448). VS Verlag für Sozialwissenschaften. https://doi.org/10.1007/978-3-531-92052-8_31

Püschel, L., Röglinger, M., & Schlott, H. (2016). What's in a Smart Thing? Development of a Multi-Layer Taxonomy. In: *Thirty Seventh International Conference on Information Systems, Dublin 2016*. https://fim-rc.de/Paperbibliothek/Veroeffentlicht/571/wi-571.pdf

Rajagopaul, A. (2022). *The role and value of special library services in the information age: a case study of the South African Broadcasting Corporation (SABC)* (Doctoral dissertation).

Raubold, U. (2011). Lebenszyklusmanagement in der Automobilindustrie. In: *Lebenszyklusmanagement in der Automobilindustrie* (pp. 41–60). Gabler. https://doi.org/10.1007/978-3-8349-6613-1_3

Reason, P. & Bradbury, H. (2001). *Handbook of action research: Participative inquiry and practice* (1st ed.). Sage Publication.

Reber, M. (2016). *A Study of Cultural Influence on the Valuation of Patents* (Doctoral dissertation, University).

Reichart, S. V., & Reichart, S. V. (2002). Begriffe und Konzepte. *Kundenorientierung im Innovationsprozess: Die erfolgreiche Integration von Kunden in den frühen Phasen der Produktentwicklung*, 10-26. Wiesbaden.

Reichertz, J. (2022). Empirische Sozialforschung und soziologische Theorie. In: *Handbuch Methoden der empirischen Sozialforschung* (pp. 69–86). Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-37985-8_4

Rizvi, S. T. A., Ahmed, S., Bhattacharya, A., & Mukhopadhyay, S. C. (2018). A framework for managing digital physical products in industry 4.0. *Proceedings of the International Conference on Industrial Engineering and Operations Management (IEOM)*.

Röcker, J., & Mocker, M. (2018). *Digital-physische Produkte: Stand und Herausforderungen beim Einsatz von IT in physischen Produkten in der Kreativwirtschaft.-(Berichte aus dem Karl-Steinbuch-Forschungsprogramm; Nr. 8)*. MFG Stiftung Baden-Württemberg.

Romero, D., Stahre, J., & Wuest, T. (2021). Digital thread and digital twin in the Industry 4.0 context: A systematic review. *Journal of Industrial Information Integration, 23*.

Romm, J. J. (2014). *Cool Companies: How the Best Businesses Boost Profits and Productivity by Cutting Greenhouse Gas Emmissions*. Routledge.

Rosenzweig, E. D., Roth, E. M., & Dean, D. L. (2013). Integrating Hardware and Software in New Product Development: Lessons from the EDA Industry. *Journal of Product Innovation Management, 30*(6).

Rowold, J. (2015). *Human Resource Management: Lehrbuch für Bachelor und Master*. Springer-Verlag.

Ruparelia, N. B. (2010). Software development lifecycle models. *ACM SIGSOFT Software Engineering Notes*, *35*(3), 8-13.

Sabou, M., Kantorovitch, J., Nikolov, A., Tokmakoff, A., Zhou, X., & Motta, E. (2009). Position paper on realizing smart products: challenges for Semantic Web technologies. *CEUR Workshop Proceedings*, *522*. http://oro.open.ac.uk/23449/

Sandelowski, M. (2004). Using qualitative research. *Qualitative Health Research*, *14*(10), 1366–1386. https://doi.org/10.1177/1049732304269672

Santiago, L. P., Martinelli, M., Eloi-Santos, D. T., & Hortac, L. H. (2015). A framework for assessing a portfolio of technologies for licensing out. *Technological Forecasting and Social Change*, *99*, 242-251.

Saunders, M., Lewis, P., & Thornhill, A. (2009). *Research methods for business students*. Pearson education.

Saunders, M., Lewis, P. & Thornhill, A. (2019). *Research methods for business students* (8th. ed.). Pearson.

Sawalsky, R. (2013). *Management und Controlling der Neuproduktentstehung: Gestaltungsansatz, Ziele und Maßnahmen*. *DUV: Wirtschaftswissenschaft*. Deutscher Universitätsverlag; Imprint.

Schäfer, T. (2006). *Marktorientierte Produktentwicklung und optimierte Time-to-Market durch den Einsatz eines Produkt-Information-Management-Systems (PIM) im Gerätebau* [Dissertation, University of Duisburg-Essen, Duisburg-Essen]. RIS. https://d-nb.info/98111976x/34

Schawel, C. & Billing, F. (2018). Produktlebenszyklus: (Problemanalysetools). *Top 100 Management Tools: Das wichtigste Buch eines Managers Von ABC-Analyse bis Zielvereinbarung*, 275-277.

Schell, R. (2020). *Exploring the digital transformation in the automotive industry to design an improved mobility service ecosystem for Mercedes-Benz* [Dissertation, University of Worcester, Worcester]. eprints.worc.ac.uk. http://eprints.worc.ac.uk/10323/

Schicker, G., & Strassl, J. (2019). *Produktportfolio-Management im Zeitalter der Digitalisierung*. *Weidener Diskussionspapiere: Nr. 69 (August 2019)*. Ostbayerische Technische Hochschule (OTH). https://www.oth-aw.de/files/oth-aw/Aktuelles/Veroeffentlichungen/WEN-Diskussionspapier/WEN-DPs-PDF/DP69.pdf

Schmuck, R. A. (2006). *Practical action research for change*. Corwin Press.

Schögel, M. & Tomczak, T. (2009). Fallstudie. In: *Empirische Mastertechniken* (S. 79–105). Gabler Verlag, Wiesbaden. https://doi.org/10.1007/978-3-8349-8278-0_3

Scholz, U., & Pastoors, S. (2018). Nachhaltige Produktentwicklung. In: *Praxishandbuch Nachhaltige Produktentwicklung* (pp. 63–77). Springer Gabler, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-57320-4_7

Schork, S. (2020). *Methodische Entwicklung aussagekräftiger Prototypen durch Analyse der Produktkonfigurationen* [Dissertation, Technical University Darmstadt, Darmstadt]. RIS. https://d-nb.info/122267422x/34

Schröder, M., & Wegner, K. (2019). *Logistik im Wandel der Zeit von der Produktionssteuerung zu vernetzten*. Gabler. https://doi.org/10.1007/978-3-658-25412-4

Schuh, G. (2011). *Handbuch Produktion und Management: Vol. 2*. *Technologiemanagement* (2nd ed.). Springer. https://doi.org/10.1007/978-3-642-12530-0

Schulz, M., Mack, B. & Renn, O. (2012). *Fokusgruppen in der empirischen Sozialwissenschaft: Von der Konzeption bis zur Auswertung*. Springer VS.

Sendler, U. (2013). *Industrie 4.0–Beherrschung der industriellen Komplexität mit SysLM (Systems lifecycle management)* (pp. 1-19). Springer Berlin Heidelberg.

Shah, M. A., Ahuja, V., & Saini, M. L. (2021). Analysis of Product Lifecycle Management in Railway Systems. *International Journal of Innovative Technology and Exploring Engineering (IJITEE),* 10(8), 374-381.

Shenton, A. K. (2004). Strategies for ensuring trustworthiness in qualitative research projects. *Education for Information*, *22*(2), 63–75. https://doi.org/10.3233/EFI-2004-22201

Shi, Y., Wang, W., & Hu, W. (2016). Wireless Sensor Networks for Railway Condition Monitoring: A Comprehensive Review. *IEEE Sensors Journal.*

Siedhoff, S. (2019). Design science research. In *Seizing Business Model Patterns for Disruptive Innovations* (S. 29–43). Springer Spektrum, Wiesbaden. https://doi.org/10.1007/978-3-658-26336-2_3

Siemens Mobility (2020). System description of Axle Counter ACM250. Siemens internal document.

Siemens Mobility (2021). Guide process rail infrastructure products. Siemens internal document.

Siemens Mobility (2022). Siemens official website. https:// www.mobility.siemens.com/global/en.html

Simons, H. (2013). *Case study research in practice*. SAGE Publications. https://doi.org/10.4135/9781446268322

Sims, N. H. (2006). *The complete guide to designing and running brilliant workshops and meetings: The Complete Guide to Designing and Running Brilliant Workshops and Meetings*. Pearson Education.

Sritanayarat, D., Kanjanajuta, C., & Tanawattanakorn, C. (2010). Positivism: To see, to hear, to taste, to smell and to touch, but not to feel. *Human Resource and Organization Development Journal*, *2*(2), 27-34.

Stake, R. E. (2010). *The art of case study research*. Sage Publication.

Stark, J. (2022). Product lifecycle management (PLM). In *Product Lifecycle Management (Volume 1) 21st Century Paradigm for Product Realisation* (pp. 1-32). Cham: Springer International Publishing.

Stauss, B. (2006). Grundlagen und Phasen der Kundenbeziehung: Der Kundenbeziehungs-Lebenszyklus. In *Grundlagen des CRM* (pp. 421-442). Gabler.

Stier, W. (1999). Auswahlverfahren. In: *Empirische Forschungsmethoden* (S. 113–160). Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-58460-2_5

Stone, M., Foss, B., Henderson, I., Irwin, D., O'Donnell, J., & Woodcock, N. (2003). The quality of customer information management in customer life cycle management. *Journal of Database Marketing & Customer Strategy Management*, *10*(3), 240–254. https://doi.org/10.1057/palgrave.jdm.3240113

Stotten, R., Maurer, M., Herrmann, H., & Schermer, M. (2019). Different forms of accommodation in agritourism: the role of decoupled farmer-based accommodation in the Ötztal Valley (Austria). *Sustainability*, *11*(10), 2841.

Subramoniam, R., Sundin, E., Subramoniam, S., & Huisingh, D. (2021). Riding the Digital Product Life Cycle Waves towards a Circular Economy. *Sustainability*, *13*(16), 8960. https://doi.org/10.3390/su13168960

Tao, F., Qi, Q., Wang, L., & Nee, A. Y. C. (2019). Digital twins and cyber–physical systems toward smart manufacturing and industry 4.0: Correlation and comparison. *Engineering*, *5*(4), 653-661.

Terry, G., Hayfield, N., Clarke, V., & Braun, V. (2017). Thematic analysis. *The SAGE handbook of qualitative research in psychology*, *2*, 17-37.

Thoben, K. D., Wiesner, S., & Wuest, T. (2017). "Industrie 4.0" and smart manufacturing-a review of research issues and application examples. *International journal of automation technology*, 11(1), 4-16.

Thomas, J. & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC Medical Research Methodology*, *8*(1), 45. https://doi.org/10.1186/1471-2288-8-45

Thommen, J.-P., Achleitner, A.-K., Gilbert, D. U., Hachmeister, D., Jarchow, S., & Kaiser, G. (2020). Produktpolitik. In: *Allgemeine Betriebswirtschaftslehre* (pp. 87–95). Springer Gabler, Wiesbaden. https://doi.org/10.1007/978-3-658-27246-3_6

Tkalich, A., Ulfsnes, R., & Moe, N. B. (2022). Toward an Agile Product Management: What Do Product Managers Do in Agile Companies?. In: *International Conference on Agile Software Development* (pp. 168-184). Springer, Cham.

Treusch, O. (2021). *Wie verändern smarte, konnektive Leistungen die Verhandlungsmacht der Kunden von Industriegüteranbietern? Eine empirische Untersuchung am Beispiel des Maschinen-und Anlagenbaus* (Doctoral dissertation, Universität Ulm).

Tuckett, A. G. (2005). Part II. Rigour in qualitative research: complexities and solutions. *Nurse researcher*, *13*(1).

Tukker, A. (2004). Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. *Business Strategy and the Environment*, *13*(4), 246–260. https://doi.org/10.1002/bse.414

Turner III, D. W. (2010). Qualitative interview design: A practical guide for novice investigators. *The qualitative report*, *15*(3).

Uhlemann, T. H. J., Lehmann, C., & Steinhilper, R. (2017). The digital twin: Realizing the cyber-physical production system for industry 4.0. *Procedia Cirp*, *61*, 335-340.

Utterback, J. M., & Abernathy, W. J. (1975). A dynamic model of process and product innovation. *Omega*, *3*(6), 639-656.

Vivar, C. G., McQueen, A., Whyte, D. A., & Armayor, N. C. (2007). Getting started with qualitative research: Developing a research proposal. *Nurse researcher*, *14*(3).

Vries, P., Béguin, P., de Waard, D., & de Reuver, M. (2021*).* Agile and lean development of digital-physical products: A systematic literature review. *Journal of Engineering and Technology Management, 62.*

Vogl, S. (2022). Gruppendiskussion. In *Handbuch Methoden der empirischen Sozialforschung* (pp. 913-919). Wiesbaden: Springer Fachmedien Wiesbaden.

Wagenblatt, T. (2019). Product Development. In: *Software Product Management* (pp. 227–314). Springer, Cham. https://doi.org/10.1007/978-3-030-19871-8_5

Wagner, F. (2017). *Gabler Versicherungslexikon* (2nd. ed.). Springer Gabler. https://doi.org/10.1007/978-3-8349-4625-6

Wagner, S., & Gassmann, O. (2019). The Rise of Siemens: A Case Study on the Role of Technological Leadership in Sustainable Development**.** *Journal of Technology Management & Innovation*

Wang, L., Liu, Z., Liu, A., & Tao, F. (2021). Artificial intelligence in product lifecycle management. *The International Journal of Advanced Manufacturing Technology*, *114*(3-4), 771–796. https://doi.org/10.1007/s00170-021-06882-1

Wang, Y., Li, K., Zhang, G., & Bai, Y. (2020). A Review on the Development of Digital-Physical Systems in Railways. *IEEE Access, 8.*

Warren, V. (2015). *Exploring Service Innovation Practices Through a Longitudinal Ethnographic Case Study* [Dissertation, University of Worcester, Worcester]. eprints.worc.ac.uk. https://eprints.worc.ac.uk/id/eprint/4530

Warren, V., & Bell, R. (2022). The Role of Context in Qualitative Case Study Research: Understanding Service Innovation. *SAGE Research Methods*.

Wassermann, S. (2015). Das qualitative Experteninterview. In: *Methoden der Experten- und Stakeholdereinbindung in der sozialwissenschaftlichen Forschung* (S. 51–67). Springer VS, Wiesbaden. https://doi.org/10.1007/978-3-658-01687-6_4

Whiting, L. S. (2008). Semi-structured interviews: guidance for novice researchers. *Nursing Standard (through 2013)*, *22*(23), 35.

Wichmann, O., Schimanski, S., Koch, J., Kohler, M., Rothe, C., Plentz, A., Jilg, W., & Stark, K. (2008). Phylogenetic and case-control study on hepatitis E virus infection in Germany. *The Journal of Infectious Diseases*, *198*(12), 1732–1741. https://doi.org/10.1086/593211

Willers, C. (2015). Integriertes Produktmanagement als Grundlage für „nachhaltige Produkte“. In *CSR und Produktmanagement* (pp. 49–68). Springer Gabler, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-45573-9_3

Wirtz, B. W., Schilke, O., & Ullrich, S. (2010). Strategic development of business models: implications of the Web 2.0 for creating value on the internet. *Long range planning*, *43*(2-3), 272-290.

Wuenderlich, N. V., Heinonen, K., Ostrom, A. L., Patricio, L., Sousa, R., Voss, C., & Lemmink, J. G. (2015). “Futurizing” smart service: implications for service researchers and managers. *Journal of Services Marketing*, *29*(6/7), 442–447. https://doi.org/10.1108/JSM-01-2015-0040

Yin, R. K. (1994). Discovering the future of the case study method in evaluation research. *Evaluation Practice*, *15*(3), 283–290. https://doi.org/10.1016/0886-1633(94)90023-x

Yin, R. K. (2009). *Case study research: Design and methods* (Vol. 5). sage.

Yoo, Y., Boland, R. J., Lyytinen, K., & Majchrzak, A. (2012). Organizing for Innovation in the Digitized World. *Organization Science*, *23*(5), 1398–1408. https://doi.org/10.1287/orsc.1120.0771

Yoo, Y., Henfridsson, O., & Lyytinen, K. (2010). Research Commentary —The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research. *Information Systems Research*, *21*(4), 724–735. https://doi.org/10.1287/isre.1100.0322

Yoon, S., & Jeong, S. (2017). Convergence of physical and digital product in design: Characteristics and design factors. *International Journal of Design, 11*(2), 55-66

Yousefnezhad, N., Malhi, A., & Främling, K. (2020). Security in product lifecycle of IoT devices: A survey. *Journal of Network and Computer Applications, 171*, 102779.

Zampino, M., Di Giuseppe, E., & Gatta, V. (2017). Technology Life Cycle in the Railway Sector: A Case Study on Signaling and Train Control Systems. *Journal of Traffic and Transportation Engineering, 4*(6).

Zamawe, F. C. (2015). The Implication of Using NVivo Software in Qualitative Data Analysis: Evidence-Based Reflections. *Malawi medical journal: the journal of Medical Association of Malawi*, *27*(1), 13–15. https://doi.org/10.4314/mmj.v27i1.4

Zhang, Y., & Luo, Y. (2018). Software Updates and Maintenance for Digital-Physical Products: Challenges and Strategies. *International Journal of Production Economics, 197*, 112-122.

Zheng, P., Wang, Z., Chen, C.-H., & Pheng Khoo, L. (2019). A survey of smart product-service systems: Key aspects, challenges and future perspectives. *Advanced Engineering Informatics*, *42*, 100973. https://doi.org/10.1016/j.aei.2019.100973

Zeng, Y., Lu, Y., Wang, L., & Li, H. (2020). A holistic framework for managing digital-physical products in the Internet of Things era. *International Journal of Production Research, 58*(14).

8 Appendix

8.1 Appendix A: Overview of the literature

<u>Overview of the literature used for the discussion sections within the literature review:</u>

Digital-physical products:

No.	Title	Author & Year	Source
Literature research on digital-physical products			
1	The Internet of Things Vision: Key Features, Applications and Open Issues	Borgia, E. (2014)	Computer communications
2	Digital Ubiquity: How Connec tions, Sensors, and Data Are Revolutionizing Business	Iansiti, M., & Lakhani, K.R. (2014)	Harvard Business Review
3	Digitalized Product-Service Systems in Manufacturing Firms a Case Study Analysis	Lerch, C., & Gotsch, M. (2015)	Research-Technology Management
4	Smart Products: An Introduction	Mühlhäuser, M. (2008)	Google Scholar
5	Position Paper on Realizing Smart Products: Challenges for Semantic Web Technologies	Sabou, M.,et al. (2009)	Google Scholar
7	Futurizing" Smart Service: Implications for Service Researchers and Managers	Wunderlich, N.V., et al. (2015)	Journal of Services Marketing
8	The New Organizing Logic of Digital Innovation: An Agenda for Information Systems Research	Yoo, Y., Henfridsson, O., & Lyytinen, K. (2010)	Information Systems Research
9	How Smart Connected Products are Transforming Companies	Porter, M., & Heppelmann, J. (2015)	Harvard Business Review
10	How Smart, Connected Products Are Transforming Competition	Porter, M., & Heppelmann, J. (2014)	Harvard Business Review
11	Digital-physische Produkte Stand und Herausforderungen beim Einsatz von IT in physischen Produkten in der Kreativwirtschaft	Roecker J. & Mocker M. (2018)	Google Scholar
12	Software Updates and Maintenance for Digital-Physical Products: Challenges and Strategies	Zhang, Y., & Luo, Y. (2018)	International Journal of Production Economics
13	A framework for managing digital physical products in industry 4.0	Rizvi, S. T. A., et al. (2018)	Proceedings of the International Conference on Industrial Engineering and Operations Management (IEOM)
14	Agile and lean development of digital-physical products: A systematic literature review	De Vries, P., et al. (2021)	Journal of Engineering and Technology Management
15	Digital-physical product development: a review and research agenda.	Hendler, S., & Boer, H. (2019)	Google Scholar
16	Conceptual design framework for hybrid products: A combination of digital and physical artifacts	Huh, J. H., Lee, S., & Seo, K. (2018)	Design Science
17	Challenging the notion of smart products: Key areas for exploration and research	El-Gayar, O. F., Moran, M., & Hawkes, M. (2020)	International Journal of Information Management
18	Convergence of physical and digital product in design: Characteristics and design factors	Yoon, S., & Jeong, S. (2017)	International Journal of Design
19	A holistic framework for managing digital-physical products in the Internet of Things era.	Zeng, Y., Lu, Y., Wang, L., & Li, H. (2020)	International Journal of Production Research
20	Producer-side Use Cases of Digitized Products: What's Best for Your Company?	Novales, A., Mocker, M., & van Heck, E. (2019)	Google Scholar
21	IT-enriched" digitized" products: building blocks and challenges	Novales, A., Mocker, M., & Simonovich, D. (2016)	Google Scholar

Product Management:

No.	Title	Author & Year	Source
Literature research on product management			
22	Railway Engineering: The Ultimate Guide for Beginners	Chandra, S. (2019)	Library
23	Inspired: How to Create Tech Products Customers Love.	Cagan, M. (2017)	Wiley library (Online)
24	The Lean Product Playbook: How to Innovate with Minimum Viable Products and Rapid Customer Feedback.	Olsen, E. (2017).	Wiley library (Online)
25	The Role of the Chief Product Officer in the Software Industry: An Exploratory Study	Cloutier, M. S., & Paré, G. (2013)	Journal of Product Innovation Management
26	Software-Produktmanagement	Fricker, 2012	Google Scholar
27	Digitales Produktmanagement	Hoffmann, S. (2020)	Google Scholar
28	Toward an Agile Product Management: What Do Product Managers Do in Agile Companies?	Tkalich et al. 2022	Google Scholar
29	Artificial Intelligence in Product Management: Systematic review.	Namatherdhala et al. (2022)	International Research Journal of Modernization in Engineering Technology and Science
30	Agiles Produktmanagement mit Scrum: Erfolgreich als Product Owner arbeiten	Pichler, R. (2014)	Google Scholar
31	Product lifecycle management (PLM)	Stark, J. (2022)	Google Scholar
32	Erfolgreiches Produktmanagement: Tool-Box für das professionelle Produktmanagement und Produktmarketing	Aumayr, K. (2019)	Library
33	Produkt-und Servicemanagement: Konzepte, Prozesse, Methoden	Bruhn, M., & Hadwich, K. (2017)	Library
34	Industrie 4.0 und resultierende Anforderungen an das Produktmanagement: Theorie und Empirie.	Gentner, D., & Oßwald, M. (2017)	Google Scholar
35	Studie „Future PLM". Product Lifecycle Management in der digitalen Zukunft - Wegbereiter für IoT, Industrie 4.0 und Digital Twin. BearingPoint.	Bahrenburg, S., Munk, S., Fischer, J., Rützel, H., Fuchs, B. (2019)	Google Scholar
36	A Scrum-based framework for new product development in the non-software industry	Cano, E. L., García-Camús, J. M., Garzás, J., Moguerza, J. M., & Sánchez, N. N.	Journal of engineering and technology management
37	Organizing for Product Management Excellence	Gopinath, S., & Kishore, S. (2017)	Journal of Product Innovation Management
38	Zentrale Zielsetzung und Rahmenbedingungen im Produktmanagement	Keite, L. (2022)	Google Scholar
39	Value Proposition Design: How to Create Products and Services Customers Want	Osterwalder, A., Pigneur, Y., Bernarda, G., & Smith, A. (2014)	Wiley library (Online)
40	Wie digitale Geschäftsprozesse und Geschäftsmodelle die Arbeitswelt verändern	Plass, C. (2020)	Google Scholar

Product Life Cycle:

No.	Title	Author & Year	Source
Literature research on product life cycle			
41	Analysis of Product Lifecycle Management in Railway Systems	Shah, M. A., Ahuja, V., & Saini, M. L. (2021)	Journal of Innovative Technology and Exploring Engineering (IJITEE)
42	Asset Management: A Key Enabler for Railway Infrastructure	Ansell, A., Froyland, T., & Rovida, F. (2019)	Google Scholar
43	Technology Life Cycle in the Railway Sector: A Case Study on Signaling and Train Control Systems.	Zampino, M., Di Giuseppe, E., & Gatta, V. (2017)	Journal of Traffic and Transportation Engineering
44	Managing Agile Open-Innovation Ecosystems: Roles of Project Managers and Core Team Leaders in Digital Transformation	Ghasemzadeh, F., & Archer, N. (2019)	Project Management Journal
45	Diffusion and pricing over the product life cycle.	Nair, H. S. (2019)	Google Scholar
46	Software Updates and Maintenance for Digital-Physical Products: Challenges and Strategies	Zhang, Y., & Luo, Y. (2018)	Journal of Production Economics
47	Security in product lifecycle of IoT devices: A survey.	Yousefnezhad, N., Malhi, A., & Främling, K. (2020)	Journal of Network and Computer Applications
48	Supply Chain Management of Digital-Physical Products: Challenges, Opportunities, and Research Directions	Khan, F. U., & Hafeez, S. (2020)	Journal of Information Management
49	Nachhaltiges Produktmanagement: Wie Sie Nachhaltigkeitsaspekte ins Produktmanagement integrieren können	Biermann, B., & Erne, R. (2020)	Google Scholar
50	Logistik im Wandel der Zeit-Von der Produktionssteuerung zu vernetzten Supply Chains	Drechsler, S., Knieps, L., & Lasch, R. (2019)	Google Scholar
51	Product life cycle: the evolution of a paradigm and literature review from 1950-2009	Cao, H., & Folan, P. (2012)	Google Scholar
52	Supply Management Research: Aktuelle Forschungsergebnisse	Keller, J., & Lasch, R. (2020)	Google Scholar
53	Integrating Hardware and Software in New Product Development: Lessons from the EDA Industry	Rosenzweig, E. D., Roth, E. M., & Dean, D. L. (2013	Journal of Product Innovation Management
54	Social Media Marketing: A Literature Review and Implications	Dwivedi, Y. K., Rana, N. P., Jeyaraj, A., Clement, M., & Williams, M. D. (2019)	Google Scholar
55	Strategic Development of Business Models: Implications of the Web 2.0 for Creating Value on the Internet	Wirtz, B. W., Schilke, O., & Ullrich, S. (2010)	Google Scholar
56	Studie „Future PLM". Product Lifecycle Management in der digitalen Zukunft - Wegbereiter für IoT, Industrie 4.0 und Digital Twin. BearingPoint.	Bahrenburg, S., Munk, S., Fischer, J., Rützel, H., Fuchs, B. (2019	Google Scholar
57	Produkt-und Servicemanagement: Konzepte, Prozesse, Methoden	Bruhn, M., & Hadwich, K. (2017)	Library

8.2 Appendix B: Thematic Analysis - Code Framework

The influence of digital-physical products in the context of the railway industry:

Thematic Analysis - Code Framework			
Theme	**Code**	**Definition**	**Example quote**
Relevance of digital-physical products within the rail industry	Relevance -1	Digital-physical products represent an intermediate step	It's an evolution for me. A sliding step, so to speak, and in the end it is, the relevance will increase.
	Relevance -2	Despite relevance; slow introduction of these products	Think of the example of the ETCS system [...]. Our constraints will prevent the rapid introduction of these value-added products.
	Relevance -3	Enabling digital possibilities	The relevance will increase in the next 5 years as, according to my interpretation, digital services can become enabled.
Basic requirements for digital-physical products	Basic R -1	Cloud based application	Cloud based is core of digital-physical products […]. Without that you can't use their advantages.
	Basic R -2	Edge Computing	The software complexity becomes bigger and bigger because we have more requirements and we have to constantly patch. Edge computing on all these connectivity layer needs to be included on the physical asset.
	Basic R -3	Cyber security	The capability of IT security must be present in every newly developed product. Whether it is used or not is an open question. But with our lifecycles, it has to be there from the beginning.
	Basic R -4	Monitoring function, diagnostic function & predictive Maintenance	There are three requirements that first of all do not exist in a mechanical product or do not exist in an electronic product. There is a monitoring function, a diagnosis function and a prediction, the prediction. Digital-physical products can cover all three requirements
	Basic R -5	Augmented Reality	For me, augmented reality is not a requirement for tomorrow's products, rather a nice gimmick. The maintainer has to go out anyway and usually the staff is always trained
	Basic R -6	Archivsystem	The use of the archive system helps us to improve our products in the long term, as it stores error events over a certain period of time.
	Basic R -7	Remote Software Update	This function would relieve us as a manufacturer enormously as well as the operator. With the help of the function, the running operation does not have to be disturbed and we save an enormous amount of costs, as no one has to physically stand in front of it anymore.
Economic significance of digital-physical products	Economic -1	Digital-physical products as growth market	This is just the beginning [...] many possibilities will be enabled so that the market for these products will be bigger from year to year.
	Economic -2	Product price increase through digital-physical products	Benefits must be integrated and the product price raised. Otherwise we start pricing every feature and after a few years you won't be able to manage it.
Added value of digital-physical products in the market phase	Value -1	Added value for the operator	[...] leads to a reduction in LCC through improved maintenance.
	Value -2	Added value for the manufacturer	Digital-physical products will extend the value proposition of the physical product".

Changes in product life cycle:

Change in the lifetime	Change PLC -1	Extension of the product life cycle	You can extend the duration of a product in the field through the optimal maintenance concepts brought about by the new possibilities
	Change PLC -2	Technical barriers	Electronic components have a certain service life from a technical point of view - this is prescribed
A cycle in a cycle	New cycle -1	A second cycle due to different stakeholders caused by demographic change	The digital aspect of it keeps undergoing revolutionary changes again and again. It would be a cycle within a cycle for sure because the development never ceases
	New cycle -2	Software cycle	The new cycle would be very similar to the software cycle, because we already use this for digital products.
	New cycle -3	Interplay between the cycles	Due to the exponentially increasing requirements, a specific software cycle should be introduced in every single phase of the hardware cycle
	New cycle -4	Phases of the product life cycle model	The basic phases of the product life cycle would not change, as the hardware part is still considered the superior cycle and sets the pace

Changes in product management:

Influence on product manager	Influence PLM -1	Increased effort	The product manager would suddenly have to manage two cycles. This would lead to an enormous effort
	Influence PLM -2	Division of PLM activities	If we want to keep doing that in the digital ecosystem and so on, you need a person that really understands and is able to sell the complete thing
	Influence PLM -3	Product Manager Digital	[…] PLM-D would be responsible for the technical and digital part of the product
	Influence PLM -4	Outsourcing of digital activities	we don't always have to do everything ourselves in-house […]. We could also just outsource the support for the digital part
Effects on the product management	Effects on PM -1	Overall management of the activities	There must be a higher hand over it that monitors everything digitally so that we don't develop everything twice.
	Effects on PM -2	Digital aspects close to the products	In this way, each product can decide individually to what extent it wants to integrate the digital part and is not subject to any external constraint"
	Effects on PM -3	Single Sources	We are already seeing that our single sources are actually no longer available.

8.3 Appendix C: Participant information sheet on example of interview participants

University of Worcester

Version: 7

Date: February, 12th 2022

PARTICIPANT INFORMATION SHEET AND PRIVACY NOTICE

TITLE OF PROJECT:

Customizing the product lifecycle for digital-physical products in the railway industry

Invitation

The University of Worcester engages in a wide range of research which seeks to provide greater understanding of the world around us, to contribute to improved human health and well-being and to provide answers to social, economic and environmental problems.

We would like to invite you to take part in one of our research projects. Before you decide whether to take part, it is important that you understand why the research is being done, what it will involve for you, what information we will ask from you, and what we will do with that information.

We will in the course of this project be collecting personal information. The UK continues to be bound by the provisions of the General Data Protection Regulation which is now the "UK GDPR" Under UK GDPR we are required to provide a justification (what is called a "legal basis") in order to collect such information. The legal basis for this project is "**task carried out in the public interest**".

You can find out more about our approach to dealing with your personal information at https://www.worcester.ac.uk/informationassurance/visitor-privacy-notice.html.

Please take time to read this document carefully.

What is the purpose of the research?

This study aims to explore the influence of digital-physical products on the traditional product lifecycle model. Specifically, the product lifecycle model within Siemens Mobility will be further developed to reflect the requirements of digital-physical products. In this way, recommendations can be given for the management of digital-physical products in the individual phases of the product lifecycle. In addition, the effects of the change in the product lifecycle model will be examined on the existing product management of Siemens Mobility. The study will thus make an important contribution to the currently discussed digital product management and improve the current academic debate in this research area.

Who is undertaking the research?

Name: Vikrant Rampal

Position/ Role: Researcher in the Doctor of Business Administration (DBA) program

Who has oversight of the research?

The research has been approved by the Research Ethics Panel for the College of Business, Psychology and Sport in line with the University's Research Ethics Policy. The University of Worcester acts as the "Data Controller" for personal data collected through its research projects and is subject to the UK GDPR and the Data Protection Act 2018. We are registered with the Information Commissioner's Office and our Data Protection Officer is Helen Johnstone (infoassurance@worc.ac.uk). For more on our approach to Information Assurance and Security visit:

https://www.worcester.ac.uk/informationassurance/index.html.

Why have I been invited to take part?

You have received this invitation because you are an expert at Siemens Mobility GmbH and you are having specific knowledge to the interface between digital-physical products and the product lifecycle. We are hoping to recruit 15 experts for this study.

How do I take part?

It is up to you to decide whether or not you want to take part in this study. Please take your time to decide and talk to others about it if you wish. Deciding to take part or not will not impact on your workplace, the organisation, your daily work, or anything else. The process by which you can agree to participate is to e-mail me (the researcher) within the next 14 days that you are interested in the study. If you do decide to take part, at the data collection stage, you will be asked to sign a consent form.

How can I withdraw from this study after agreeing to participate?

Once you have agreed to participate you can withdraw from the study anytime until 14 days following data collection. If you wish to have your data withdrawn please contact us (our contact details are given below). With the help of your name, I can assign the content and data you have mentioned and will accordingly not further consider and remove them.

What will happen if I agree to take part?

If you agree to take part, you will be offered the opportunity to arrange an appointment (phone or video call) with the researcher before you sign the informed consent and the data collection phase. The appointment gives you the chance to ask questions to clarify things mentioned in this document or also to address worries. As soon as you feel ready and comfortable to participate in the study, you will be asked to send the signed consent form to my academic email address. I will keep the signed consent form in a folder that I have password protected. I would very much like you to send me the signed consent form, as only then can we proceed with the next steps. If you do not need a call prior to the data collection event, you will be asked to send me the signed informed consent form right after you have agreed to take part in the study. To keep your identity confidential, the researcher will use a participant number. As mentioned, you will find your participant number on the informed consent document.

After receiving your signed informed consent form, I will contact you to schedule an appointment for the expert interview. The interview will be conducted using a video conferencing tool. The interview will occupy between 30 and 45 minutes. In sum the interview will not take more than 60 minutes. The questions during the interview can be roughly divided into three parts. The first part is about questions regarding digital-physical products, for example, how do you define digital-physical products for yourself; what relevance do you assign to this kind of products etc.? The second part asks about the impact of digital-physical products on the traditional product lifecycle and the third part asks about the impact on product management. These are questions such as whether and how the product lifecycle has to change when considering digital-physical products or whether product management in its current arrangement is optimally positioned for managing digital-physical products. In all probability, one interview will be sufficient to gain the data needed. However, it can come to the situation that you need more time to set your reflection process in progress for answering the questions. In this case we would arrange a second appointment to proceed with the interview. After the data collection phase, you might be asked to review interpretations that I make during the data analysis phase if I see the need for accuracy/clarification. The study aims to collect data by the means of semi-structured interviews. The interview will be conducted by the researcher.

A prepared interview schedule with predefined topic areas and related questions will guide the conversation but will be used in a flexible manner.

The study requires an audio record of the interview and a transcript of all the spoken words of the interview participants. In view of this, it is necessary that the whole conversation has to be audio recorded. The interview will only be audio-recorded and not video-recorded. The researcher will also take some handwritten notes during the interview. Afterwards the audio recorded data will be transcribed (representation of spoken language in written form). Your name, names of persons or organizations will be anonymized in the transcript. Finally, the transcript will be analysed. The gained recorded data will be exclusively used for the research. The recorded and processed (transcribed) data will be stored securely and safely in a password protected space on the University drive that will be only accessible by the researcher. The audio recordings will be kept until the data have been transcribed and analysed. Afterwards the recordings will be deleted. The transcripts will be deleted after the completion of the dissertation. Notes that will be taken during the interviews will be stored securely in the researchers' safe at home. After the completion of the dissertation, these notes will be shredded.

What are the benefits for me in taking part?

You will get access to my thesis and the results will be made available to all participants to support the optimal use of digital-physical products in every phase of the product lifecycle model. Additionally, if you wish, I will share my personal findings in a face-to-face/ virtual meeting with you as soon as the thesis is published.

Are there any risks for me if I take part?

The research does not pose any immediate potential risks. Since all data will be anonymized and all Covid-19 regulations will be in place there are no risks for you in participating in this research. In case you feel discomfort during the interview, I will provide support through meeting your individual needs.

What will you do with my information?

Your personal data / information will be treated confidentially at all times; that is, it will not be shared with anyone other than the project supervisors. It will also not be shared with any third parties specified in the consent form unless it has been fully anonymised.

The exception to this is where you tell us something that indicates that you or someone else is at risk of harm. During the project, all data / information will be kept securely in line with the University’s Policy for the Effective Management of Research Data and its Information Security Policy. We will process your personal information for a range of purposes associated with the project primary of which are:

To use your information along with information gathered from other participants in the research project to seek new knowledge and understanding that can be derived from the information we have gathered. To summarise this information in written form for the purposes of dissemination (through research reports, a thesis / dissertation, conference papers, journal articles or other publications). Any information disseminated / published will be at a summary level and will be fully anonymised and there will be no way of identifying your individual personal information within the published results. To use the summary and conclusions arising from the research project for teaching and further research purposes. Any information used in this way will be at a summary level and will be fully anonymised. There will be no way of identifying your individual personal information from the summary information used in this way.

If you wish to receive a summary of the research findings or to be given access to any of the publications arising from the research, please contact us.

How long will you keep my data for?

Your personal data will be retained until the project (including the dissemination period) has been completed. At the completion of the project, we will destroy all data relating to the project.

How can I find out what information you hold about me?

You have certain rights in respect of the personal information the University holds about you. For more information about Individual Rights under GDPR and how you exercise them please visit: https://www.worcester.ac.uk/informationassurance/requests-for-personal-data.html.

What happens next?
Please keep this information sheet.

We will wait for at least 10 days before asking for your decision on whether you would like to take part and will be delighted to answer any further questions you have about the research.

Our contact details are:

Vikrant Rampal

E-Mail: ramv1_18@uni.worc.ac.uk

If you have any concerns about the project at this point or at any later date you may contact the researcher (contact as above) or you may contact the Supervisor / Principal Investigator / Project Lead:

Thank you for taking the time to read this information.

If you would like to speak to an independent person who is not a member of the research team, please contact the University of Worcester, using the following details:

Secretary to Research Ethics Panel for College of Business, Psychology and Sport
University of Worcester
Henwick Grove
Worcester WR2 6AJ
ethics@worc.ac.uk

8.4 Appendix D: Interview guide

Opening question(s):

- Please tell me what you do in your job?
- Please describe how you place your role in the job in terms of digital-physical products?
  Possible prompts: Have you already had contact with digital-physical products?

Question focused on digital-physical products:

- What do you understand by digital-physical products in the context of the railway industry?
  Possible prompts: What relevance do you assign to digital-physical products in the railway industry?
- How do you distinguish digital-physical products from physical products?
  Possible prompts: What characteristics stand out particularly in digital-physical products?
- What (new) requirements do you see for digital-physical products?
  Possible prompts: Can you assign the requirements that you consider essential to specific areas?
- How do these requirements differ in the individual phases of the product lifecycle by physical products?

Questions focused on relation to product lifecycle model:

- To what extent does the existing product lifecycle model within Siemens Mobility reflect the requirements coming from digital-physical products?
- In your opinion, what should change in the individual phases of the product lifecycle model in order to be able to map and optimally manage the requirements of digital-physical products?

Questions focused on potential impact on product management

- What effects would a change in the product lifecycle model have on the product management as it is now in place?
- What new tasks should product management take on in order to be able to optimally manage digital-physical products?
  Possible prompts: What new tasks should be assigned to the product manager?

8.5 Appendix E: Focus Group guide

Introduction (~ 15 min):

- In the introduction stage I will demonstrate my appreciation for the participants participation in the study. I will reiterate the purpose of the study and the voluntary nature of it. In this context, I will emphasize that there will be no right or wrong answers to make the participant comfortable to speak freely. I will point out that the participant does not have to answer every question and that she/he can end the meeting any time, if she/he feels uncomfortable. I will also point out confidentiality and anonymity. In addition, I will point out that what is said must be treated confidentially and respected. Furthermore, I will emphasize that it is not necessary to name any employer, colleagues or supervisors etc. Again, the participant will get the chance to ask further questions if they have any more. Afterwards I will inform the participant about starting the audio recording.
- The introduction phase still includes an introduction as well as welcome of all participants. At the beginning of the discussion, the moderator introduces himself and welcomes the participants. The agenda is described as well as the research project and its context. In addition, the topic of discussion is mentioned and the term focus group is explained. In addition, the participants are briefly informed about what their task will be in the focus group and how long the session will last.
- Introductions of the participants: For the short introduction of the participants, everyone introduces their name, profession, product responsibility and relation to digital-physical products.

Transition phase (~ 20 min):

- The moderator presents the company's internal product lifecycle with its characteristics to the participants. This gives all participants again an overview of the model. In addition, the model will be displayed on a flipchart/ screen the whole time so that the participants always have the model in front of their eyes.
- Collection of criteria on post-its (virtually via a tool called **concept board**): Each participant is asked to write down up to five criteria on what he/she understands by digital-physical products and how they differ from physical products. These are collected by the participants on a flipchart paper/the virtual tool and will be presented afterwards.
- A short summary by the moderator and, if necessary, a clustering of the post-its-.

Break (5 min)

Discussion phase (each phase around 30 min; after the first phase a 5 min break)

After each discussion phase and especially at the end of the discussion, the moderator asks about the completeness of the collection. This is very important in order to possibly pick up on special features.

1. Phase: Focus on product lifecycle model

- The participants discuss an adaptation of the product lifecycle model in the context of digital-physical products. The aim would be to write out at least 5 major changes to the previous model.
    - Input questions from the moderator:
        - To what extent does the previous product lifecycle model meet the requirements for digital-physical products?
        - What new aspects should be added to the existing model?
        - What should change in the individual phases of the product lifecycle model in order to be able to optimally manage digital-physical products?

2. Phase: Impact of digital-physical products on existing product management
    - The participants discuss the impact of the change in the product lifecycle model on product management. The aim would be to write out at least 3 major changes to the product management.

- Input questions from the moderator:
    - To what extent will the product management have to change when the product lifecycle model changes?
    - What new tasks should product management take on in order to be able to optimally manage digital-physical products

Closing (~5min):

In the closing phase I will thank the participants for their time and I will inform them that I will contact them only if I need them to review my interpretation related to accuracy/clarification. At the end of the meeting, I will point out again the confidentiality and anonymity of the data. I will refer to the basic rule that what is said hast to be treated confidentially and respected - even after the end of this meeting. Furthermore, I will offer them access to the final study after its completion.

8.6 Appendix F: Letter for gatekeeper approval

Doctor of Business Administration – V. Rampal

Dear Mr., xyz,

My name is Vikrant Rampal and I'm currently working as a Product Portfolio Manager withing Siemens Mobility GmbH. I started on that position two years ago and in addition to my work, I have been working on my DBA (Doctor of Business Administration) at the University of Worcester for about 1.5 years. My request is related to the DBA as I am currently writing my DBA thesis. With this message I would like to ask for permission to conduct this research within Siemens Mobility GmbH (Business Unit Rail Infrastructure) and to approve my proposed recruitment strategies through our company book. But before I go into the details, I will give you a brief overview of the content as well as the title of the thesis:

"Customizing the product lifecycle for digital-physical products in the railway industry"

The broad aim of the thesis is to explore the influence of digital-physical products on the traditional product lifecycle model. Specifically, the product lifecycle model within Siemens Mobility will be further developed to reflect the requirements of digital-physical products. In this way, recommendations can be given for the management of digital-physical products in the individual phases of the product lifecycle. In addition, the effects of the change in the product lifecycle model will be examined on the existing product management of Siemens Mobility. The study will thus make an important contribution to the currently discussed digital product management and improve the current academic debate in this research area. In addition to a detailed examination of the existing research literature, I would like to incorporate the expertise of some of our experts from the company on this topic into my work. The method of data collection will be an expert interview/focus group conducted via a video conferencing tool (MS Teams) as requested by the company for non-business critical appointments. Of course, the data is anonymous, confidential and cannot be considered as individual results. The support would be about one hour, during which I would like to talk to him/her about his/her experiences, approaches and strategies in dealing with digital-physical products on a subsidiary level. Participation is of course voluntary and the appointment will take place during normal company working hours (between 8h to 18h).

The participants for the research would be recruited within the existing organizational network. I would mainly rely on my personal networks within the company as well as our official company book to recruit people. In total, I would want to recruit 6-10 people for the focus group and 12-15 people for the interviews. The plan is to recruit people from the product management, sales, marketing and R&D departments as participants.

I'm now writing to you to ask for your permission to contact potential participants for research and to use our official company register for this purpose. Normally, the use of internal communication methods is not directly designed for this purpose, which is why I am asking for your permission. Furthermore, the reason why I am addressing my request for permission to you is related to your managerial function in the company. I would not like to ask the direct manager for permission, as otherwise conclusions could be drawn about the participants. By asking permission from your managerial position, no further participant details would have to be given. In the event of positive feedback from you, I would contact the participants by mail. The first contact would be to introduce the researcher and the purpose of the study. If the person contacted is interested in participating in the study, they would be asked to contact the researcher via their academic email address for further information. I would be very grateful for positive feedback and would ask you to sign in the space provided if you agree. This signed document will be stored on my secure laptop and a hard drive kept in my private office where the risk of loss or theft is low.

If you have any questions about the study or need further information, please feel free to contact me via email so that I can send you more information/answer your questions: ramv1_18@uni.worc.ac.uk

Thank you very much for your help and with best regards,

Vikrant Rampal

Place, date Signature (V. Rampal)	Place, date Signature (xyz)
DBA Researcher	(Head of product business – Wayside)